Public Comment
Bay-Delta Phase II Working Draft Report
Deadline: 12/16/16 12:00 noon

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December 15, 2016

Submitted via email: commentletters@waterboards.ca.gov

Ms. Jeanine Townsend
Clerk to the Board
State Water Resources Control Board
P.O. Box 100
Sacramento, CA 95812-2000

Subject: Comment Letter – Bay-Delta Phase II Working Draft Science Report

The State Water Contractors ("SWC") appreciate this opportunity to provide input regarding the Working Draft Scientific Basis Report for New and Revised Flow Requirements on the Sacramento River and Tributaries, Eastside Tributaries to the Delta, Delta Outflow, and Interior Delta Operations ("Phase II Report"). The SWC submit these comments on their behalf and on behalf of the SWC's 27 member agencies.[1]

The comments contained in our technical memorandum, attached, are limited to technical review of the Phase II Report, as requested in the State Water Resources Control Board's ("Water Board's") notice dated October 19, 2016. To the extent that the Water Board would like to discuss alternative actions that are achievable and likely to provide species benefits outside of a technical review of the Phase II Report, the SWC would be pleased to participate in such discussions. The SWC and its members are involved in many collaborative scientific efforts, scientific studies (including field work), and habitat restoration projects. The SWC have been, and will continue to take proactive steps to improve the Delta ecosystem, and would be willing to partner with the Water Board to find achievable and resilient solutions.

It is unfortunate that the Phase II Report does not provide a scientific basis for realistic solutions. Overall, the SWC are extremely disappointed by the analysis contained in the Phase II Report. The document appears to have been written in 2010, providing only a few selected references to the more recently published literature. To the extent new analyses are included in the Phase II Report, those references are most often to analyses that are preliminary, unpublished, and not peer reviewed.

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[1] Alameda County Flood Control & Water Conservation District, Zone 7, Alameda County Water District, Antelope Valley-East Kern Water Agency, Casitas Municipal Water District, Castaic Lake Water Agency, Central Coast Water Authority, City of Yuba City, Coachella Valley Water District, County of Kings, Crestline-Lake Arrowhead Water Agency, Desert Water Agency, Dudley Ridge Water District, Empire, West Side Irrigation District, Kern County Water Agency, Littlerock Creek Irrigation District, Metropolitan Water District of Southern California, Mojave Water Agency, Napa County Flood Control and Water Conservation District, Oak Flat Water District, Palmdale Water District, San Bernardino Valley Municipal Water District. San Gabriel Valley Municipal Water District, San Gorgonio Pass Water Agency, San Luis Obispo County Flood Control and Water Conservation District, Santa Clara Valley Water District, Solano County Water Agency, and Tulare Lake Basin Water Storage District.

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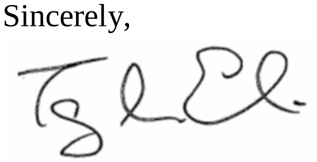
The Phase II Report does not contain a discussion of the best available science and fails to provide uncertainties associated with the science cited. This type of information is critical to provide Water Board members with a tool to make decisions in the future. As currently drafted, this report does not provide an unbiased discussion of the scientific literature.

The Water Board was provided with valuable guidance from at least two independent expert panels that provided reports describing the best available science, but their guidance was largely ignored in the Phase II Report. After the Water Board's Water Quality Control Plan workshops in 2012, the Water Board asked the Independent Science Program to provide assistance in reviewing the significant technical information it received during the workshops. In response, the Independent Science Program organized and hosted at least two independent expert review panels: the Delta Outflow and Related Stressors ("Outflow Panel"), and the Interior Delta Flows and related Stressors ("Interior Flows Panel").[2] The Phase II Report ignores much of the recommendations and guidance provided by these independent expert panels, particularly with respect to disclosure of uncertainty and standard statistical practices.

The independent peer review panels were significantly more qualified in their expectations regarding what could be achieved with new flow in the current Delta. The attached Technical Memorandum provides specific examples of revisions to the Phase II Report to reflect the direction provided by the independent review panels, as well as identifies many relevant studies that were not acknowledged in the Phase II Report.

As the October 19, 2016, notice from the Water Board was limited to technical review of the Phase II Report, the SWC have not provided comments regarding our more fundamental concerns with the flow proposal, even though our concerns are significant regarding implementation, viability, and the legality of the current proposal. The SWC understand that this first review of the Phase II Report is just the initial step in the process. We look forward to continuing the dialog with the Water Board with the shared goal of developing an effective and viable proposal.

Sincerely,



Terry L. Erlewine
General Manager

Enclosure

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[2] There have been other expert panels providing input regarding best scientific practices, and those reports provide similar guidance.

TECHNICAL MEMORANDUM
STATE WATER CONTRACTORS' REVIEW OF PHASE II REPORT

This memorandum is in response to the State Water Resources Control Board's ("Water Board") request for written comments on the Working Draft Scientific Basis Report on the Phase II ("Phase II Report") update of the 2006 Water Quality Control Plan for the San Francisco Bay/ Sacramento – San Joaquin Delta Estuary ("WQCP").[1] The SWC have identified a number of major flaws with the Phase II Report that will require substantial revisions. The Phase II Report should be substantially revised and recirculated for public comment before peer review, and before being used as a basis for management.

I. The Phase II Report's technical rationale does not support its proposal.

A. Unimpaired flow is not a proxy for pre-development or "natural" flow.

Best available science shows that unimpaired flow is not an appropriate measure of natural flow on the valley floor or in the Delta. We recommend that the revised draft of the Phase II Report cite recent supporting scientific work, including work by Howes et al. (2015) on the evapotranspiration from natural vegetation that was present in the Delta and Central Valley and work by Fox et al. (2015) that quantifies the expected mix of vegetation in the Delta and Central Valley under natural or pre-development conditions. Further, we recommend that the revised draft Report cite work by Huang (2016) that utilized the above-cited work to compare annual and seasonal unimpaired and natural Delta outflow estimates. Huang found, similar to Fox et al. (2015), that unimpaired outflow estimates are a poor proxy for natural outflow estimates, significantly overestimating natural flows. Huang's comparison of average annual and unimpaired and natural Delta outflow is shown in Figure SWC-1 by 40-30-30 water year type. Similarly, his comparison of average monthly unimpaired and natural Delta outflow is shown in Figure SWC-2.

Given that the best available science shows unimpaired flow to be an inappropriate measure of natural flow on the valley floor or in the Delta, proposed flow standards should be justified based on flow function and not on purported benefits associated with emulation of natural conditions. Thus, use of unimpaired flow criteria (as an accounting tool) should not be:

- Justified as a means to improve habitat conditions through restoration of natural flow conditions, functions, etc.
- Used as a justification for the need to increase required flows on the valley floor and/or in the Delta.
- Used as a baseline from which to measure annual or seasonal trends in flows on the valley floor or in the Delta.

[1] The Technical Memorandum contains comments addressing global concerns about the Phase II Report. Exhibit A to the Report includes specific comments with page references.

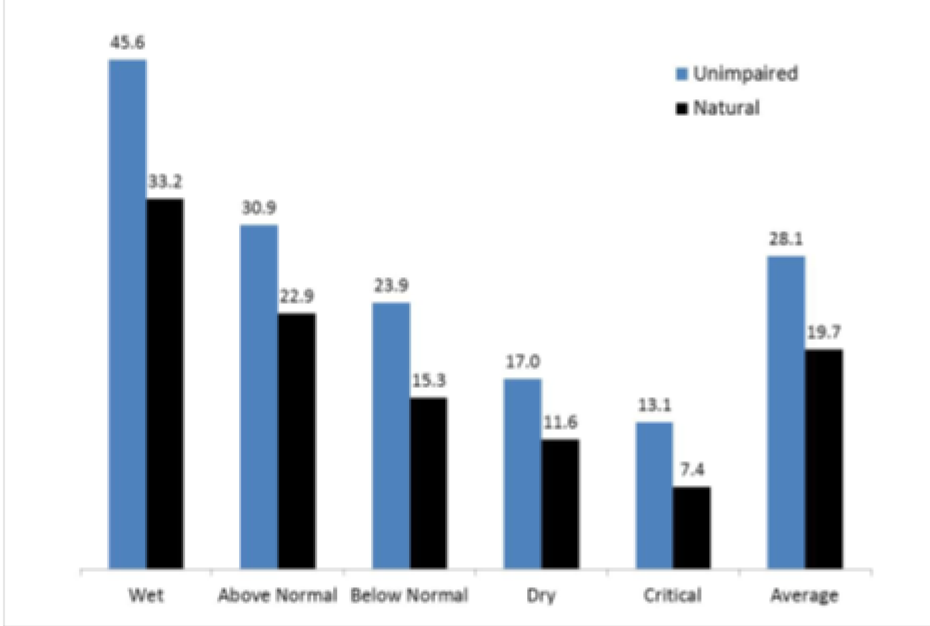

Figure SWC 1. Average Annual Unimpaired and Natural Net Delta Outflow (MAF)

This chart compares annual average "unimpaired" and "natural" Delta outflow estimates (in units of million acre-feet) for the 93-year hydrologic period spanning water years 1922 through 2014. Comparisons are shown by 40-30-30 water year type as well as the full period average. This chart clearly shows that unimpaired flow estimates are significantly higher than natural flow estimates under all hydrologic conditions. Under average conditions, the annual unimpaired flow estimate is 43 percent higher than the natural flow estimate. (ref: Huang (2016))

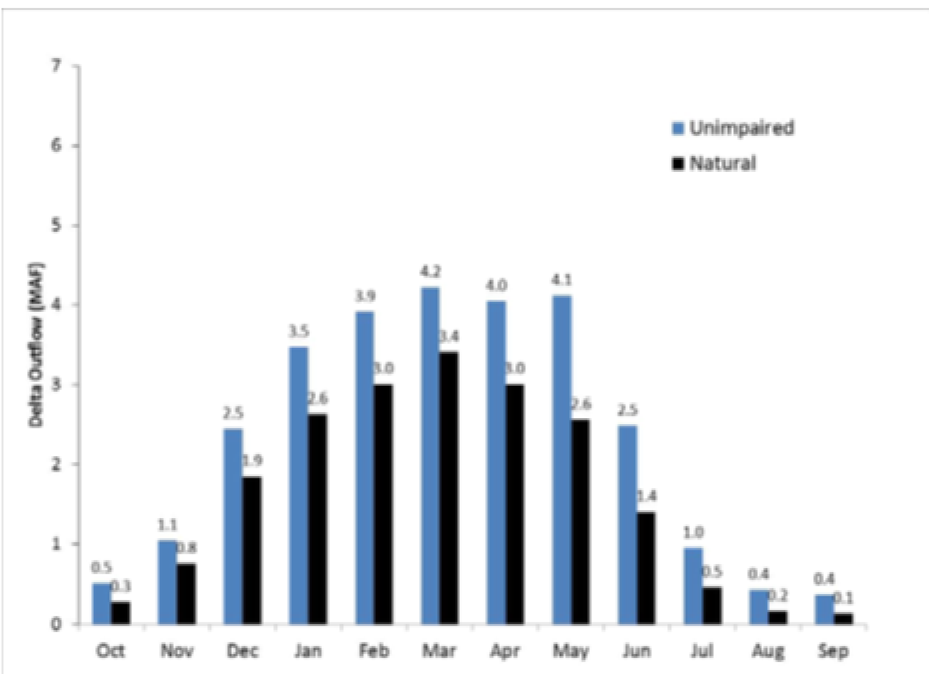

Figure SWC-2. Comparison of Monthly Natural and Unimpaired Net Delta Outflow Estimates by 40-30-30 Water Year Type: Water Years 1922-2014 Averages

B. The Phase II Report is not proposing "natural flow."

The regulatory flow proposal is based on DWR's unimpaired flow calculation as a means to define a pool of water for adaptive management for the intended purpose of "sculpting" flows. (See e.g., Phase II Report pp. 1-9 and 1-10.) The Phase II Report does not identify the types of actions it would take to "sculpt" flows, and therefore it is unclear what the Water Board means by this term. The SWC recommend that the Phase II Report be revised to provide examples of the types of flow being proposed, as well as the conceptual model that the Water Board would be evaluating as part of its adaptive management plan.

The Phase II Report cites literature supporting the idea that a percent of the natural hydrograph be preserved as a method for restoring the Delta ecosystem. However, the Water Board is really proposing a plan where it would "sculpt" flows, not necessarily in proportion to unimpaired flows. Therefore, the cited literature does not support the intended action. It should be further noted, as the water contractors and others explained during the 2012 Water Board workshops, the literature relevant to using unimpaired flows as a restoration tool cautions that the outcome, particularly in highly altered systems, is highly uncertain. See SWP-CVP Water Contractors (2012) pp. 6-2 to 6-5, citing Poff et al. (1997), Poff and Zimmerman (2010), Pierson et al (2002), and Bunn and Arthington (2002)[2] ["The advice from aquatic ecologists on environmental flows might be regarded at this point in time as largely untested hypotheses about the flows that aquatic organisms need and how rivers function in relation to flow regime."].)

The Phase II Report should have disclosed the uncertainty associated with this literature.

C. The Phase II Report is not proposing a "functional flow."

During the recent workshop, there was a definitional discussion about what is a "functional flow." The SWC have been discussing the need for functional flows for many years, so knowing that there is a misunderstanding regarding the use of this term is informative. Based on the literature, the SWC define a functional flow as supporting a specific ecological function that is relevant to one or more native fish species. It requires an investigation of the conditions under which native fish evolved, how those conditions have changed, and what can be done to restore those conditions within the context of today's highly altered system. Historically, the water and landscape were much more interconnected where high flows would spill out onto the landscape creating spawning and rearing habitat, and feeding the rivers as it slowly drained back into the main channels carrying nutrients, detritus, and lower trophic organisms produced in these nutrient rich, often shallow and slow moving waters, among other important functions. Merely putting more water down rip-rap lined levees does not recreate these historical conditions. The best opportunities for restoring functional flows may be in areas where some remnant of the predevelopment environment still exists, like floodplains, or in the restoration of these land-water connections elsewhere. To further explain this point, we recommend that the Water Board review the SFEI 2016. (Attached for your convenience, Exhibit B.) In our highly altered system, the concept of unimpaired flow is not the same as functional flow or natural flow, as it

[2] The Phase II Report also cites Rozengurt et al. 1987, which appears to be an unpublished technical report from the Water Board hearings in 1987. From this submittal, it is not possible to determine the technical basis for the author's conclusion. With all of the research that has been completed in the last nearly 30 years, it is surprising that the Phase II Report would rely on an unsubstantiated document.

would merely provide for transport functions (i.e., increasing the depth and velocity of water in leveed and rip rapped channels) without providing for many other important functions.

D. The concept of flow as mitigation for past harm is unsupported.

At the December 7, 2016, workshop, it was suggested that since land and water are disconnected in our highly altered system, perhaps more water than pre-development annual outflow is required to compensate for past damage. This may be the case to restore specific functions, like recreating cold water pool below rim dams to compensate for blocking salmon passage to higher elevation spawning grounds. However, this concept only serves to reinforce why a blanket application of a percent of the unimpaired hydrograph flows in this highly altered system is inappropriate. For example, additional flow could dilute pesticides, assuming that is a beneficial use of water, or it may merely flush the problem further downstream. The additional flow may not enhance lower food web productivity. In fact, we may need to create areas with lower flows to restore some of the productivity that was lost when we eliminated the Delta's dendritic, dead-end channels for flood control and navigation. As part of our submittals during the 2012 Water Board workshops, the state and federal water contractors provided a detailed discussion and literature review on the subject of flow and flow function in regard to what could be achieved in this system with additional flow. Please State Water Contractors and Central Valley Project Contractors' (2012) (Submittal to SWRCB: Ecosystem Changes to the Bay-Delta Estuary: A Technical Assessment of Available Scientific Information, available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/daniel_nelson.pdf.)

II. The historical flow trends analysis is skewed by the selected baseline.

The SWC would like to further clarify that the appropriate time period for defining the flow patterns under which native species evolved is predevelopment. It should not be assumed that the native fish were doing well until recently, as is suggested in the Phase II Report. (Phase II Report, p. 1-3 ["…many of the native fish and wildlife species maintained healthy populations until the past several decades when water development intensified.") The native fishes had already experienced enormous ecological change as early as the beginning of the last century. When evaluating changes in flow patterns, the Phase II Report uses a baseline of the 1940s, 1950s, or 1960s, which were highly artificial time periods when the reservoirs were in place but demand was not fully developed. During these time periods, the reservoirs were releasing significant flow at times when there would not have been as much water under "natural" or pre-development conditions. Comparing a time period with unnaturally high outflow to more recent time periods is not a biologically meaningful comparison.

The state and federal water contractors provided information regarding flow trends in their 2012 submittal to the Water Board during the Analytical Tools Workshop. Since that time, the referenced work has been peer reviewed and published (Hutton et al. (2015).) The Phase II Report presents the older unpublished work and ignores the more recent published literature. For example, the Phase II Report at p. 2-65 (Figure 2.4-9) cites the unpublished Fleenor et al. (2010) report to the Water Board and concludes:

> …the position of X2 has been skewed eastward in the recent past, as compared to pre-development conditions and earlier impaired periods, and that variability of salinity in the western Delta and Suisun Bay has been significantly reduced.

The Phase II Report (Figure 2.4-9) shows daily X2 over several time periods, with the associated text suggesting a trend. However, as shown in Hutton et al. (2015) at p. 9, Table 3, whether there is a trend in the location of X2[3] depends on the selected baseline years as well as the month. From 1968-2012, there is no statistically significant trend in the location of X2 for the months January through August. Conversely, the results for the longer record, 1922-2012, show a statistically significant increasing trend (more salinity) in the location of X2 in the months January through June; no trend in July; and a decreasing trend in X2 (less salinity) in the months August and September.

During the Fall X2 months of September-November, the trend analysis also varies depending on the baseline years chosen. On p. 2-67, Figure 2.4-10, the Phase II Report uses a baseline of 1967 and suggests an increasing trend (more salinity) over time. Hutton et al. 2015 also observed this trend using a 1967 or 1968 baseline. However, Hutton et al. (2015) shows multiple comparisons using different baselines, and the results using the longer time period of 1922-2012 show mixed results (September= decreasing trend, October= no trend, November = increasing trend). (See, Figure 2, below, Hutton et al. 2015, p. 8.)

[3] The Phase II Report recommends that the "… Dayflow X2 equation should be updated using more salinity and flow data which is now available to reduce uncertainty in the relationship between Delta outflow and daily average X2…" Given their potential role in future Bay-Delta outflow and salinity standards, the SWC agree that empirical X2 equations should be updated to reflect best available flow and salinity data. The SWC recommend that alternative approaches in addition to Jassby et al. (1995), i.e. the Dayflow X2 equation, be summarized in the Phase II Report and evaluated for future use by the Water Board, including: Monismith et al. (2002), MacWilliams et al. (2015), Hutton et al. (2015), and Rath et al. (2016).

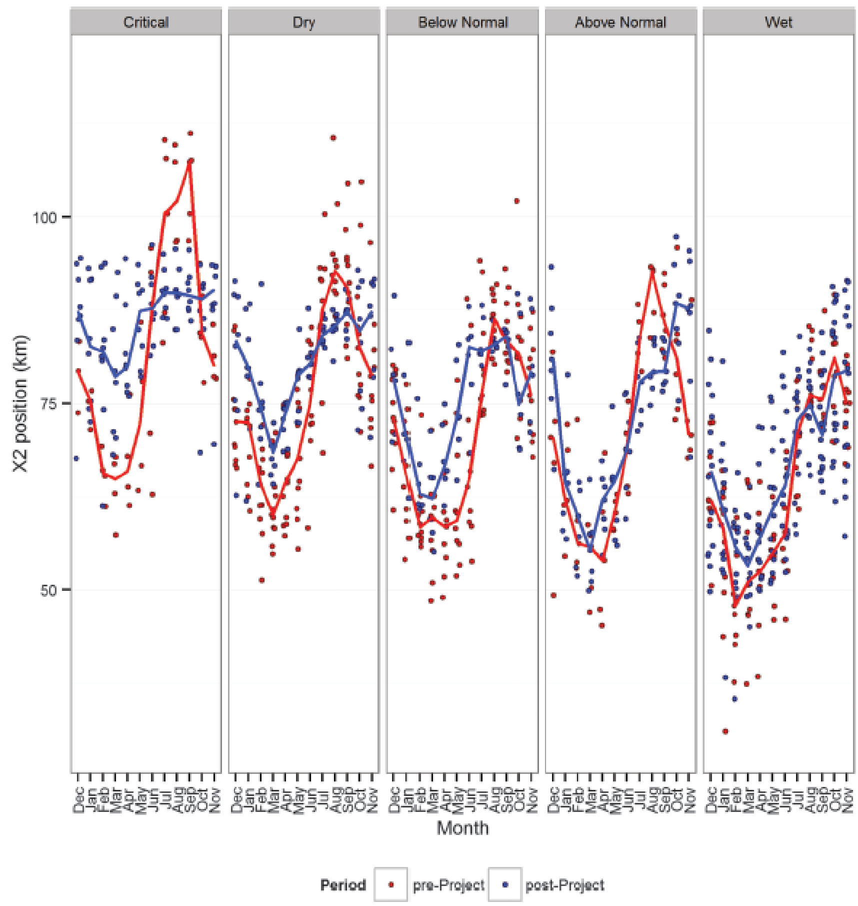

Fig. 3. (Color) Average monthly X2 position is shown by water year class on the Sacramento River branch under preproject (water years 1922–1967) and postproject (water years 1968–2012) conditions, with lines connecting the seasonal medians; symbols show individual year values (red = preproject and blue = postproject), with lines connecting the seasonal medians; in all but wet years, the postproject X2 position tends to be further downstream (i.e., lower) in summer months and further upstream (i.e., higher) in other months; the X2 position in October and November is generally more closely associated with the previous water year; thus, the x-axis spans the months December through November

The changes in X2 location post-project should be expected, reflecting use of the project reservoirs to manage salinity and buffer against dry years. Upstream water storage construction and increased in-basin and out-of-basin water use has affected X2 in different ways, depending on season and water year class. For example, X2 position exhibits less intra-annual variability in the post-project period than it did in the pre-project period (water years 1922-1967). (Hutton et al. (2015).) Post-project X2 position is typically further upstream (i.e., higher) in wet months (February through May) of dry and critically dry years and further downstream (i.e., lower) in the dry months of August and September. This reduction in dry year variability is a straightforward result of reservoirs being operated to store water in wet periods and to release water during dry periods, thus damping the variation in Delta salinity. At the other hydrologic extreme, in wet years, flows are sufficiently high that reservoir operations have less effect on the Delta salinity gradient, resulting in great similarity between pre-project and post-project X2 position.

The SWC recommend that figures, such as Phase II report, Figure 2.4-4, p. 2-63, and other scientific presentations purported to show long term trends, yet based on truncated time series, be removed or updated to reflect the full available nine-decade record. The SWC further recommend that statements that attribute flow and salinity trends to key drivers be removed unless attribution is supported by quantitative analysis. (See e.g., Phase II report, p. 2-62 ["Since 2000, there has been reduction in spring outflow and a reduction in the variability of Delta outflow throughout the year (Figure 2.4-7) due to the combined effects of exports and variable hydrology."].) There are many actors and drivers in the system, and the causes of changes in outflow[4] are not always obvious.

III. The Phase II Report should follow the recommendations of its independent expert review panels, particularly in the areas of best statistical practices and disclosure of uncertainty.

After the Water Board's WQCP workshops in 2012, the Water Board requested that the Delta Science Program provide assistance in reviewing and assessing the written materials and oral presentations it received in order to identify the best available science to inform the Water Board's decision related to the Water Quality Control Plan Update, Phase II. In response, the Delta Science Program organized and hosted at least two independent expert review panels who produced reports in response to the Water Board's request: the Delta Outflow and Related Stressors ("Outflow Panel Report"), and the Interior Delta Flows and related Stressors ("Interior Flows Panel Report").[5] The Phase II report does not follow the recommendations and guidance provided by these independent expert panels, particularly with respect to disclosure of uncertainty and standard statistical practices. The independent expert panels also provided specific guidance regarding the types of analyses that should be given greater consideration, and that guidance has been ignored as well.

A. The Phase II Report should follow the expert panels' recommendations regarding disclosure of uncertainty.

The Outflow Panel Report (Reed et al. 2014, p. 36) advised that, "It is critical that quantitative analyses communicate uncertainty in recommended flow criteria to decision makers." The Outflow Panel Report (Reed et al. 2014, p. 29) stated further that:

> As with the use of all indices of abundance, the link between changes in the index and changes in the population-level abundances are not claimed to be exact. We emphasize the importance of communicating uncertainty in functional relationships when using them to evaluate the efficacy of various flows.

And, at Reed et al. (2014), p. 25, "…they should also include estimates of uncertainty derived using the same (standardized) statistical methods."

[4] The Scientific Basis Report describes the existing approach for estimating Delta outflow through the Net Delta Outflow Index (NDOI) calculation. The Report also discusses the USGS monitoring station network and how measurements compare with the NDOI calculation. The SWC recommend that the Report summarize relevant aspects of Sandhu et al. (2016), Fleenor et al. (2016), and Monismith (2016). We agree with Sandhu et al. (2016) that,"*A water balance approach similar to the Net Delta Outflow Index (NDOI) remains the most suitable tool to define net Delta outflow for regulatory purposes, but should be updated to incorporate improvements to consumptive use estimates and correct a few known water accounting errors.*" However, the SWC also acknowledge that, given its scientific complexity and regulatory importance, alternative approaches should be explored to increase our scientific understanding of Delta outflow on various timescales.

[5] There have been other expert panels providing input regarding best scientific practices, and those reports provide similar guidance.

1. **For example, the Phase II Report should have disclosed scientific uncertainty in its Longfin Smelt analysis.**

Contrary to the Delta Science Program review panel's recommendations, the Phase II Report does not communicate the uncertainty associated with the X2-abundance relationships. Instead, the Phase II Report uses the Longfin Smelt X2-abundance relationship to predict how much water would be required to achieve the United States Fish and Wildlife Service's recovery goal, without any mention of uncertainty. (Phase II Report, p. 3-46. ["The analysis indicates that flows in excess of 100,000 cfs are needed since the *Corbula* invasion to meet the USFWS recovery goal of 6,400. In comparison, before the *Corbula* invasion, flows of 50,000 and 30,000 cfs would have been sufficient to meet the goal in January-March and March-May, respectively."]) By being silent on the issues of uncertainty, the Phase II Report leaves the false impression that if we provide the volume of flow, recovery targets will be achieved.

As one method of communicating uncertainty, the Outflow Panel Report recommended that the X2-abundance relationships be viewed on a linear scale, stating at Reed et al. (2014), pp. 24-25 that:

> …X2-abundance relationship should also be shown using linear scales (i.e., these can be in addition to logarithmic and other transformed scales). The more appropriate transformations and best practices used for statistical analyses must still be used; linear plots are an addition to these analyses. This is important for more clearly showing the magnitude of the expected species response as X2 shifts.

The Outflow Panel Report included a figure showing the Longfin Smelt X2-abundance relationship on a linear scale as an illustration of the expected magnitude of the species response. See Figure 3, below, Reed et al. (2014), p. 30. From its Figure 3, it can be observed that after 1987, the Longfin Smelt X2-abundance relationship indicates that abundance is significantly less responsive to changes in X2.

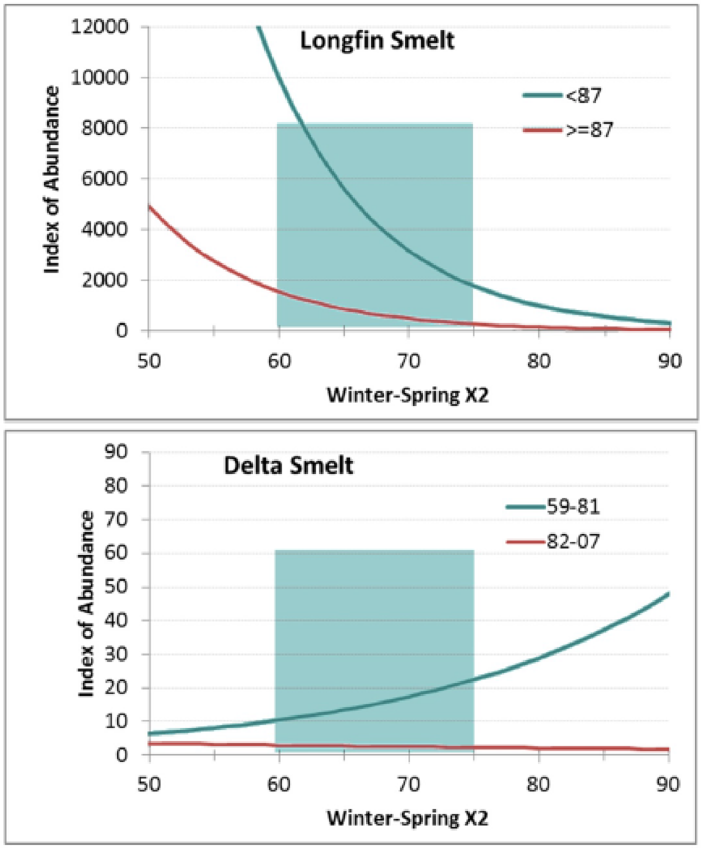

Figure 3. Relationships between Longfin (upper panel) and Delta Smelt (lower panel) abundance indices (mid water trawl and tow net series respectively) and average X2 over the winter-spring period during two different periods of time (before 1987 and after 1986 for Longfin Smelt; 1959-1981 and 1982-2007 for Delta Smelt). These relationships are based on parameters from Table 2 of Kimmerer et al. (2009) transformed from $\log_{10}$ to linear space. The blue boxes represent the X2 range required to achieve low salinity conditions in Suisun Bay.

Again, the Phase II Report does not follow the Outflow Panel's recommendation and only considers the relationship on a log-scale. (See Phase II report, p. 3-47.)

Based on its understanding of uncertainty, partially informed by its Figure 3, the Outflow Panel Report (Reed et al. (2014), p. 29 (emphasis add.)) concluded:

> In the Panel's judgment, based on X2-abundance relationships the evidence that the relatively modest changes in fall[6] Delta outflows that are being proposed are going to result in substantial increases in abundance of key pelagic species is highly uncertain. Substantive increases in Longfin Smelt abundance index may be realized under the proposed 75% winter-spring unimpaired flow standard. **Even in that case, population changes may be very difficult to detect given the variance of the regression, potentially high observation error in the sampling programs, and the infrequent implementation of high flows, even under the unimpaired flow strategy**.

[6] This paragraph relates to Longfin Smelt, so it appears that this reference to fall is a typo. Although, as the paragraph immediately above the referenced section is in regard to fall X2 for Delta Smelt, it could be a reiteration of the Outflow Panel's view on the certainty associated with Delta Smelt Fall X2.

Once again failing to follow the expert panel's recommendation, and without any explanation or qualification, the Phase II Report's conclusion is to the contrary, predicting increases in Longfin Smelt abundance. (Phase II Report, p. 3-49 ["Delta outflows predicted to increase longfin smelt population…."].)

2. For example, the Phase II Report should have disclosed uncertainty regarding the indirect effects of the SWP-CVP on out-migrating San Joaquin River Chinook salmon.

The Phase II Report's discussion of the potential relationship between San Joaquin River flow, SWP-CVP exports, and San Joaquin River Chinook salmon survival is based almost entirely on the 2009 National Marine Fisheries Service Biological Opinion ("NMFS BiOp") thereby ignoring all of the current literature. (Phase II Report, pp. 3-43 to 3-44.) The best available science does not support the Phase II Report's conclusion that, "Juvenile salmonids migrate out of the San Joaquin basin during February through June (SWRCB 2012) and may need protection from export-- related mortality at any time during this period in order to preserve life history diversity." In fact, it is unclear how or if any change in current project operations would further benefit salmonid survival.

The Phase II Report should rely on the description of the current state of the science, and recommended management actions contained in the Draft Collaborative Adaptive Management Team (CAMT) Salmon Scoping Team Synthesis Analysis (Draft Salmon Synthesis Report).[7] The Draft Salmon Synthesis Report is a collaborative effort between state and federal fishery agencies, environmental interests, and the state and federal water contractors. The limitation of the report is that it focuses exclusively on the potential effects of the SWP and CVP, and therefore would not necessarily provide the Water Board with information regarding what actions could improve species abundance. The SWC nevertheless believe that the Draft Salmon Synthesis Report provides a useful description of the best available science and should inform future revisions to the Phase II Report.

The SWC understand that the final Salmon Synthesis Report will not be released until later this month. [8] However, the draft findings that were presented to the CAMT management team are informative, indicating areas of scientific disagreement and gaps in available information that should be discussed in the Phase II Report. The initial findings of the Draft Salmon Synthesis Report include, for example, that there is, "**Inconclusive evidence of a relationship between exports and through-Delta survival**." (See Draft Salmon Synthesis Report, Presentation to CAMT, at slide 17, emphasis add.) The Delta Science Program concluded similarly during its review of the implementation of the 2009 NMFS BiOp stating, "**The study found that fish entrainment into the inner Delta was not related to pumping operations…**." (Anderson et al. (2012), p. 31.)

The Draft Salmon Synthesis Report explains the reasons for this uncertainty, which include:

[7] The SWC appreciate the Phase II Report's reference to the Salmon Synthesis Report and we understand that the final report was not available to Water Board staff.

[8] The SWC have attached the CAMT Power Point presentation that summarizes the Salmon Synthesis Report. (See Exhibit C.) We will forward the complete report when it is available to the CAMT members.

- All observations are in the presence of management operations (I:E, E:I, OMR restrictions) which makes it difficult to assess their effectiveness.
- There has been low variability and limited replication in conditions during tagging studies.
    - Most observations of smolts have been at low levels of inflows and exports.
- Low overall survival makes it difficult to detect changes in survival.

(See Draft Salmon Synthesis Report, Presentation to CAMT, slide 31.) The findings of the Draft Salmon Synthesis Report further include a finding that:

- Export effects vary with distance from the facilities**.**
- Largest export effect was estimated in Old River near the SWP and CVP intakes.
- Almost no effect at junctions off Sacramento River such as Georgianna Slough.
- Small effect at junctions leading off San Joaquin River, except HOR.

(See Draft Salmon Synthesis Report Presentation, slide 34, emphasis add.) This finding is important as it highlights the importance of being spatially explicit when characterizing the effects of the state and federal water projects on hydrodynamics.

Of course, the Phase II Report has the obligation to identify changes in hydrodynamics that are biologically relevant to the species. There is a high degree of uncertainty regarding such relationships. For example, the fundamental assumption underlying the Phase II report is that an increase in river flows is predicted to result in increased abundance or survival of a targeted fish species. The fact that results of juvenile Chinook salmon survival studies conducted in the lower San Joaquin River in 2006 and 2011, both higher flow years during the spring juvenile salmon migration period, did not result in markedly higher survival rates when compared to years with substantially lower spring flows, underscores the high level of uncertainty in these biological relationships that is not discussed in the report.

Management actions up to now, like those contained in the 2009 NMFS BiOp, have largely focused on tidally averaged flows. In its review of the implementation of the 2009 NMFS BiOp, the Delta Science Program (Anderson et al. (2012), p. 21) explained that tidally averaged flows aren't biologically meaningful:

> The general project operations have been managed in terms of mean flows in OMR and in the San Joaquin River. This has been the fundamental approach for operations of the system for years but has resulted in inadequate protection for fishes. In part, this is because attempts to understand the movement and survival of fish through the Delta to date have not considered effects of tides, which are the dominant control on flow velocities and mean direction of flow.
>
> Delta survival of steelhead, and especially Chinook, was extremely low based on tagging studies. Characterizations of survival in terms of river km or mean flows are inadequate because the rapid travel time and complex routing of fish through different reaches cannot be explained by these mean measures. The IRP suggests the travel, routing and survival of fish through the system needs to account for migrant behavior and the behaviors of predators in response to the strong tidal influences in the Delta.

Interior Flow Panel Report (Monismith et al. (2014), p. 53) made a similar observation stating:

> Metrics useful for managing water diversions (e.g. water exports, Old and Middle River flow) must be used with caution because they represent highly aggregated measures of the velocities fish detect and respond to in the near field.

The 2009 NMFS BiOp is an example of this tidally averaged flow management approach, where net flows were estimated using the particle tracking model. This approach assumes net flow in a tidal environment is an important factor influencing juvenile salmonids. On this topic, during review of studies in 2012, the Delta Science Program (Anderson et al. (2012), p. 15) concluded:

> The Spring 2012 plan for water operations focused on characterizing smolt movement with mean project operations, OMR flows, pump exports and I/E ratio. The plan appeared to be based upon the assumption that fish movements and survival would be correlated with measures of mean flow. However, studies cited in the Tech Memo demonstrated weak correlations between smolt movement and particle tracking model studies and between project operations, OMR flows and smolt movement and survival. Studies available in the literature and many published in the region have demonstrated that fish movement across a wide range of taxa exhibit behavioral response to tidal oscillations.

The Draft Salmon Synthesis Report includes information related to biologically relevant flows, for example changes in velocity. As also explained, however, there is scientific uncertainty regarding, "The magnitude of change in flow or velocity needed to influence salmonid behavior or survival that is biologically relevant." (See Draft Salmon Synthesis Report Presentation, slide 44.)

The findings in the Draft Salmon Synthesis Report are based on the published literature, which is available to the Water Board, and a more complete discussion of the available scientific information would have highlighted areas where acknowledgement of uncertainty is appropriate.

B. The Phase II Report should follow the recommendations of its independent expert review panels regarding application of best statistical practices to inform decisions regarding reliability of technical information.

The Interior Flows Panel (Monismith et al. (2014), p. 2) stated:

> The Panel was concerned that little experimentally validated quantitative guidance on flow management was available to the Board. We provide a set of criteria for identifying the most useful science on which to base updated flow standards. In particular, we suggest the Board look favorably on synthesis papers that have the following characteristics:
>
> 1. Hypotheses establish *a priori,* not developed after the fact;
>
> 2. Parameter estimates (i.e., effects estimates) with uncertainty bounds are reported rather than simply significant P values; and

3. Models that are not overfit; the ratio of independent observations to the number of fitted parameters is at least 10.

The Phase II Report does not follow this guidance. For example, the Outflow Panel provided a specific example of failure to follow number 2, disclosure of uncertainty bounds. The example is the TBI/NRDC Longfin Smelt analysis that is also Figure 11 of the Water Board's 2010 Flow Policy Report. The Outflow Panel observed (Reed et al. (2014), pp. 35-36) that:

> On the negative side, we feel the strength of the relationship has been oversold because there is no consideration of uncertainty in model predictions. This deficiency is not unique to the TBI/NRDC analysis within the flow criteria report. Here, we repeat the TBI/NRDC analysis in a Bayesian framework, as an example, to highlight the importance of communicating uncertainty to policy makers.

The results of the Outflow Panel Report's Bayesian framework showed (Reed et al. (2014), p. 36) that:

> Examination of the data points in the TBI/NRDC analysis shows considerable overlap in flows for years when populations decline (y=0) and grow (y=1), and only four of the 20 years with positive population growth had flows larger than those of years with population declines (Fig. 5). Not surprisingly then, the uncertainty envelope for this relationship is relatively wide, and is also asymmetric (dashed lines in Fig. 5).

And, (Reed et al. (2014), p. 36) further:

> That is, outflow requirements to achieve population growth in 50% of years could be 40% lower or 70% higher than the reported mean…These wide ranges illustrate a much different and more uncertain outcome then impression based solely on the expected value, and the expected value is all that is provided in the flow criteria report (SWRCB 2010).

The Phase II Report repeated the same error that the Outflow Panel observed in the 2010 Flow Policy Report. The Phase II Report does not discuss the wide range of uncertainty in the results. (Phase II Report, 3-46, pp.3-48, and 3-49.) The Phase II Report did not mention nor address the critical comments regarding this analysis provided by the Outflow Panel. The Phase II Report also failed to discuss Nobriga and Rosenfield (2016), whose results also suggest that outflow cannot be used to rebuild the Longfin Smelt population over time.[9]

C. The Phase II Report should follow the recommendations of its independent expert review panels regarding use of correlation analysis to inform management actions.

Contrary to the direction of the Outflow Panel, the Phase II Report takes the standard set of species abundance-X2 relationships, and uses those correlations to predict increased species abundance at various levels of potential future outflow.[10] By being silent as to uncertainty, the

[9] Nobriga and Rosenfield 2016 will be discussed in more detail in the Longfin Smelt section.

[10] The Phase II Report's stated purpose is to provide flows to support native species, but it then references abundance-X2 relationships for species that are non-native (e.g., striped bass, American Shad). The Water Board

Phase II Report gives the false impression that its analysis is highly predictive and reliable. Rather than fully acknowledging the importance of understanding the biological mechanism underlying a correlative analysis when formulating management actions, the Phase II Report basically concludes that the correlations are so strong that management action is justified. What the Phase II Report fails to acknowledge is that the nature of the appropriate management action is informed by understanding the underlying biological mechanism. Stated differently, we don't know what the appropriate management action is until the mechanism is understood. This limitation of the use of correlative analysis should have been more fully disclosed in the Phase II Report.

The Outflow Panel (Reed et al. (2014), p.65) provided advice regarding correlation analysis as a basis for regulatory action, as follows:

> Even when all of these conditions are met, [11] the abundance relationships with outflow (X2) are correlations, sometimes quite strong and robust, but they are still correlations. In the case of using outflow in the Delta ecosystem, as in many other ecosystems, correlations can be misunderstood and over-interpreted because they are specific to a set of conditions and they do not provide information on causality.

And:

> …correlations can appear to be simple and direct but often reflect many steps in a complicated set of processes and mechanisms. An example is the conceptual model relating outflow to the population dynamics of Longfin Smelt (Figures 3-5, Rosenfield 2010); outflow appears in many places in the conceptual model and these are many pathways that relate outflow to environmental conditions and biological processes that ultimately combine to affect population abundance and distribution.

And:

> Without a very long data record for field observations sufficient to tease out effects of multiple factors (which is impractical) and a strong basis of experiments and process-level studies (not just monitoring of abundance indices), correlation-based indicators have inherent uncertainty that can result in projections with various levels of inaccuracy or even unexpected results.

The Phase II report should more completely acknowledge the limitations of correlative analysis, and discuss the more recent scientific information focusing on mechanism.

For example, for Longfin Smelt, there have been analyses and field studies that do provide insight into potential mechanisms. And, these studies do not necessarily support the prevailing hypothesis that Longfin Smelt spawn upstream in the freshwater areas of the Delta, with greater upstream spawning success in wet years.

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should reconsider whether it should be enhancing predator species, like striped bass, when they are predator fishes that threaten native Chinook salmon smolts.

[11] The Outflow Panel Report includes recommendations related to "conditions" for a scientifically sound adaptive management program for flow based management actions. See Outflow Panel Report at pp. 63-64.

Lenny Grimaldo and others have completed several years of larval sampling in the tidal marshes around Suisun Bay and San Pablo Bay. Grimaldo et al. (presentation and in review) found that even in the recent drier years, the tidal marshes around San Pablo Bay, Suisun Bay and Napa River are replete with newly hatched Longfin Smelt. This finding is significant for several reasons. First, this observed indication of spawning in brackish/low salinity regions is counter to the prevailing view that Longfin Smelt spawn in upstream freshwater locations. Second, this spawning and larval rearing is occurring in tidal marshes, rather than open water. And third, significant spawning and larval rearing is occurring at these downstream locations, suggesting a counter-hypothesis that more Longfin Smelt spawn downstream of the Delta in normal and wetter years and then move upstream into the Delta by fall.

Their field work is supported by the surveys as there is no statistical relationship between winter-spring outflow and larval abundance in the Delta. The relationship to spring outflow is with the following fall, suggesting that Longfin Smelt move upstream after spawning in wet years. See Figure SWC-3, below, Grimaldo et al. presentation at UCD Smelt Symposium.

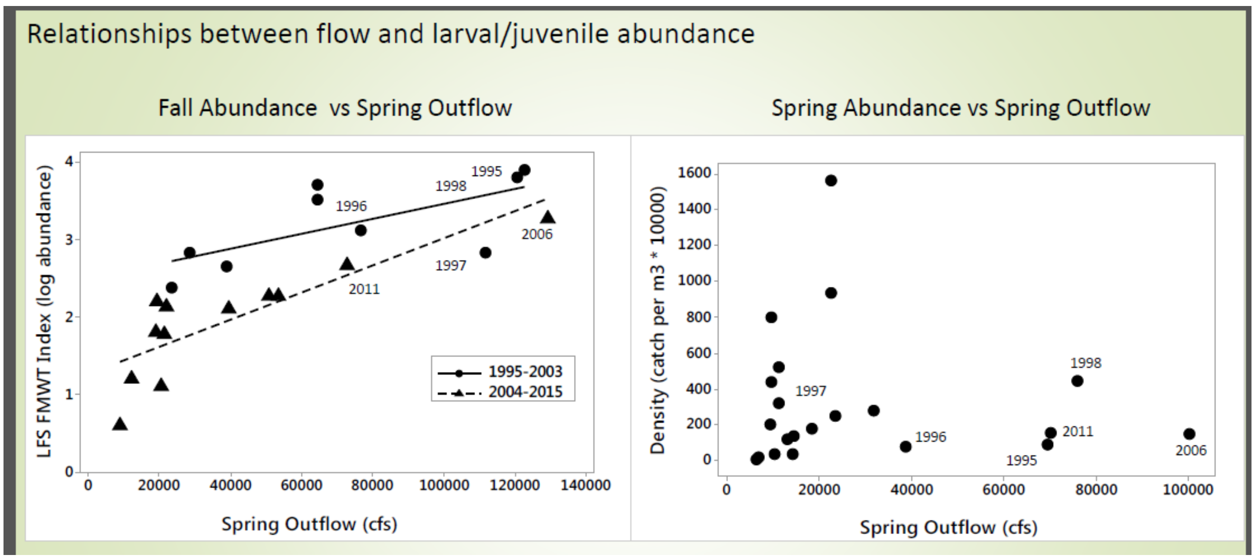

Figure SWC-3. Grimaldo et al., Presentation to UCD Smelt Symposium, Power Point at p. 5, Relationships between flow and larval/juvenile abundance.

The finding by Grimaldo et al. is consistent with the life cycle modeling results by Maunder et al. (2015). The life cycle modeling results confirmed that winter-spring flow is important to Longfin Smelt but the operative flow was not necessarily Delta outflow, as Napa River flow, used as a surrogate for local inflow, performed equally well.

The recent field studies and modeling efforts suggest that the most effective management action may be restoration of tidal marshes surrounding the Bays, and potentially even agreements with downstream water users to increase flows in Bay tributaries.

However, even if the underlying biological mechanism is related to Delta outflow, it does not necessarily follow that reservoir releases can create the conditions that are beneficial to Longfin Smelt. Flow resulting from wet hydrology has different properties than flow resulting from reservoir releases. Dr. Cliff Dahm made this point in a presentation to the Delta Science Council on October 5, 2016, with a figure showing how concentrations of things like nutrients increase with wet hydrology, being the result of run-off from land. See Figure SWC-4, below. Reservoir releases do not create flows with nutrient and turbidity and other properties that benefit fish.

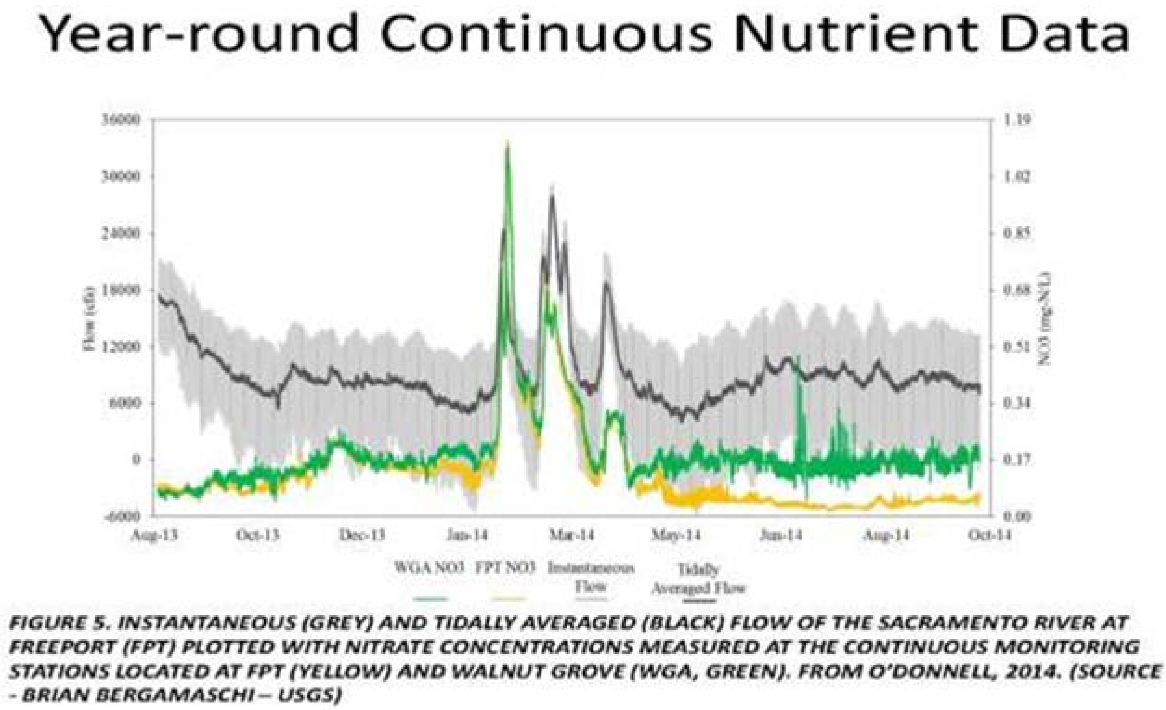

Exhibit SWC-4. Slide presentation to Delta Science Council (October 5, 2016) by Dr. Cliff Dahm.

Longfin Smelt is just one example of the importance of understanding the underlying mechanism. This is true for each species with an abundance-X2 correlation. As further example, Kimmerer (2002) hypothesized that the mechanism underlying American shad's and splittail's abundance-X2 relationship is floodplain inundation. In this case, more outflow will not necessarily increase floodplain inundation and shad and splittail abundance. In addition, by knowing that floodplain inundation is what is needed for the fish, engineering fixes can facilitate floodplain inundation at lower river flows, and that saved water could then be reused for other beneficial uses further downstream. It may also be true that the Bay Shrimp, Starry Flounder and Pacific Herring relationships are really driven by gravitational circulation in the seaward reaches of the estuary, since these species hatch in or near the ocean and presumably use net landward bottom currents to move into and up the estuary (Kimmerer (2002).

Regardless of the ultimate outcome of these studies and others, the Phase II Report should have more fully acknowledged the uncertainty associated with relying solely on correlative analysis as a basis for management actions.

IV. The Phase II Report fails to incorporate the valuable technical information received during the 2012 WQCP workshops, as well as more recent technical information.

The science contained in the Phase II Report appears to focus on published literature that existed around the time of the 2010 Flow Criteria Report, largely ignoring the large quantity of relevant, peer reviewed and published scientific literature that has become available since that time.

Interestingly, to the extent newer analyses are referenced, the selected analyses are largely unpublished and preliminary and therefore should be considered with caution until those analyses have been properly reviewed.

The SWC are providing examples of highly relevant literature that should have been included in the Phase II Report, below. While the SWC have tried to provide a comprehensive list, we may have unintentionally missed some important work. Since ICF International, who appears to be currently under contract to the Water Board, is also involved in the preparation of the California WaterFix planning documents, the SWC know that ICF has in-house staff that are very knowledgeable and aware of the current literature and ongoing science investigations. Generally, the studies we reference, below, are also referenced in the existing California WaterFix Planning documents, and/or have ICF field staff currently participating in the studies. The SWC recommend that ICF also be asked to provide a list of relevant literature and scientific information that should have been included in the Phase II Report.

A. The Phase II Report failed to discuss the more recent literature regarding fall outflows for Delta Smelt.

The Phase II Report cites Feyrer et al. (2007), the 2008 Fish and Wildlife Biological Opinion, and Nobriga et al. (2008) to support fall outflow for Delta Smelt. (Phase II Report, p. 3-6, 3-63, 3-68.)

Nobriga et al. (2008) is not relevant to the issue of fall flows as it was an analysis related to summer habitat.

The 2008 Biological Opinion relied on Feyrer et al. (2007) in addition to some unpublished work also provided by Feyrer et al. The unpublished work eventually became Feyrer et al. (2011), which took a different approach than Feyrer et al. (2007) and the earlier unpublished work referenced in the 2008 Biological Opinion. The Feyrer et al. (2007) paper has received critical comments. (See e.g, Deriso (2008), unpub., NAS (2010).) Among other criticisms, Feyrer et al. used a linear additive model that produces the result that zero adults in one year could still yield some young in the following year, a result that is biologically implausible. The limitations of the Feyrer et al. (2007) analysis should be discussed, at least in terms of full disclosure of uncertainty.

At present, the fishery agencies rely most heavily on Feyrer et al. (2011) to justify the Fall X2 RPA action. The Phase II Report should have referenced and discussed Feyrer et al. (2011), as well as the subsequent review of that paper contained in Manly et al. (2014). The Phase II Report should have also discussed Kimmerer et al. (2009) and (2013). Of particular interest is the conclusion in Kimmerer et al. (2013) at p.13[12] that:

> The lack of consistent parallels between the availability of salinity-based habitat and abundance could have had several causes. First, our use of salinity as the only variable that defines habitat is clearly inadequate…Given the difficulty in determining the controls on the delta smelt population, it is not surprising that such a simple descriptor of habitat is inadequate for this species.

[12] See also p. 3, Table 1, Sept-Dec. period analyzed.

The only other referenced analysis in the Phase II Report is from the 2015 IEP MAST Report. The referenced analysis is preliminary and has not been peer reviewed. Even the MAST Report cautions against the reliance on the referenced analysis stating, "Furthermore, results are preliminary and included for illustrative purposes only; peer-reviewed publications of these analyses need to be completed before they can be used to draw any conclusions." (MAST Report, p. 152.)[13] This disclaimer from the MAST report is not disclosed in the Phase II Report.

The Phase II Report should have provided a more comprehensive description of the referenced figure from the MAST Report. For example, as explained at p. 160, Table 8, of the MAST Report, Figure "81(b)" on p. 159, reproduced in the Phase II Report on p. 3-70 (Figure 3.8-4.), is not the best model. The MAST Report's best models did not find that fall flows or X2 had important explanatory power. The SWC did their own calculation converting the Mast Report's AIC scores into evidence ratios. That conversion shows evidence that the MAST Report's best model was 16 times greater than the model reproduced in the Phase II Report, which was actually the third best MAST Report model. The Mast Report's best model did not find that fall flows or fall X2 were important drivers of species abundance. (See Mast Report at p. 160, Table 8.)

The Phase II Report should also have discussed the currently available life cycle models and multivariate analyses. The Delta Outflow Panel highlighted the value of life cycle models in the context of the MAST Report analysis referenced above. The Outflow Panel stated (Reed et al. (2014, p. 35):

> Many of the uncertainty, but restrictive, assumptions that would need to be stated explicitly in a properly documented full life-cycle model are often implicit, but never evaluated, in simpler analyses. A good example here would be the negative relationship between the trend in 20 mm tow-net series for Delta Smelt and fall X2 (IEP MAST 2013, as presented by Mueller-Solger at the workshop on day 2). If that relationship alone is used to support increased flows, then decision makers are implicitly assuming that increasing the abundance of larval Delta Smelt will lead to a similar increase in the population of adults. This may not be the case if flow has substantial effects on growth and survival in later life stages or if the effects of environmental factors unrelated to X2 are important in determining the ultimate survival to the adult life stage. Life-cycle modeling offers a framework for making explicit the calculations from changes in larvae to populations-level responses.

The currently available life cycle or multivariate models have not identified fall flows as being an important driver of species abundance. (Thomson et al. (2010), MacNally et al. (2010), Rose (2013), Maunder and Deriso, (2011).[14]) The results of these models should have been described in the report. If other model results are available, for example from the Newman model developed by the United States Fish and Wildlife Service, these results should be discussed as well.

[13] This disclaimer also applies to the MAST analysis on Phase II Report p. 3-70 regarding spring outflow for Delta Smelt.

[14] Maunder and Deriso are currently re-running their model using an updated version of the NCEAS data used in Thomson et al. 2010 and MacNally et al. 2010. The preliminary results suggest that fall outflow/X2 has poor explanatory power.

B. **The Phase II Report discussed preliminary and unpublished analyses related to summer flows for Delta Smelt.**

The referenced analysis, CDFW (2016), is unpublished and has not been peer reviewed. The CAMT is currently reviewing the CDFW analysis and planning future studies.

The figures reproduced in the Phase II Report at p. 3-67 illustrate some of the limitations of the analysis that should have been discussed. For example, does the variance explained (R^2) get worse as the summer progresses? Are these results indicating a benefit of summer flows or are they the result of flows, or some other condition correlated with flows, from some earlier time period? Does the correlation breakdown if different time periods are investigated (it does)? Does the correlation breakdown if different surveys are used to assess survival, for example using ratios between the Spring Kodiak Trawl and 20 millimeter survey instead of Summer Tow Net (it does)? And, why does the observed relationship breakdown when the data is analyzed differently?

C. **The Phase II Report failed to discuss the more recent literature related to winter-spring flows for Longfin Smelt.**

The Phase II report references Nobriga and Rosenfield (2016) in support of the finding that, "The population abundance of juvenile longfin smelt in fall is positively correlated to Delta outflow during the previous winter and spring reproduction period." (Phase II Report at p. 3-46.) However, the Phase II report should have also discussed the Nobriga and Rosenfield finding on pp. 55-56 that:

> We found no indication that freshwater flow moderated the survival of Longfin Smelt between age 0 and age 2, but we did detect evidence that survival during this life stage transition is density dependent,

And,

> …freshwater flow variation has been linked to productivity early in the life cycle- an effect that is subsequently tempered by density-dependent survival during the juvenile life stage.

The implication is that new flow is unlikely to build the Longfin Smelt population overtime because of density dependence. This finding certainly questions the reasonableness of a management action that would use additional flows to increase Longfin Smelt abundance.

In regard to potential biological mechanisms underlying the observed relationship, see discussion regarding correlation analysis, above. The correlation discussion is relevant as to whether X2 (Delta outflow) is the flow that is biologically relevant to Longfin Smelt.

The Phase II Report does cite Kimmerer et al. (2009) for the conclusion that, "...the observed X2-abundance relationships are inconsistent with a mechanism that involves extent of low-salinity habitat." This finding, however, should have been more than a passing reference as it also raises questions regarding whether increased Delta outflow in the winter-spring could increase Longfin Smelt abundance. If the underlying biological mechanism isn't low-salinity habitat, and it isn't larval transport (since as shown above many Longfin Smelt are born and rear downstream in the bay), there is significant uncertainty as to whether additional outflow, particularly outflow created from reservoir releases rather than from wet hydrology, could be reasonably expected to improve Longfin Smelt abundance.

The Phase II Report should have provided a more complete discussion of the existing literature.

D. The Phase II Report failed to discuss the more recent literature related to flows for Chinook salmon.

The Phase II Report should have provided a more balanced discussion of the published literature regarding the relationship between flow and fish survival, particularly on the San Joaquin River.[15] The 2009 NMFS BiOp relies heavily on studies of coded wire tagged smolts performed from the late 1960's to the late 1970's, and analysis of adult returns 2.5 years after a set of flow conditions were observed (Kjelson et al (1981); Kjelson et al. (1982). The Phase 2 Report follows the same approach.

The Phase II Report should have discussed the more recent literature.[16] For example, releases of coded wire tagged salmon in the San Joaquin River and Old River as part of the Vernalis Adaptive Management Plan (VAMP) and earlier coded wire tag releases (1985-2004) were analyzed by Newman (2008). This analysis showed a positive but non-significant effect of flow on survival of fall-run smolts in both the San Joaquin River main stem and Old River route. Similarly, Zeug and Cavallo (2013) failed to find a flow effect on the recovery of coded wire tagged salmon released in the San Joaquin and recovered in the ocean. Releases of acoustically tagged salmon in the San Joaquin River have yielded survival estimates much lower than those estimated from CWT releases (SJRG (2011); Buchannan et al (2013); SJRG (2013). The effect of flow on survival of these releases has not been directly integrated into statistical models. However, qualitative information suggests that through-Delta survival during 2011 (a high discharge year) was similar to survival during lower discharge years (2010 and 2012). This finding suggests that San Joaquin River salmon survival is not responding to higher flows.

E. The Phase II Report failed to discuss the more recent science related to Old and Middle River flows

The Phase II report relies exclusively on the 2008 FWS BiOp and the 2009 NMFS BiOp to characterize the direct effects of the state and federal water projects. (See e.g., Phase II Report, p. 3-41.)

Old and Middle River Flow (OMR) is not a flow metric that is particularly meaningful to the fish. OMR is merely a method of estimating take by the SWP-CVP. The Phase II Report cites no evidence supporting the use of OMR as a habitat variable. The discussion provided in section II(A)(2), above, regarding the inadequacy of using tidally averaged flows, like OMR, as a management action is relevant to this discussion as well. As the Draft Salmon Synthesis Report Presentation explains, "[OMR] Effects on indirect mortality are hypothesized; data are limited." Draft Salmon Synthesis Report, Presentation to CAMT, slide 38 [OMR Flow Management].)

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[15] In regard to studies on the Sacramento River, there is some indication of a flow-survival relationship. (See Perry et al. 2010.) However, the type of magnitude of flow that could support increased survival is unclear. Whether flows originating from reservoirs would have a beneficial effect is unknown.

[16] The SWC have provided a list of relevant literature published since the 2009 NMFS BiOp. See Exhibit D, Attached.

Direct and indirect "take" at the SWP and CVP, as defined by the state and federal Endangered Species Acts, is already being managed by three different fishery agencies, state and federal. The best available science does not suggest that further restrictions on SWP-CVP operations would provide significant species benefits.

1. The Phase II Report failed to discuss recent science related to direct take of Delta Smelt and Longfin Smelt.

There is no evidence cited to suggest that already low salvage needs to be lower to protect the fish and wildlife beneficial uses. For example, as the United Fish and Wildlife Service explained in its recent Longfin Smelt listing assessment (FWS 2016, pp. 30-31):

> …the best available science suggests that the vast majority of Longfin Smelt do not spawn or rear in areas of the Delta (CDFW, no pagination), where they or their progeny are in danger of entrainment…current regulations put in place to protect Delta Smelt have reduced entrainment.

The 2012 Longfin Smelt federal listing decision stated similarly, "**Entrainment is no longer considered a major threat to longfin smelt in the Bay-Delta because of current regulations.**" (77 Fed. Reg. 63, 19774.)

In regard to Delta Smelt, the OMR technical discussion in the Phase II Report is outdated, solely referencing the analyses contained in the 2008 BiOp. For example, since the BiOp, it has become apparent that turbidity is an important environmental indicator of a Delta Smelt salvage event. The FWS and the water agencies are in agreement on this point. In recent years, the FWS, DFW, DWR and Reclamation have been closely monitoring Delta Smelt distribution and turbidity from December through June; and when necessary, taking real-time management actions in an effort to avoid entrainment events.

At a minimum, the Phase II Report should have discussed existing management actions being taken to avoid Delta Smelt entrainment, and acknowledged that entrainment is currently not a concern for Longfin Smelt.

2. The Phase II Report fails to discuss recent science related to direct take of salmonids.

There is little evidence to suggest that further limiting SWP-CVP export pumping would provide important species benefits.

Current direct take of Chinook salmon at the SWP-CVP is very low, representing only a fraction of allowed take under the current incidental-take permits issued by NMFS. As explained by the Delta Science Program, even if the total population is over estimated in calculating the incidental take limits, current take by the water projects is likely not a concern. Each year, the Delta Science Program reviews different aspects of the implementation of the biological opinions. As part of this review, the expert panel reviewed the juvenile production estimate (JPE) in 2014. The JPE is the basis for each year's allowed incidental take by the water projects. At the conclusion of their review, the Delta Science Program (Anderson et al. (2014) at p. 17) concluded:

> …the JPE for the 2014 drought year could have been overestimated by up to a factor of three. However, even at this level of actual take (338 WRCS) would be only 4% of the Annual Take Limit. Thus, even if the JPE were significantly overestimated in WY 2014, the run was not likely endangered by export operations.

The Phase II Report should have discussed the current very low levels of take.

F. The Phase II Report fails to provide a sufficiently detailed and updated description of "other stressors."

Chapter 4 of the Phase II Report provides a general description of aquatic ecosystem stressors and the effects of the stressors on aquatic wildlife. The stressor descriptions are brief and provide little detail regarding the effect of the stressors on aquatic species, the management programs to address the stressors, and the interactions between stressors and flow management. Chapter 4 also includes very little discussion of how the information on ecosystem stressors interacts with the flow recommendations in the report. The Delta Independent Science Board (Delta ISB) is reviewing the Phase II Report, at the request of the Water Board. The Delta ISB discussed their comments on the Phase II Report at their meetings held on November 18 and December 8, 2016. One of the main comments that the Delta ISB identified is that the Phase II Report suffers from a lack of quantitative treatment of any effects from non-flow stressors, and provides little information regarding methods for reducing effects of non-flow stressors. The Delta ISB recommends that the Phase II Report include a fuller description of non-flow stressors, the agencies that are responsible to regulate the stressors and our scientific understanding of the stressors, to provide better balance to the fuller descriptions of flow stressors in the report. The SWC agrees with these comments and urges the Water Board to substantially revise Chapter 4 of the Phase II Report to address the Delta ISB comments.

The Delta Science Program is completing its State of Bay-Delta Science 2016 this month, with the expected publication of the third and last group of SBDS papers. The SBDS (2016) papers address several ecosystem stressors, including Delta habitat changes, predation, Delta food web changes, climate change, nutrients and contaminant effects. The papers provide an up-to-date synthesis of science on these topics, with focus on scientific findings of the last ten years. The SWC urges the Water Board to thoroughly consider the SBDS (2016) as it revises the Phase II Report to include a more comprehensive discussion of non-flow stressors.

The section on physical habitat loss and alteration describes changes to the landscape (e.g. loss of tidal marsh, riparian, floodplain habitat) but does not mention that historical flows, the natural flows that Delta species evolved with, would spill into these areas, creating rearing and spawning habitat, and providing an influx of food as the waters drained back into the channels. These are functions that will not be restored by simply increasing flows down the existing channels. This section also lacks a discussion of the complex relationship between flows and phytoplankton growth and that primary productivity is amongst the lowest of all estuaries studied. The Phase II Report should be revised to consider the important interrelationships between flows and the landscape, including timing and placement of flows, and residence time, to enhance the food web.

The water quality section includes general descriptions of Bay-Delta water quality conditions and the regulatory programs in place or in development; however, the chapter lacks information regarding the expected water quality improvements and timeline for those improvements, and the importance of addressing the water quality stressors to improve the Bay-Delta ecosystem. The chapter describes several specific contaminants and their general effects with an example or two, but fails to convey that most water samples collected in the Delta contain multiple contaminants and that mixture effects can be additive or synergistic. Recent monitoring studies have detected multiple contaminants occurring simultaneously in water samples collected in the Delta (Orlanda et al. (2013), Orlando et al. (2014)). For example, in 2012 and 2013, 27 pesticides and/or degradates were detected in Sacramento River samples, and the average number of pesticides per sample was six. Similarly, in the San Joaquin River samples, 26 pesticides and/or degradates were detected and the average number detected per sample was nine. The water quality section also includes very limited discussion of the evidence of contaminant effects in the Bay-Delta. The SBDS (2016) paper addressing contaminants, which is expected to be published at the end of December 2016, will be important information for the Water Board to consider as it revises the Phase II Report.

The water quality section includes several statements that the stressors interact with flows, but not much detail on how they interact. For example, the document states that flows dilute contaminants, but does not mention that concentrations of many contaminants are greatest during large flows due to transport from land applications. On page 4-5, the document states, "Reduced freshwater inflow from the Sacramento---San Joaquin River system may also reduce the estuary's capacity to dilute, transform, or flush contaminants (Nichols (1986))." The Phase II Report should also note that some contaminant degradates are more toxic than their parent compound, and that diluting and flushing contaminants may only move the problem downstream.

The water quality section does not include discussion of changes in loads and types of nutrients and the impacts of those changes, other than a brief description of ammonia/ammonium. The SBDS (2016) paper addressing nutrients, which is expected to be published at the end of December 2016, will be important information for the Water Board to consider as it revises the Phase II Report. Page 4-7 states the Microcystis aeruginosa blooms tend to occur with elevated nutrient concentrations, among other things, but does not mention the evidence that these blooms are growing on ammonium. For example, a recent study by Lee et al. (2015), found that Microcystis aeruginosa in Delta field experiments and lab experiments had much higher uptake rates for ammonium as compared to other forms of nitrogen.

The section on nonnative species includes limited discussion on changes in the food web, but fails to convey how significantly the food web has changed, and makes no mention of all the evidence of food limitation in many of the at risk fish species. The section on nonnative species also describes the different ways nonnative species can impact native species including competition and predation, but fails to mention the negative correlation between nonnative and native species.

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Exhibit A, Specific Comments

Page	Comment
1-9	The PWAs have previously commented extensively on the fact that unimpaired flows are not the same as natural flows (see, e.g., the PWA's submittal to the SWRCB on ecosystem changes to the Bay-Delta estuary, section 6). Continued recommendation to use unimpaired flows as the yardstick by which percentages of flow for ecosystem services are applied will overestimate both summer and fall flows. These seasons have seen higher flows than are natural via reservoir releases. The majority of literature citations used in the Draft Scientific Basis report do not mention unimpaired flows or an equivalent metric (see, e.g., Rozengurt et al. 1987, Poff et al. 1997, Pringle et al. 2000, Freeman et al. 2001, Bunn and Arthington 2002, Poff and Zimmerman 2010, Petts 2009, Montagna et al. 2013, Kiernan et al. 2012, all cited on p. 3-2).
2-54	The Phase II report states that, "The Sacramento River is a major source of the fresh water in the Old River Channel which is ***pulled upstream through*** Georgiana Slough and the Delta Cross Channel Gates". [Emphasis added] These waters flows by gravity into these channels. It is not "pulled" there by exports. See Cavallo et al. (2015) for an analysis of exports influence flow and fish proportions at these junctions.
2-56	The Phase II Report states that, "Export operations combined with changes in channel geometry, gates and barriers have greatly altered ***the natural direction of flow*** in the Delta…." [Emphasis added]. In some channels of the central and south Delta, a calculated tidally averaged flow will yield a negative value, however, this does not mean the direction of flow has changed. As explained in Monismith et al. (2014) flow direction in most Delta channels does not change as a result of exports. Fish cannot perceive "net" flows and therefore have minimal significance to them- except for fish that are passively drifting (a seemingly uncommon strategy among Delta fishes).
2-56	The Phase II Report states that, "…high export pumping rates has caused reverse flows in the Southern Delta…" Reverse flows implies a meaning that is contrary to the reality of Delta hydrodynamics. The use of a term like "reverse flows" without a detailed explanation and definition is something more typical of news report than a scientific document about Delta flow conditions.
2-57	The Phase II Report indicates agricultural barriers are installed beginning April 15th. This is incorrect, agricultural barriers are typically installed in mid-May or later.
2-57	The Phase II report states that the HORB is installed, in part, to keep salmon smolts away from predators in the interior Delta. Acoustic tagging studies indicate predation problems are at least as bad in the mainstem San Joaquin River downstream of HOR and at points of the interior Delta accessible by other junctions also downstream of HORB.
2-58	The Phase II Report indicates exports can greatly reduce Delta outflow and alter Delta hydrodynamics. This description is vague or even misleading. Exports can only reduce outflows up the maximum allowable export level- a fraction of typical total Delta inflow (particularly in spring).
2-58	The Phase II Report states: "The most prominent example of changes in flows direction in the Delta occurs in the Old River and Middle River Channels of the San Joaquin River." [emphasis added] This excerpt and the sentences which follow it misrepresent Delta hydrodynamics. Again, no evidence has been provided of changes in flow direction. Tidally averaged "net" flow and OMR is not a measure of flow direction. As indicated previously and expanded upon in the Appendix to this technical memo, net negative flows do not correspond with changes in flow direction. This is important because fish perceive and are potentially impacted by changes in flow direction, but do not perceive and are unlikely to be influenced by "net" flows alone (Monismith et al. 2014).
2-60	The Phase II Report states, "Large tidal exchanges below the confluence of the Sacramento and the San Joaquin Rivers make it difficult to measure flow through the larger channels".

Page	Comment
	This statement is true, and it highlights the inappropriateness of relying upon tidally averaged flows. Large tidal flows are what fish and other organisms are actually experiencing- tidally averaged flows are an abstraction that fish are incapable of perceiving (see Monismith et al. 2014).
3-1	The report is based on flow information in the absence of consideration of other competing factors such as other water uses or the need for cold water to support salmonids in the tributaries. Reservoir storage and coldwater pool management have been identified as critical factors effecting salmonid spawning, egg incubation, hatching, and juvenile rearing. Depletion of coldwater results in seasonal exposure to elevated water temperatures that can result in high levels of salmonid stress and mortality. Isolating flow alone in the analysis has the potential to result in depletion of coldwater and significant reductions in habitat quality and availability, reduced salmonid production, survival, growth, and population abundance and diversity. The analysis must integrate instream flows with reservoir storage and coldwater pool management to produce meaningful and beneficial management strategies.
3-1	The report identifies the importance of stressor reduction and habitat restoration in addition to instream flows as "essential for protecting fish and wildlife resources" but provides no linkage for implementing the suite of management actions needed to meet biological goals. Implementing flow alone is not expected to achieve the stated goals and could lead to unintended adverse impacts to other beneficial water uses. For example, SWRCB D-1485 prescribed a flow regime for striped bass based on an analysis of juvenile abundance and spring Delta outflows similar to those reported in Chapter 3 for other species. Despite providing the spring Delta outflows striped bass abundance did not increase as predicted. Similarly, high flows during the spring of 2006 and 2011 occurred in the San Joaquin River but survival of juvenile fall-run Chinook salmon did not increase as predicted. These examples illustrate the high degree of uncertainty in predicting flow-abundance relationships which is not reflected in Chapter 3. Chapter 3 page 3-1 states that the report "identifies flows that are predicted to either produce population growth of specific native indicator aquatic species populations more than half of the time or maintain populations near abundance goals previously identified in the Delta Flow Criteria Report". This foundation for the recommendations ignores the interaction among environmental factors such as availability of suitable coldwater and other stressors such as predation as well as the high degree of uncertainty that species will respond to flow alone as predicted by the report.
3-2	The Phase II report states, "Flow is not simply the volume of water, but also the direction, timing, duration, rate of change and frequency of specific flow conditions." This is true, but directly contradicts the simplified presentation of "net" flows in the prior chapter. Estuary flows are complex, and boiling them down to a simple metric leads like "net" flows leads to misunderstandings about how much river inflows or exports can change habitat and hydrodynamics in the tidal Delta.
3-2	The report cites Rozengurt et al. 1987 as the basis for a finding that upstream diversions that exceed 30 to 40-50% of unimpaired flows result in degraded habitat and fish populations that are not able to recover. Relying on a single reference that is almost 30 years old is not a sufficient scientific basis for establishing thresholds reported in this finding.
3-2	Much of the discussion in Section 3.2 on flows and the ecosystem are presented as if the statements are established facts directly related to the Bay-Delta system. The discussion would be more appropriately characterized and presented as a conceptual model and series of hypotheses related to potential management actions that require testing and validation and are currently subject to unknown levels of uncertainty regarding the actual response of various species and lifestages to these and other environmental conditions.
3-4	The Phase II report indicates natural flow regime can offset the negative effects of hatchery on naturally produced populations. This is wild speculation with no logical foundation or basis in the scientific literature.

Page	Comment
3-4	The discussion of how the rim dams and altered flow regimes have caused a loss of geomorphic processes related to the movement of water and sediment is missing more recent research into sediment transport in the Bay-Delta. Without question, the rim dams have trapped sediment. It is widely acknowledged that a step change in sediment transport occurred sometime after 1983 as the sediment pulse from hydraulic mining cleared the Bay-Delta (Wright and Schoellhamer 2004; Schoellhamer 2011). Other anthropogenic activities have also affected the sediment load in the Bay-Delta, such as riverbank protection and altered land uses (Wright and Schoellhamer 2004). In the Suisun Bay region, land surface erosion and wind resuspension are the major determinants of turbidity (Ruhl and Schoellhamer 2004; Brown et al. 2013). Turbidity in the Bay-Delta is largely uncoupled from flow (Wright and Schoellhamer 2004; Hestir et al. 2013). Sediment inputs from small tributaries have become more important than the larger river systems (McKee et al. 2013). No matter that turbidity decreases predation and cues migration if flow changes cannot increase it.
Table 3.4-5	The table presents a count of watersheds supposedly impacted by water related-stress. The source of the data is the NMFS recovery plan (2014). NMFS (2014) is not an appropriate source of information for such an analysis as it does not provide any data analysis- just a listing of stressors.
3-7	The Phase II Report states: "…most relationship continue to remain strong since first described and better understanding of the likely mechanisms is rapidly developing." This claim is inaccurate, no evidence has been provided which supports mechanisms. Studies such as Bever et al. (2016) suggest that different Delta outflows do not appreciably affect hydrodynamics and other physical factors thought to be important to Delta fishes.
3-7	The report states that modeling results show the low salinity zone has been skewed eastward in the recent past and variability in salinity in the western Delta has been reduced. The report does not discuss how reservoir releases and managed Delta outflow has been used to provide reduced salinity in the Delta during some seasons and years when compared to unimpaired conditions to support other beneficial uses such as municipal drinking water and agricultural irrigation supplies. The SWRCB is required to balance all of these beneficial uses rather than focus solely on estuarine habitat for aquatic species. The report should provide a discussion of how information developed through the flow analysis will be integrated with other analyses of balanced and competing uses.
3-7	The report cites Jassby et al. 1995 as the single reference for a finding that "statistically significant inverse relationships have been demonstrated between the landward extent of X2 and the abundance of a diverse array of estuarine species". Many of these earlier relationships have changed over the past 20 years as a result of interactions with other factors such as the introduction and rapid population expansion of non-native Asian clams, expansion of predator populations, and proliferation of non-native submerged vegetation. The implication of the report statements is that if the Delta outflows were increased to levels that occurred in the past the abundance of many of the estuarine species would also increase. This is overly simplistic and fails to account for a number of factors that have changed that have major implications for how estuarine species are likely to respond to changes in flow or X2 location alone.
3-8	The report discusses the importance of turbidity in Grizzly and Honker bays as a habitat feature for delta smelt and salmon. The report correctly discusses the importance of wind-driven re-suspension of sediments rather than outflow on turbidity in the western region of the estuary. The report does not, however, discuss the effects of proliferation of submerged aquatic vegetation (SAV) on turbidity conditions throughout the Delta and whether increased flows or wind would result in turbidity conditions as in the past. This is example of over-simplification of the estuarine dynamics that contribute to high uncertainty in the biological and abiotic response to environmental conditions.
3-8	Reference to Bever et al. (2016) is inaccurate. Bever et al. (2016) did not find that Delta Smelt are found most frequently in the shoals of Grizzly and Honker bays; they found that Delta

Page	Comment
	Smelt are found more frequently in areas where specified salinity and turbidity metrics were met, along with low seasonally-averaged velocity. These conditions were met in 2011 but not 2010, as reflected by the higher FMWT catches in Grizzly and Honker bays in 2011. These were the only two years considered in the Bever et al. (2016) analysis.
3-8	Reference to MacWilliams et al. (2016) is inaccurate. MacWilliams et al. (2016) did find that there has been a decline in the percentage of time the LSZ has occupied >75 km-2. However, this does not tell the complete story of the findings of MacWilliams et al. (2016). They also found that there has not been a significant trend in fall average Delta outflow from 1980 through 2014, and that there may be only a very weakly significant trend in increasing X2 from 1980 to 2014 between September and November. Therefore, the trend of decreasing average LSZ area is not solely attributable to either increases in X2 or to decreases in outflow. Also, MacWilliams et al. (2016) examined only the LSZ, defined as between 0.5 and 6 psu, ignoring upstream freshwater areas where Delta Smelt are known to congregate. Hence, the value of the findings of MacWilliams et al. (2016) in a population context is unknown. The associated maps of seasonal salinity gradients and Delta Smelt CPUE (Feb-Jun) in MacWilliams et al. (2016) show just what one would expect – downstream movement of Delta Smelt during high outflow years and upstream movement during lower outflow years.
3-8	After inaccurately describing MacWilliams et al. (2016), the Draft Scientific Basis report ties itself to the Feyrer et al. (2007) hypothesis that decreases in the extent of the LSZ is of crucial concern, because it limits the foraging area of Delta Smelt and is therefore a bottleneck. In previous comments, both in this document and on the Flow Criteria report, the PWAs have demonstrated that the notion of maintaining fall X2 downstream of the confluence is not strongly supported. Even though the National Academy of Science characterized the fall X2 requirement in the USFWS BiOp effects analysis (2008) as "conceptually sound," they also characterized the weak statistical relationship between the location of X2 and the size of smelt populations as "difficult to justify." An independent peer review of the USFWS effects analysis (2008) questioned the utility of the fall X2 habitat analysis, noting that a few data points may have had high influence on the outcome. The independent reviewers even questioned whether the fall X2 stock-recruit model was inappropriate for the data used (Rose et al. 2008 at 7). The Flow Criteria report did not include a requirement for fall outflow.
3-9	The report states that "reverse flows in the southern Delta are associated with increased entrainment of some fish (Grimaldo et al. 2009) and disruption of migration cues for migratory fish". Although the report states this as a demonstrated fact there is no scientific reference or analysis of the potential effect of reverse flows on disruption of migration cues for migratory fish. Although presented as fact this statement is an unsupported hypothesis and has not been demonstrated.
3-9	The report states that "long-term water diversions also have contributed to reductions in the phytoplankton and zooplankton populations in the Delta itself as well as alterations in nutrient cycling within the Delta ecosystem (NMFS 2009)". The NMFS 2009 Biological Opinion did not develop independent analyses to support this finding. Although the BiOp may have made these statements the primary reference sources supporting scientific analyses of these relationships is needed. This is an example of many citations in the report that are presented as fact without actual scientific references or support.
3-11	The report states that updated analyses of flow and abundance for selected species were developed based on data from the CDFW fall midwater trawl and Bay otter trawl surveys. The report provides no discussion or justification of the selection of these two data sources for the analyses. For example, why was the Bay Study otter trawl data used but apparently not the Bay Study midwater trawl data which covers the same geographic area and time period as the otter trawl surveys? The report should include an appendix documenting the methods used to develop abundance indices from each survey, how missing surveys were addressed, how changes in sampling stations were addressed, etc. The appendix should also provide tabular

Page	Comment
	documentation of all of the data used in these flow-abundance relationships given their importance in the updated analyses and findings.
3-11	The report states that abundance indices used in the updated flow-abundance relationships were developed by SWRCB staff but omitted zero values for the abundance indices citing Kimmerer 2002 as the rationale. Many more recent analyses of species abundance include zero values in the analysis. The methods and assumptions used in the SWRCB flow-abundance analyses should be subject to independent scientific peer review by qualified statisticians and biologists before they are accepted for use in this analysis. At a minimum, the flow-abundance relationships should be recalculated and presented based on indices that include zero catch values as well as new methods or estimating abundance such as those recently developed by Newman and others. Credibility of the updated flow-abundance relationships is critical to the review and confidence that can be placed on the results and their interpretation. As currently presented, results of the analyses presented in the report do not meet the basic criteria of independent scientific peer review.
3-12	The Phase II Report makes the case that increased river inflow will improve through-Delta survival of juvenile salmonids. No evidence is offered to support the claim. The Appendix to this technical memo explains the weak mechanistic basis for river flows to have a hydrodynamic benefit to juvenile salmonids in the tidal Delta.
3-12	The report states that "a combined species evaluation has been prepared for all four runs of Chinook salmon and Central Valley steelhead". The report states that steelhead and salmon share similar life history strategies that factors that benefit salmon will also benefit steelhead. The use of data from salmon as a surrogate for steelhead, however, has been criticized in several forums including the NMFS 2009 BiOp. No data are presented in the report to support the assumption that salmon are a suitable surrogate for salmon in the Delta. In fact, results of acoustic tag survival studies conducted in the lower San Joaquin River support the opposite conclusion that salmon are not a surrogate for juvenile steelhead. Comparative survival estimates for acoustic tagged fish in 2011 and 2012 estimated juvenile steelhead survival as 0.32 and 0.54 respectively while juvenile fall-run Chinook salmon survival at the same times was 0.02 and 0.03 respectively; over an order of magnitude different in both years. The large disparity in these results supports a conclusion that juvenile Chinook salmon should not be used as a surrogate for juvenile steelhead without validation. Findings in the report representing combined salmon and steelhead should not be relied on in the analysis.
3-12	The report presents a finding that "flows greater than 20,000 cfs at Rio Vista between February and June are expected to improve juvenile salmon survival during outmigration". The report presents no results of analyses or even a reference to the scientific literature as support for this fundamental conclusion. What data were used to support the finding that survival increases at Rio Vista flows greater than 20,000 cfs? What is the basis for a 20,000 cfs threshold? Is this the average flow between February and June or the minimum flow? This is an example of one of the many key findings presented in the report without scientific support. At a very minimum the report should discuss the data used in support of each finding and present results of graphic and statistical analyses supporting each of the specific findings and conclusions.
3-12	The report states a conclusion that "juvenile salmon emigrating from both the Sacramento and San Joaquin Rivers through the Delta have better survival if smolts remain in the main stem river channels and do not migrate through the interior Delta". This is another example of an unsupported conclusion in the report. No data or even references to the scientific literature are provided to support this finding. In fact, results of recent acoustic tag survival and migration studies in the lower San Joaquin River and Delta refute the broad finding in the report noting that juvenile salmon survival was not different between those fish migrating in the mainstem and those that migrated into interior Delta channels. In fact, for some of the studies survival to Chipps Island was greater for those salmon that migrated into the interior Delta and were

Page	Comment
	salvaged at the CVP and trucked to a release site in the western Delta. Unsupported and in some cases incorrect findings and conclusions presented in the report undermine the credibility and value of the report and support the need for independent scientific peer review of the report before findings are used in developing management actions for further balancing and analysis.
Figures 3.4 through 14	These figures present course and unreliable data and should be deleted in favor of peer-reviewed data provided by Zeug and Cavallo (2014).
3-16	The report states "juvenile Chinook salmon movements are controlled by tides in the Delta. Juveniles move into shallow water habitat on the rising limb of the tide and return to main channels when the tide recedes (Ley and Northcote 1981; Healey 1991)". The report is misleading in implying information regarding the importance of tides on juvenile rearing habitat or movements in the Delta. No studies are available that document the tidal movement of juvenile salmon in the Delta. The report cites no Delta-specific literature. Both the cited references for Levy (note the typo in the report citation) and Northcote and Healy were based on juvenile salmon rearing in British Columbia and not the Bay-Delta estuary. This is an example of overstating the basis of knowledge used in support of the report findings and discussion.
3-17	The document cites MacFarlane and Norton (2002) to support the claim that through-Delta migration takes 40 days. This study is based upon inferences from the size of captured fish- not from fish tagging. Numerous fish tagging studies now available indicate a much faster transit rate.
3-20	Many of the figures presented in Section 3.4 are based on adult salmon escapement from a 2012 version of GrandTab. GrandTab data are available through 2015 (2016 CDFW reporting) and could be used to update all of these figures. The drought started in 2012 and is not reflected in the current figures in this section. Rather than relying on escapement for Chinook salmon abundance trends a better metric would be total adult ocean abundance (escapement and harvest) since escapement alone is affected by changes commercial and recreational harvest.
3-26	The document indicates there are six Central Valley hatcheries raising fall run Chinook salmon including (in the footnote) Trinity and Klamath River Hatcheries. This is an error. Five CV hatchery produced fall Chinook- Trinity and Klamath are not CV hatcheries.
3-27	Figure 3.4-10 presents information on the cumulative smolt outmigration of juvenile fall-run Chinook salmon from the San Joaquin River drainage based on CDFW sampling at Mossdale. Since this report focusses on the Sacramento River system primarily, the relevance or use of juvenile fall-run migration data from the San Joaquin River in the analysis is not clear. Why does the report not use juvenile salmon monitoring data from the Sacramento River system such as rotary screw trapping at Red Bluff and Knights Landing, trawling at Sacramento, and trawling at Chipps Island? Why are data on run timing not presented for each of the races of Chinook salmon of relevance rather than only for fall-run?
3-32	Table 3.4-5 presents results of a SWRCB staff analysis of the percentage of watersheds affected by flow-related stressors. The report does not, however, present information describing the basic criteria that were used to assess habitat conditions and stressors, the assumptions and methods used in the analysis, separate the analysis based on salmonid runs or watersheds, or discuss the application of the results of this analysis to the recommendations or conclusions presented in the report. The report discussion should be revised to provide sufficient information to assess the results of the analyses being presented. Results of all of the analyses presented in the report should be subject to independent peer review prior to being used as a basis for management recommendations.

Page	Comment
3-32	The report presents in Table 3.4-6 information on the effects of pulse flow operations on adult straying rates from the Mokelumne River. The use and relevance of this information in the flow analyses presented in the report is not apparent. The report discussion should be expanded to describe how these results are being factored into the report findings and recommendations
3-33	See comment above regarding analyses presented in Table 3.4-5
3-33	The discussion of reestablishment of cottonwoods and other native trees along the Sacramento River ignores the fact that the Sacramento River and many of its tributary systems are managed for flood control. CDFW (2012) itself recognizes this, stating (at p. 27): "More uniform flows year-round and stream bank armoring have resulted in diminished natural channel formation, altered food web processes, and slower regeneration of riparian vegetation." The Board must balance the extent to which flow strategies can be used to reestablish native trees along the river with the flood control and other beneficial needs of downstream beneficial uses.
3-35	The report states "studies indicate that higher flows during these periods are protective of outmigrating juveniles increasing both the abundance and survival of emigrants out of the Delta". The report provides not citations to the scientific literature to support this fundamental finding. No analyses are presented that show the relationship between river flow or Delta outflow and either abundance or survival of juvenile salmon from various watersheds. Further, the report draws simplified and general findings without providing the scientific support or details of the analyses. For example, results of recent acoustic tag survival studies on the lower San Joaquin River showed that estimated survival to Chipps Island was 2% in 2011 a high flow year and 3% in 2012 a low flow year. These results directly contradict the statement in the report. Similarly, survival estimated in 2006, a high flow year, was not greater on the lower San Joaquin River than estimated for low flow years. Further, the production of juvenile salmonids (abundance) is determined in large part by abundance of spawning adults and flow and temperature conditions during the summer and fall spawning and egg incubation period which is separate from the flows in late winter and spring on juvenile migration and survival.
3-35	The report again states that survival is greater for those juvenile salmon that migrate downstream in the main stem rivers and lower for those that migrate into the interior Delta. See comment on page 3-12 above.
3-35	The report cites Kjelson and Brandes 1989 on a positive relationship between salmon smolt survival between Sacramento and Suisun Bay and mean daily flow at Rio Vista during May or June with increasing survival as flows increased from 7,000 to 25,000 cfs. The report, however, does not present data from these early coded wire tag studies on the relationship between Rio Vista flow and salmon smolt survival. Results of more recent survival studies should be presented in the report to support flow-survival relationships for mark-recapture and acoustic tag studies on both the Sacramento and San Joaquin Rivers. A large body of survival information has been collected over the past 20 years that is not well represented in the report.
3-35	The report cites Brandes and McLain 2001 as reporting "a positive relationship between abundance of unmarked outmigrating Chinook salmon and April-June flow at Rio Vista". Figure 3.4-12 (page 3-36) also present information on Chinook salmon catch and Rio Vista April-June average flows. The upper panel presents results for the period 1978 to 1997. The lower panel presents results for two time periods including 1976-1997 and 1998-2015. Data from the upper panel (a) was reported to be replicated in lower panel (b) for comparison and yet the two plots appear to be different. The data sets used in generating these figures should be re-checked. In addition, the discussion should be expanded to include: are the differences in catch a function of differences in actual population abundance or simply a seasonal change in migration timing as a function of flow or other conditions, and how would flow in April-June effect abundance for fall-run salmon that were spawned in October-December and reared

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	in the upper watershed until migrating downstream in the spring.
3-35	The Phase II report cites Brandes and MClain (2001) for evidence of a positive relationship between abundance and catch-per-unit-effort. In fact, there is no evidence to suggest CPUE was tracking increased abundance- higher flows and turbidity are often associated with more efficiency capture due to turbidity.
3-37	The report concludes that flows greater than 20,000 cfs between February and June are expected to increase the abundance of juvenile fall-run and winter-run Chinook salmon at Chipps Island. Data are available from several sources including acoustic tag survival studies, spawning surveys, lifecycle modeling, Knights Landing and Sacramento surveys and others that should be integrated and synthesized to further evaluate this key finding and flow threshold effect. The limited data analysis presented in the report is sufficient to develop a testable hypothesis for a flow-survival and flow-abundance relationship but requires further validation prior to use as a basis for management actions.
3-37	The report again relies on information from juvenile salmon for use as a surrogate for steelhead with no validation (see comment page 3-12 above). The report states that similarities in life histories among these species are justification for the assumption. The juvenile life history of fall-run Chinook salmon that migrate downstream as fry and young-of-the-year smolts (typically 40-100 mm in length after only a few months of rearing in the river) is substantially different than for steelhead that spend 1 to 2 years rearing in the river and migrate downstream at 150 mm or larger.
3-37	The document cites Schaffter 1980 as cited by Low et al. 2006 regarding entrainment at junctions, but fails to cite more recent acoustic telemetry based analyses including Cavallo et al. (2015) which provided a comprehensive analysis of such data.
3-38	Relationships between the mean proportion of flow diverted into the interior Delta in January (Figure 3.4-13) and December (Figure 3.4-14) and juvenile winter-run Chinook salmon losses at Delta export facilities are based solely on only two years in both plots with virtually no relationship for all other years included in the analysis. These analyses should be updated to include results of monitoring between 2006 and 2016. Management of the DCC gates has changed in recent years and results of these earlier estimates may not be applicable to current conditions.
3-39	The report briefly discusses the results of non-physical barrier testing conducted at Georgiana Slough. The report attributes these studies to USGS and cites papers by Perry et al. 2014. DWR was the agency that directed the studies and there are additional detailed reports and analyses that are not cited or used in the report description. The discussion of flow alternatives for guiding juvenile salmonids and improving migration and survival should be expanded.
3-39	The report states that tagging and modeling studies have shown improvements in juvenile Chinook salmon survival in the lower San Joaquin River with the Head of Old River Barrier (HORB) installed during the spring. The report should be updated to include information from more recent acoustic tag survival and migration studies for both juvenile Chinook salmon and steelhead as a function of the Old River channel junction. The report should be revised to include more recent study results.
3-39	The report states that juvenile salmon may be more likely to migrate toward the export facilities during periods when exports are increased compared to when exports are reduced. The report cites Vogel 2004 as the basis for the statement. Data available on juvenile salmon migration and survival prior to 2004 that could be used by Vogel would have been limited to coded wire tags. These tags do not provide information on migration route. In the absence of additional information presented in the report there is no basis to assess the analyses of a relationship between south Delta route selection and SWP and CVP export rates. Rather than relying on CWT data these analyses should be based on recent results of acoustic tag migration and survival studies using both salmon and steelhead. The analyses presented in the

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	report should be revised and updated.
3-40	Table 3.4-7 reports to present a synthesis of information on seasonal timing and magnitude of flows intended to increase juvenile salmonid survival and abundance. The analyses presented in the report, however, are generally inadequate to actually assess these flow conditions. For example, no data or references to scientific literature are presented in the report to support a relationship between either abundance or survival of juvenile salmonids and positive flows in the San Joaquin River at Jersey Point, flow-survival relationships at Georgiana Slough, relationships between OMR reverse flows and either salmonid abundance or survival, or the San Joaquin River inflow to export ratio and either salmonid survival or abundance. Many of the relationships included on Table 3.4-7 have been hypothesized but have not been explicitly tested or validated. Information summarized in the report is inadequate for use as scientific support for these seasonal flow recommendations.
3-41	The report discusses the use of PTM model results to assess the risk of entrainment and salvage of juvenile salmonids. Past PTM model results have been criticized in their application to assessing migration behavior of actively swimming juvenile salmon and steelhead. The PTM approach used in the past as part of the NMFS 2009 BiOp has been revised and more refined hydrodynamic simulation modelling approaches are being developed and applied. Presenting results of the earlier PTM approach in the report may be confusing and potentially misleading and inaccurate.
3-42	The Phase II Report cites the1995 Working Paper and USFWS 1995 to support the influence of “net” negative flows on juvenile salmonids. These studies are outdated and have been supplanted by superior statistical analysis and particularly by acoustic telemetry studies. Newman (2008) provides the definitive analysis of export-survival for SJR origin juvenile salmon.
3-42	Results of analyses of salmon salvage at the SWP and CVP as a function of OMR reverse flows presented in Figures 3.4-15 and 3.4-16 from the 2009 NMFS BiOp have been extensively criticized. Monthly losses used in these plots were not normalized for abundance of juvenile salmon in the population and therefore the reported relationships were confounded. These graphs are confusing and should not be included in the report. Revised graphs are available.
3-43	Figure 3.4-17 reports temperature corrected survival indices from CWT juvenile Chinook salmon released at Jersey Point and recaptured at Chipps Island. The report presents no discussion of the basic methods used in these studies, how survival was corrected for temperature, or why only results from 1989-1991 are reported when a large number of additional CWT releases have been made at Jersey Point. Further, given the tidal nature of the Delta in the vicinity of Jersey Point and Chipps Island no mechanism has been hypothesized for the reported relationship presented in the report. Additional refined data from more recent acoustic tag studies as well as survival studies conducted as part of VAMP should be used to further assess this hypothesized relationship. In addition, results of hydrodynamic simulation modelling should be reviewed to determine the physical relationship between Delta inflow, flow at Jersey Point, the effects of inflow on water velocity and flow direction at Jersey Point, and how flows may affect migration behavior and survival in this reach of the estuary.
3-43	The report states that “studies also indicate that San Joaquin River basin Chinook salmon <u>production</u> increases when the ratio of spring flows at Vernalis to exports increases” (emphasis added). Salmon production is a function of the number of spawners (number of eggs) and hatching success producing juvenile salmon fry and smolts. For fall-run Chinook production occurs between October and February or March. No mechanism is hypothesized in the report for how the Vernalis inflow to export ratio in the spring could affect juvenile salmon production. The discussion in the report should be expanded and clarified.
3-43	The report states that “it should be noted that the flow at Vernalis is the more significant of the two factors”. The report, however, does not present any discussion or analysis of the relative

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	contribution of flows and exports to the ratio or how these during the spring relate to either salmon production. The effect of the spring ratio of flow and exports on salmon or steelhead survival is largely uncertain.
3-44	The report states that average daily outflows of 41,900 and 29,200 cfs in January-March and April-May were associated with positive longfin smelt population growth in half of the years. No literature citation is presented to support these flow thresholds in the report. Was the basis for these thresholds documented and peer reviewed? In addition, the report fails to acknowledge that detailed statistical modeling conducted as part of a state-space longfin smelt population dynamic model (Maunder et al. 2014) tested these two flow thresholds and found that they did not significantly improve predictions of smelt abundance.
3-45	Figure 3.5-1 presents a declining trend in longfin smelt abundance as reflected in the fall midwater trawl surveys. The report predicts that longfin smelt abundance will increase with increased late winter and early spring Delta outflow increases. The graph, however, shows a generally declining trend. Abundance in 2011 following high flows in the winter and spring increased somewhat but was the increase as great as would be predicted by the earlier relationships? The change in the intercept of the flow-abundance relationships presented in Figure 3.5-2 (page 3-47) has a dramatic effect on the predicted abundance of longfin smelt that could be achieved under managed flow regimes. The report should discuss uncertainty in the flow-abundance relationships and the ability of the longfin smelt population to achieve historic high levels of abundance under current conditions independently of Delta outflows.
3-48	Figure 3.5-3 shows estimated relationships between Delta outflow and the probability of longfin smelt population growth. It should be noted from the figures that positive population growth has been observed over a wide range of Delta outflow conditions including those above and below the flow thresholds included in the report. Further, the report should include a discussion regarding the potential mechanisms through which Delta outflow may effect longfin smelt geographic distribution, survival, and abundance. The report should also include a discussion of the other factors effecting longfin smelt including predation and limitations on zooplankton food availability as well as non-flow methods, such as shallow water habitat restoration that could contribute to increase food production to benefit longfin smelt.
3-50	Figure 3.5-4 presents data on longfin smelt salvage and OMR reverse flows. As discussed for salmon it is not clear from the presentation in the report whether or not estimates of total salvage have been adjusted to account for variation in population abundance. The graph should be updated to reflect salvage data between 2008 and 2016 under the OMR operating criteria. Results from earlier years included in the presentation may not be relevant to more recent conditions.
3-51	Figure 3.5-5 presents information on longfin smelt salvage and OMR reverse flows through 2007. The data and graphs should be updated to also include more recent results from 2008 to 2016 to show current patterns and trends.
3-52	Figure 3.5-6 presents information on longfin smelt salvage and X2 location through 2007. The data and graphs should be updated to also include more recent results from 2008 to 2016 to show current patterns and trends.
3-53	Table 3.5-1 presents a summary of seasonal flows thought to be protective of longfin smelt. As noted above, further analysis and conflicting results exist regarding the Delta outflow thresholds and relationships for longfin smelt. The technical basis for developing flow relationships for longfin smelt requires further analyses.

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3-53	The report includes a conclusion that average Delta outflows over 37,000 cfs between March and July appear to be needed to consistently produce strong white sturgeon year class recruitment. The report should include a scientific reference in support of this finding. Given the high fecundity and long lifespan of sturgeon how frequently are high flows needed to support the population from a lifecycle perspective? The report also includes an unsupported assumption that white sturgeon are a suitable surrogate for green sturgeon that should be discussed.
3-56	The report notes that CDFW analyses of white sturgeon indicate a stock-recruitment relationship that that reduced recreational harvest results in a reduction in Delta outflow requirements. Given their listed status green sturgeon cannot be harvested legally and therefore flow needs for green sturgeon may be lower than those estimated for white sturgeon. Further, a non-flow management action that curtailed white sturgeon harvest in the estuary could be used to improve recruitment and population abundance. The report should include a discussion or these and other factors contributing to sturgeon population dynamics
Section 3.6.2.1	The discussion of reestablishment of cottonwoods and other native trees along the Sacramento River ignores the fact that the Sacramento River and many of its tributary systems are managed for flood control. CDFW (2012) itself recognizes this, stating (at p. 27): "More uniform flows year-round and stream bank armoring have resulted in diminished natural channel formation, altered food web processes, and slower regeneration of riparian vegetation." The Board must balance the extent to which flow strategies can be used to reestablish native trees along the river with the flood control and other beneficial needs of downstream beneficial uses.
3-58	The report notes that Delta outflows of 38,000 to 47,000 cfs are needed between February and May to improve Splittail abundance. The overview summary should include a citation to the source of information supporting this conclusion. The mechanisms thought to affect Splittail reproduction in high flow years is seasonal inundation of floodplain habitat. Channel margin habitat restoration to include areas of shallow water lower velocity inundation for a sufficient period of time to allow spawning, egg incubation, and hatching represent non-flow actions that would benefit Splittail and reduce flow requirements. Further, since the expected function mechanism is floodplain habitat inundation flows should target upstream riverine areas and would not necessarily represent Delta outflow.
3-64	Figure 3.8-1 presents information on the trend in delta smelt abundance based on the fall midwater trawl surveys. It is not clear from the presentation if the smelt abundance index has been standardized to a core group of sampling stations or if the sampling has varied for the period used in this trend analysis. The report should also be expanded to discuss the delta smelt inhabiting the Cache Slough complex and the hypotheses regarding habitat suitability in the northern Delta. The report should also acknowledge restoration actions designed to improve delta smelt habitat and implementation of the delta smelt resiliency strategy as current and near future actions to increase smelt abundance.
3-65	The discussion of various investigations into factors affecting delta smelt should be expanded to also include information on the current delta smelt lifecycle model being developed by Newman. Further, detailed analyses of delta smelt data are currently underway as part of the CAMT delta smelt scoping team activities and will be available to further inform the technical foundation for delta smelt management.
3-67	The report should acknowledge the comments on the recent analysis of summer and fall flows for delta smelt. The flows in many months are autocorrelated and difficult to interpret potential cause-effect relationships which contribute to management uncertainty.
3-68	There were a number of criticisms of analyses and interpretations of data regarding the importance of fall flows and X2 location for delta smelt. Many of these were part of the USFWS litigation. The report does not acknowledge or address many of the alternative analyses or the level of uncertainty associated with summer and fall flow needs for delta

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	smelt.
3-69	Table 3.8-1 simply presents a summary of the flows and X2 locations outlined in the 2008 USFWS BiOp. These should be regarded and untested hypotheses rather than a strong scientific basis for future management actions. Further analysis is underway on many of these topics and needs to be factored into the synthesis of information available on delta smelt population dynamics and their habitat needs including zooplankton food resources, low salinity habitat, shallow water and other biotic and abiotic factors. The application of the delta smelt lifecycle model is also expected to provide useful insights into the relative contribution of various management actions on different lifestages of delta smelt.
3-71	Figure 3.8-5 presents information on the cumulative percentage of adult delta smelt salvaged at the SWP and CVP. Data used in the graph extend through 2006. Data should be updated to also include an analysis of the most recent 10 years of salvage operations. Changes have occurred in use of turbidity and other factors in managing smelt salvage. The report states that "flows and turbidity of 20,000 to 25,000 cfs and 10 to 12 Nephelometric Turbidity Units (NTU) initiate upstream migration (Figure 3.8-5)". Figure 3.8-5, however, presents no information in support of either flows or turbidity stimulating upstream migration.
3-73	Figure 3.8-7 shows delta smelt salvage and OMR reverse flow from the 2008 USFWS BiOp. The delta smelt salvage data has been criticized as not accounting for population abundance as a confounding factor in the analysis. There is no discussion of the methods used or purpose of using OMR reverse flows weighted by salvage. Current operations take into account the geographic distribution of pre-spawning adult delta smelt as well as turbidity conditions in the Delta. The report should be revised to include a discussion or current operations and their effectiveness in reducing and avoiding delta smelt salvage.
3-73	As with other sections of the report the overview findings for starry flounder would benefit from citation to the source of information used as the basis to conclude that a Delta outflow of 21,000 cfs between March and June is needed to improve starry flounder abundance.
3-75	The report states that more Delta outflow results in higher age-one starry flounder abundance the following year based on Bay Study surveys. It is unclear and not discussed in the report whether higher flows result in greater abundance of juvenile starry flounder or simply that high flows and lower salinity result in a greater number of juveniles entering San Francisco Bay where they are then sampled in the Bay Study surveys.
3-76	Throughout the report flow analyses are based on historical median Delta outflow over a period of time and the abundance target for a given species based on the 2010 Flow Criteria Report. The technical basis for the Flow Criteria Report abundance targets should be critically reviewed by an independent peer review process in combination with review of the current report and analyses. Simply basing a flow objective on a historic median flow condition such as that done for starry flounder assumes, with no support, that changes in flows are the controlling factor for species abundance despite a number of other non-flow changes that have occurred in the estuary over that period of time (e.g., expansion of non-native predator populations, reductions in prey availability, physical habitat alterations, etc.) will not impact the population response to a prescribed change in Delta outflow.
3-77	Citations for the basis of a 19,000 to 26,000 cfs Delta outflow in March-May for bay shrimp is needed in the overview.
3-78	Figure 3.10-1 shows no trend in abundance for bay shrimp in the Bay Study surveys over the period from 1980 through 2013. Given the lack of trend in abundance over time the rational of a need to change or manage Delta outflow in a way different from that over the past 30 years is not clear and requires explanation.
3-81	The range in flows included in the analysis from 19,000 to 26,000 cfs, representing a change of 7,000 cfs over a three month period reflects the magnitude in variability among methods and assumptions used in this report. Variation in the range of almost 40% reflects a high degree of uncertainty in the approach and interpretation of results, especially for a species that

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	has shown no trend of declining abundance over the past 30 years. The report should discuss these factors as part of the context for interpreting results as a basis for management.
3-83	The report states that mysid abundance has declined in recent years most likely in response to competition for food with the Asian clam and other grazers. If the decline in mysid abundance is the result of these biotic factors no basis is presented in the report that increased flows would result in increased abundance. The report also states that after 1987 abundance showed a positive relationship with X2 with lower flows related to higher mysid abundance. Given the logic outlined for other species in the report there appears to be no basis or rational for recommending higher Delta outflows than have occurred recently and potentially lower flows could be beneficial.
3-84	No data or supporting analysis is presented in the report for the flows ranging from 11,400 to 29,200 cfs recommended by CDFW. The wide range of 17,800 cfs in the recommendations reflects the high degree of uncertainty in these recommendations. There does not appear to be any technical basis presented in the report to support a recommendation for modified Delta outflows.
3-84	Given the increasing trend in abundance and size of largemouth bass inhabiting the Delta, and their role as a major predator on native fish, it is not clear why Section 3.12 does not include a discussion of largemouth bass in a way parallel to striped bass.
3-85	Based on evidence documenting predation on native fish by striped bass, and the goals of the flow study to increase native fish abundance, it does not seem consistent to increase Delta outflow for the benefit of striped bass which could contribute to increase predation mortality on other sensitive native species. The report should acknowledge and address these policy conflicts among species and well as among other beneficial water uses in the subsequent integrated analyses.
3-85	The comments outlined above are all applicable and need to be taken into consideration and addressed/resolved as the technical and scientific foundation for the discussion presented in Section 3.13. The conclusions will need to be revised based on response to the individual species analyses.
4-1	Section 4 provides only a very general discussion of other stressors and offers no substance on how these critical stressors can or will be addressed as part of an integrated approach to improving conditions for Bay-Delta fish and other aquatic resources. The report appropriately acknowledges the need to address both hydrology and other stressors to implement an integrated strategy that has the potential to substantially improve conditions within the rivers and estuary for native fish species. Modifying Delta outflow criteria alone is not expected to result in major fishery benefits in the absence of addressing other major stressors. In addition, modifying Delta outflows alone without adequate consideration of interactions with other key factors such as coldwater pool management or salinity control for other beneficial uses is not expected to achieve the broader goals of improving conditions for a variety of native fish species. The discussion in Section 4 provides little substance regarding how other stressors would be addressed or the integration and coordination between Delta outflow and other stressors as part of an overall strategy that balances and meets a wide range of needs. Section 4 requires major revisions in order to provide meaningful input to the process.
5-1	The report states that the conceptual basis for all of the requirements are supported by the best available scientific information on functional flow needs for individual species and the ecosystem as well as statistical analyses. As outlined above, the analyses presented in Chapter 3 are lacking in a number of areas information on the methods used in the data analyses, key assumptions, and technical documentation and have not been subject to independent scientific peer review which should be part of the scientific standard for best available information. Many of the analyses have not been updated to include more recent data and many of the discussions of data and results, including concerns, are incomplete and imbalanced. Further, many of the analyses are only partially completed as a result of the initial approach for

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	including consideration of only instream flows and Delta outflows in the absence of integration with other key elements of developing an integrated management framework that also considers factors such as reservoir storage and coldwater pool management, temperature control, other stressors, other beneficial water uses, etc.
5-2	The report discusses how "science indicates that more natural flows that closely mimic the shape of the unimpaired hydrograph including general seasonality, magnitude, and duration of flows generally provide those functions". The report focus has been on increasing Delta outflow but must also address and analyze impacts associated with adopting an unimpaired hydrograph approach means dealing with periods when Delta outflows may be substantially lower than under current conditions. Low flow conditions such as those that occurred historically during the late summer and during droughts would result in salinity intrusion further upstream into the Delta and have a major impact on water quality and subsequently water supplies for irrigation and municipal use. These low flow periods are also part of the hydrologic dynamics that effected estuarine functions and processes and need to be addressed in the report and subsequent analyses of management alternatives.
5-4	In analyzing an unimpaired flow range from 35 to 75% potential impacts to reservoir storage and coldwater pool management as well as to other beneficial uses require a systematic approach to simulation modeling and application of quantified performance metrics. For example, and standard set of temperature suitability criteria such as those proposed by EPA (2003) using 7DAMDT by lifestage may provide comparison of habitat changes across alternatives. Changes in salinity intrusion into the Delta and changes in water supplies should also be based on standardized metrics of analysis.
5-5	The report states that the Water Board "generally does not plan to consider flows that are lower than drier baseline conditions". Adoption of an unimpaired hydrologic scenario includes both higher and lower flows. Low flow periods historically were important in maintaining ecosystem functions through reduction in invasive vegetation, reduction in resident predatory fish populations, and other functions. One of the concerns expressed is that flow management under current conditions provides higher summer flows and more stable conditions that alter these ecological dynamics. The analysis should include a full range of unimpaired flows and not be artificially constrained by current baseline flow operations.
5-6	The report recommends that year round baseflows be maintained in all Delta tributaries. As noted above, low late summer flows or in some systems seasonally dry channels served an ecological function such as vegetation and predator control. The analysis should reflect a full range of unimpaired flow conditions and not be constrained artificially. For example, it is thought that one of the reasons seasonally inundated floodplain habitat is so productive as a juvenile salmonid rearing habitat is that it is dry most of the year and hence populations of predatory fish are not present.
5-10	The report states that "lack of hydrologic connection between tributaries and the Sacramento River was identified as the most common stressor for both adult and juvenile salmon, The loss of connectivity commonly results of water temperatures that are too elevated . . ". The magnitude of seasonal instream flows is just one of the many factors that affect thermal conditions in a tributary. Given the warm summer air temperatures, the length of many tributaries, lack of riparian shading, in some cases limited to no water storage, and shallow and wide channels exposed to solar heating it is not clear how the SWRCB plan will achieve the goal of maintaining suitable summer temperatures for juvenile salmonid rearing throughout many of the valley tributaries. The analysis of interactions between tributary flows and water temperatures will require the development and application of water temperature simulation models and other analytic tools as part of the evaluation of flow alternatives. The ability of flow management, given all of the other constraints, on meeting the objective of maintaining suitable temperatures and perennially flows while also meeting specific habitat needs for migration, spawning, egg incubation, and upstream juvenile rearing is highly

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	uncertain.
5-11	The report discusses implementation of the unimpaired flow strategy through an adaptive management framework but provides no details on how adaptive management will be implemented. The report should be expanded to provide additional description on how adaptive management of the flow elements of the plan will be performed, decision making, performance monitoring, testable management hypotheses, and other elements of an adaptive management process.
5-12	The report recommends increased Delta outflows from January through June. As noted above, embracing the concepts of unimpaired flows for ecological processes also includes greater hydrologic variability and lower late summer flows than may be currently occurring. The report should address how the full range of flow variability is being integrated into the management strategy and how analyses will be performed to assess potential adverse impacts to other water uses and water quality including both temperature and salinity
5-13	The report is recommending higher Delta outflow during the winter and spring but also higher fall flows for X2 based on the USFWS 2008 BiOp. The report does not adequately establish a scientific basis for adopting a fall flow and X2 element. Given the water costs and level of uncertainty in biological benefits to delta smelt and potential impacts to other species and water uses the fall action should be considered to be an untested hypothesis. Additional analyses are currently underway to further explore the fall action and limited field monitoring has been performed. In the absence of results of further analyses of integrated operations under the range of proposed flows outlined in the report recommending inclusion of a summer or fall flow action is premature.
5-17	The report states that in wetter years modeled and actual flows are frequently greater than the minimums identified through these analyses and therefore higher flows should be regulated to protect from them from future water development. Since any future diversions would need to be permitted by the SWRCB on an individual basis it is not clear why added flow regulation is needed at this time. The report discussion should be expanded and clarified regarding the need and intent of identifying added regulation at this time.
5-19	The report states that D-1641 and the 2006 Bay-Delta Plan do not provide for Delta outflow that meet the flow goals outlined in Table 3.13-2 during dry water years. The analyses that were used to support the flow thresholds discussed in Chapter 3 of the report focused only on the high flow range. Although the report discusses the ecological benefits of wider flow variation the report and analyses presented do not adequately address either the frequency or magnitude of low flow conditions and therefore do not provide a scientific basis to factoring low flows into the proposed management strategy. The native fish inhabiting the Bay-Delta evolved to respond to both high and low flow conditions. The report implicitly assumes that addressing only high flows will meet the biological needs. The analysis and consideration of flow ranges included in the report should be broadened to also address naturally occurring droughts and other low flow conditions.
5-19	The key assumption underlying the report and its recommendations is "the higher the flows up to 100 percent of unimpaired flow (and higher in the summer and fall) and the lower the X2 value, the greater the benefits are for native species and the ecosystem . . ". This fundamental assumption is guiding all of the analyses presented in the report. This, however, differs from the unimpaired flow regime where variability in hydrologic conditions between high and low flow conditions is a key attribute of ecosystem functions. The report approach, analyses, assumptions, and recommendations need independent peer review and a broader consideration of the application of the unimpaired flow strategy than is currently part of the analyses. The analysis of potential benefits associated with changes in flow regimes needs to also address the highly altered state of the Delta, biotic and abiotic factors other than flow that effect ecosystem dynamics, and other stressors that impact fish species. The simple paradigm embodied in the report that more flow alone is the answer is overly simplistic, unrealistic, and

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	subject to high uncertainty. This same concept is discussed on page 5-26 and generally throughout the body of the report.
5-27	The report recommends including the fall X2 outflow operations managed adaptively. See comments on pages 5-11 and 5-13 above
5-31	The report suggests a potential narrative requirement regarding water temperature management in tributaries. See comments page 5-10 above. The discussion in the report should be expanded to describe how a narrative requirement will provide suitable salmonid habitat in these tributaries
5-33	The report provides a general discussion of cold water habitat requirements within various Central Valley watersheds for salmonid migration, spawning, egg incubation, and juvenile rearing. The report acknowledges the importance of water temperature conditions impacting habitat availability and suitability and the adverse impacts of exposure to seasonally elevated temperatures. The report does not, however, provide results of modeling or analysis of how the proposed unimpaired flow regimes will impact reservoir storage, coldwater pool, or downstream temperatures and their effect on habitat suitability for various lifestages of Chinook salmon, steelhead, sturgeon, and other species. Given the difficulties currently encountered with coldwater pool management and maintaining suitable temperatures the report provides no discussion of how greater instream flow releases can or will be managed or the impacts of greater releases on temperature conditions year round, especially in dry years.
5-38	The report includes additional DCC gate closures in October, new limitations on OMR reverse flows, and added constraints on spring and fall exports as a function of San Joaquin River flows. The report does not present results of modeling or analysis of the potential impacts of these recommendations on water quality, or native fish survival or abundance. For example, DCC gate closures in October have been identified as an action to improve adult fall-run Chinook salmon migration into the Mokelumne River and reduce straying, but this action has potential adverse impacts on Delta water quality and other factors that are not identified or addressed in the report. Similarly, Chapter 3 of the report provides no analyses or technical basis for modifications to OMR reverse flows as a method for increasing survival. No data are presented on juvenile salmon or steelhead survival in response to OMR reverse flow magnitude, timing, or duration. Similarly, the report provides no analyses of the relationship between San Juaquin River flow and export ratio during the spring and juvenile salmonid migration or survival. These are additional examples that occur throughout the report of recommended changes to management actions without scientific support, analysis, or disclosure of potential impacts and uncertainty in outcomes. In many instances the report appears to simply adopt actions that were included in the 2008 USFWS or 2009 NMFS BiOps without critical analysis of supporting information or analysis of data collected over the past decade while the BiOps have been in effect.
5-42	The report states that information in Chapter 3 supports an expanded window of limited maximum export rates to protect juvenile salmonids and a lower minimum export rate of 800 cfs. The report, however, presents only limited information on potential relationships between export rates, flow to export ratios, or minimum export rates on juvenile salmon and steelhead survival to Chipps Island. The analyses presented in the report are insufficient and inadequate to support specific modification to south Delta export operations.

Exhibit B

A DELTA TRANSFORMED

ecological functions, spatial metrics, and landscape change

IN THE SACRAMENTO-SAN JOAQUIN DELTA

SAN FRANCISCO ESTUARY INSTITUTE
AQUATIC SCIENCE CENTER
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ASC

A DELTA TRANSFORMED

ecological functions, spatial metrics, and landscape change

IN THE SACRAMENTO-SAN JOAQUIN DELTA

A Report of the Delta Landscapes Project:
Management Tools for Landscape-Scale Restoration of Ecological Functions

PREPARED FOR THE CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE AND ECOSYSTEM RESTORATION PROGRAM

OCTOBER 2014

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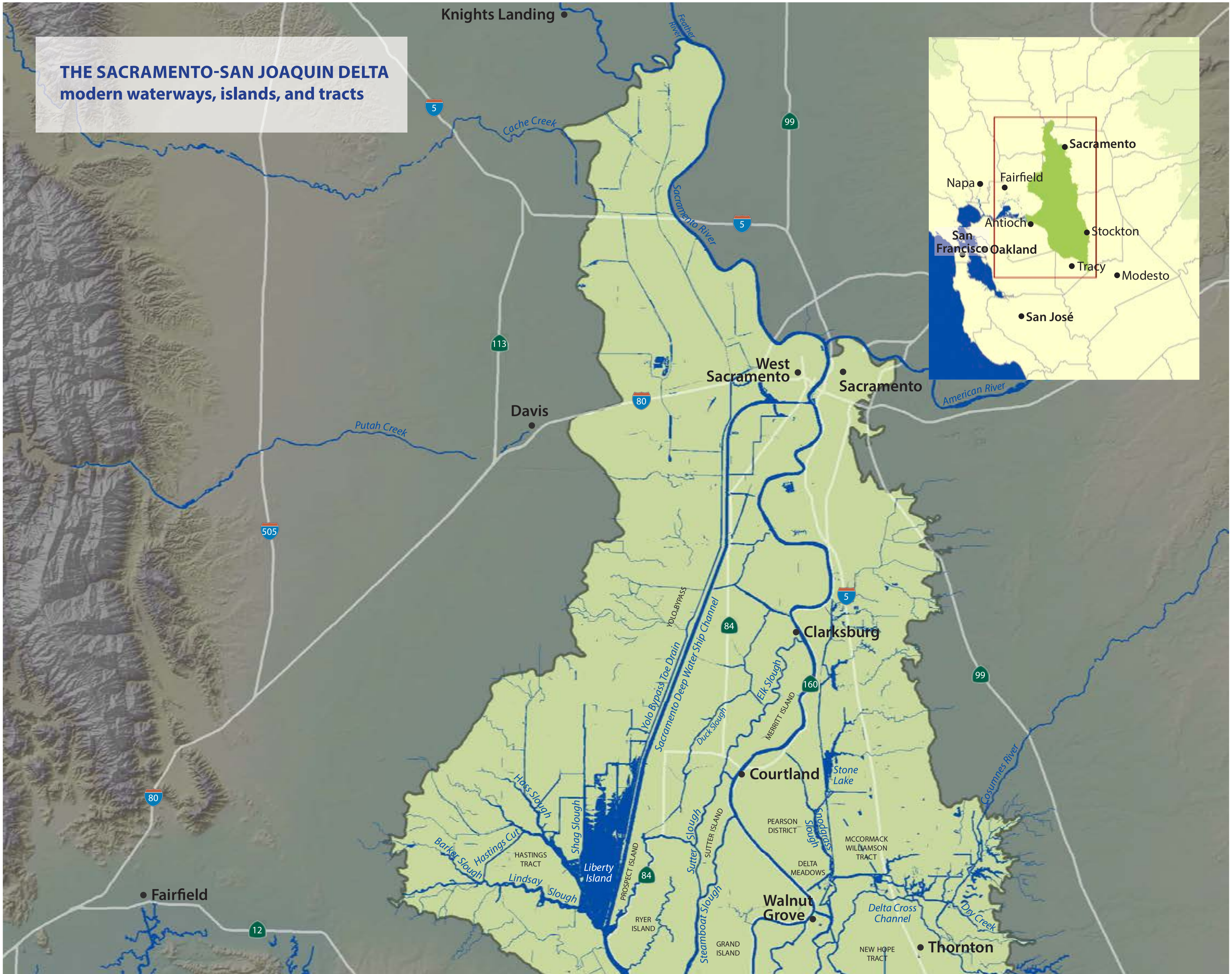
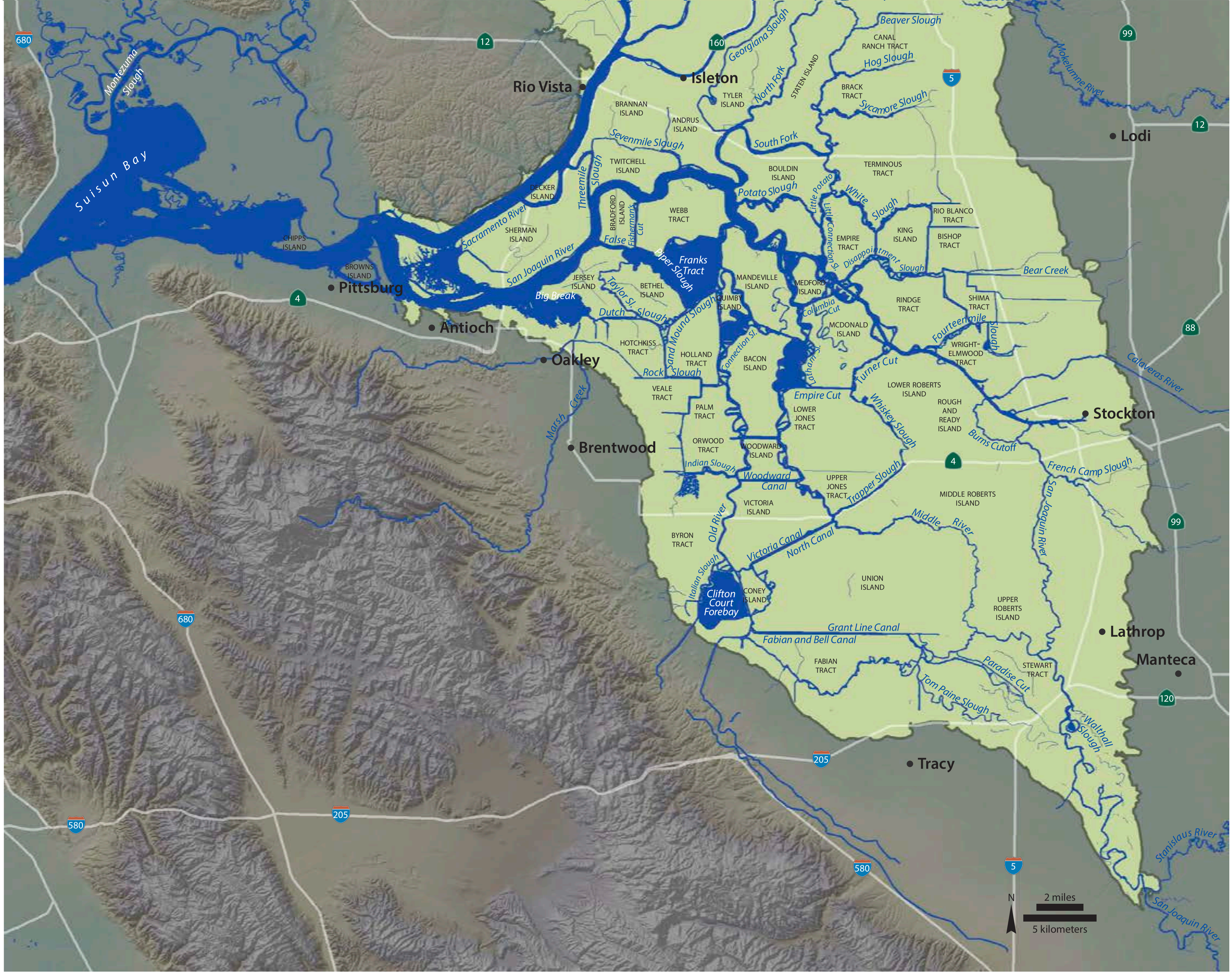
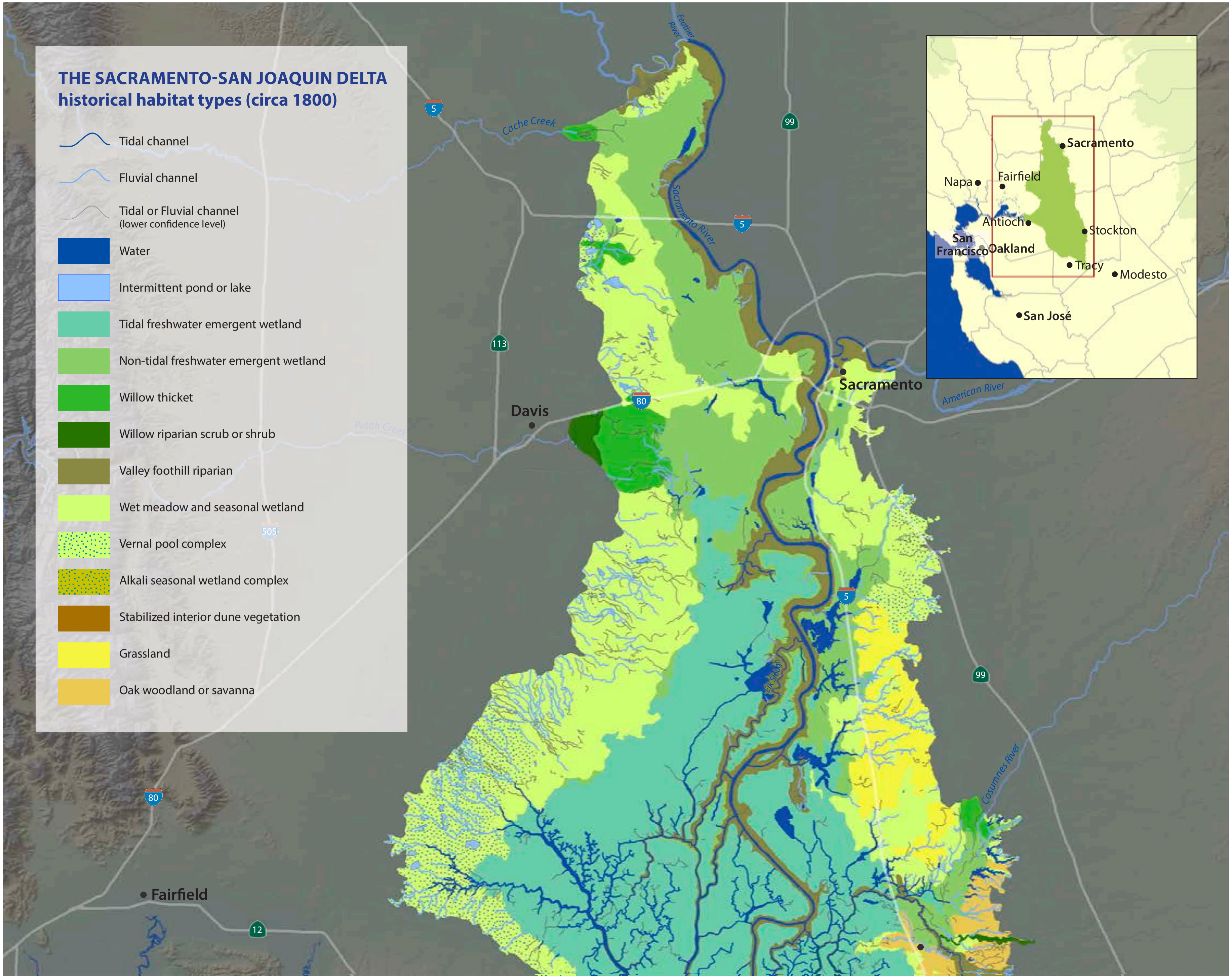
Ecosystem Restoration Program

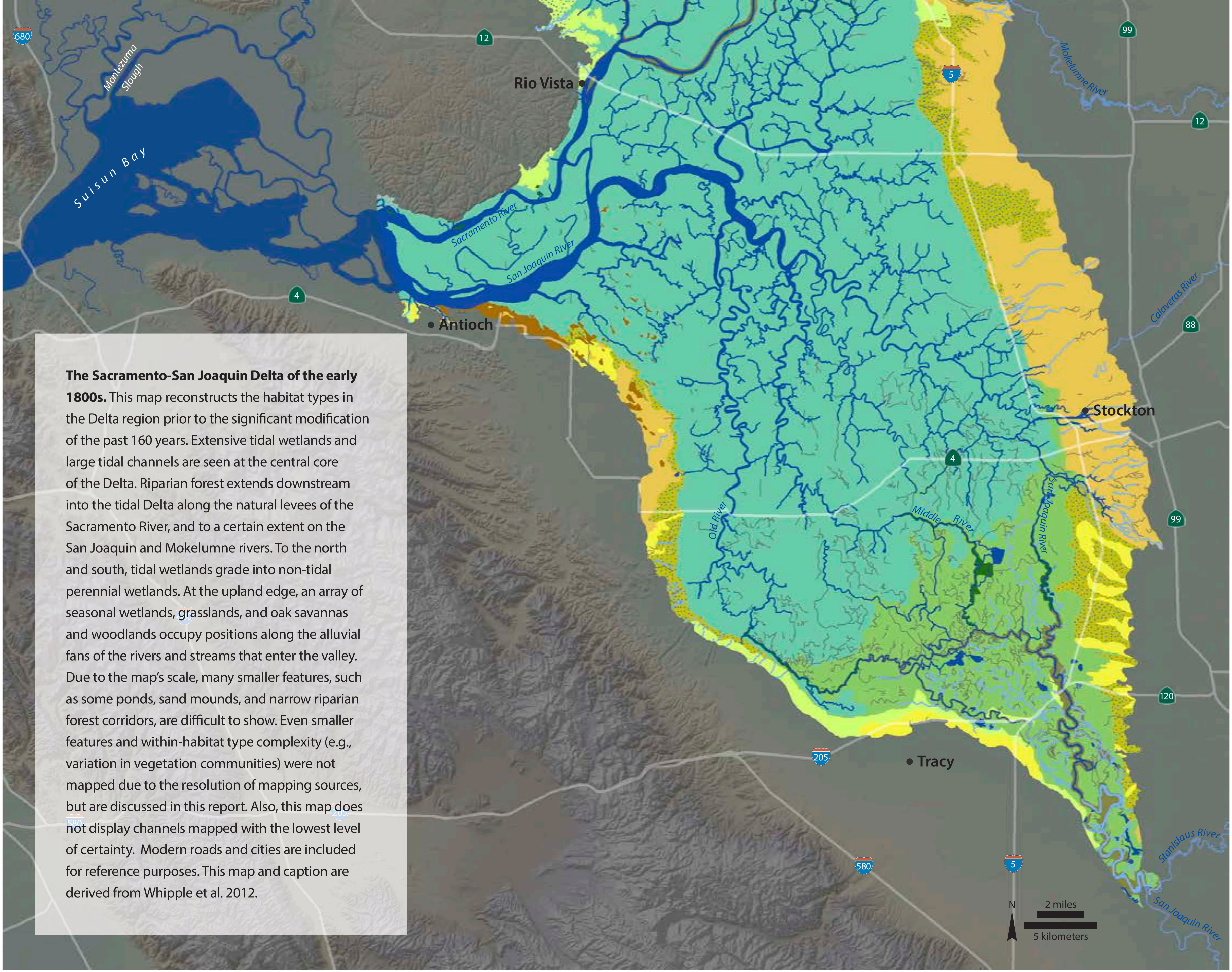

THE SACRAMENTO-SAN JOAQUIN DELTA
modern waterways, islands, and tracts
Knights Landing
Feather River
Cache Creek
Sacramento River
Putah Creek
Davis
West Sacramento
Sacramento
American River
YOLO BYPASS
Yolo Bypass Toe Drain
Sacramento Deep Water Ship Channel
Clarksburg
Elk Slough
Duck Slough
MERRITT ISLAND
Courtland
Stone Lake
PEARSON DISTRICT
Snodgrass Slough
MCCORMACK WILLIAMSON TRACT
DELTA MEADOWS
Walnut Grove
Delta Cross Channel
Dry Creek
Cosumnes River
Thornton
NEW HOPE TRACT
GRAND ISLAND
Steamboat Slough
SUTTER ISLAND
Sutter Slough
RYER ISLAND
PROSPECT ISLAND
Liberty Island
Shag Slough
Hass Slough
Hastings Cut
HASTINGS TRACT
Barker Slough
Lindsay Slough
Fairfield
5
99
113
80
505
84
160
12
Sacramento
Napa
Fairfield
Antioch
Stockton
San Francisco
Oakland
Tracy
Modesto
San José



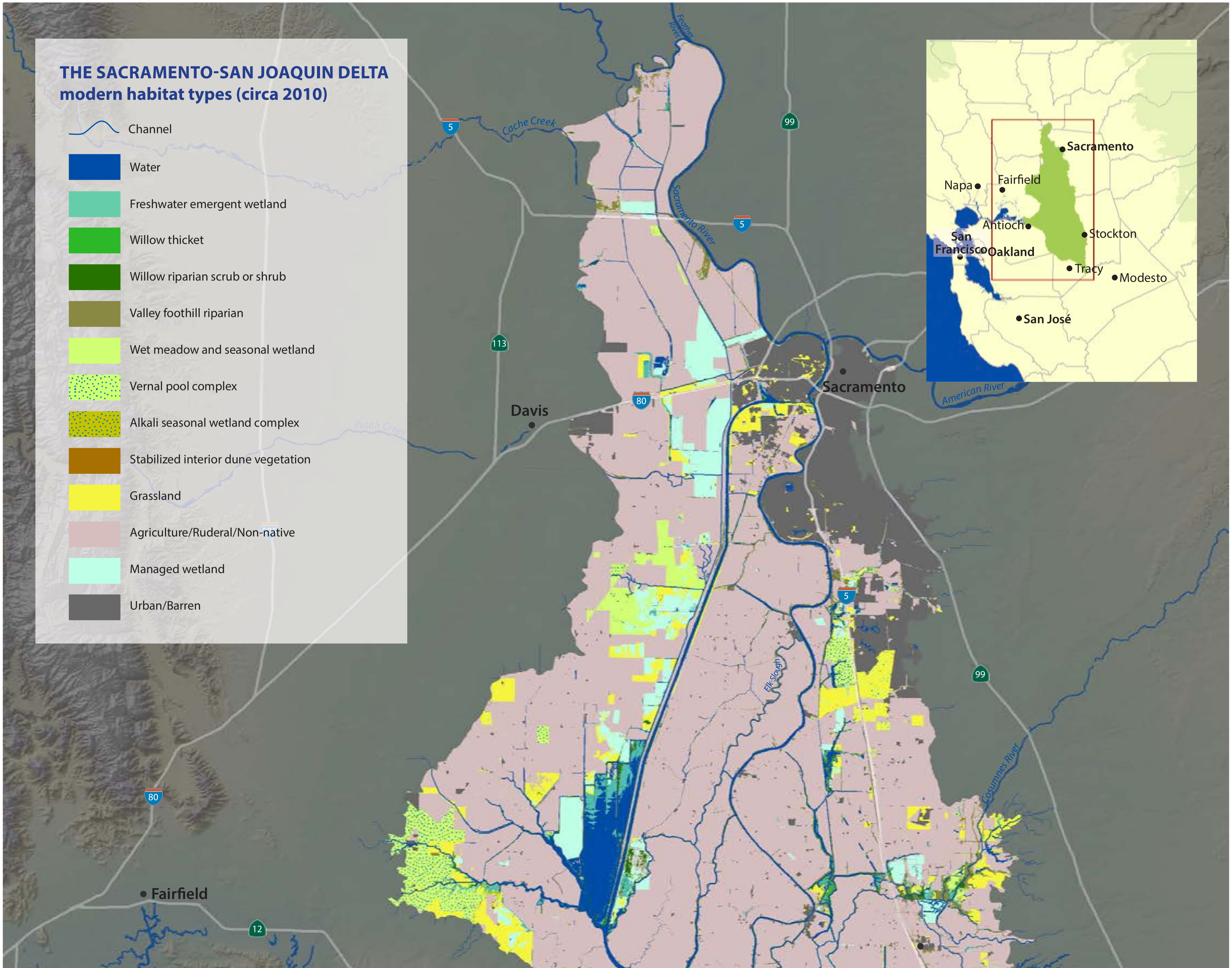
Suisun Bay
Montezuma Slough
Rio Vista
Isleton
Lodi
Pittsburg
Antioch
Oakley
Brentwood
Stockton
Lathrop
Manteca
Tracy
CHIPPS ISLAND
BROWNS ISLAND
SHERMAN ISLAND
DECKER ISLAND
BRANNAN ISLAND
TYLER ISLAND
ANDRUS ISLAND
TWITCHELL ISLAND
BRADFORD ISLAND
WEBB TRACT
JERSEY ISLAND
BETHEL ISLAND
HOTCHKISS TRACT
HOLLAND TRACT
VEALE TRACT
PALM TRACT
ORWOOD TRACT
BYRON TRACT
CONEY ISLAND
FABIAN TRACT
VICTORIA ISLAND
WOODWARD ISLAND
BACON ISLAND
QUIMBY ISLAND
MANDEVILLE ISLAND
MEDFORD ISLAND
MCDONALD ISLAND
LOWER JONES TRACT
UPPER JONES TRACT
UNION ISLAND
UPPER ROBERTS ISLAND
MIDDLE ROBERTS ISLAND
LOWER ROBERTS ISLAND
ROUGH AND READY ISLAND
STEWART TRACT
EMPIRE TRACT
BOULDIN ISLAND
STATEN ISLAND
TERMINOUS TRACT
BRACK TRACT
CANAL RANCH TRACT
KING ISLAND
RIO BLANCO TRACT
BISHOP TRACT
RINDGE TRACT
SHIMA TRACT
WRIGHT-ELMWOOD TRACT
Sacramento River
San Joaquin River
Threemile Slough
Sevenmile Slough
Georgiana Slough
North Fork
South Fork
Potato Slough
Little Potato
White Slough
Little Connection Sl.
Disappointment Slough
Beaver Slough
Hog Slough
Sycamore Slough
Bear Creek
Fourteenmile Slough
False
Fisherman's Cut
Franks Tract
Piper Slough
Big Break
Taylor Sl.
Dutch Slough
Sand Mound Slough
Rock Slough
Connection Sl.
Latham Sl.
Columbia Cut
Empire Cut
Turner Cut
Whiskey Slough
Burns Cutoff
French Camp Slough
Calaveras River
Mokelumne River
Marsh Creek
Indian Slough
Woodward Canal
Trapper Slough
Old River
Victoria Canal
North Canal
Middle River
Italian Slough
Clifton Court Forebay
Grant Line Canal
Fabian and Bell Canal
Tom Paine Slough
Paradise Cut
Walthall Slough
Stanislaus River
680
12
160
5
99
88
4
205
580
120
N
2 miles
5 kilometers



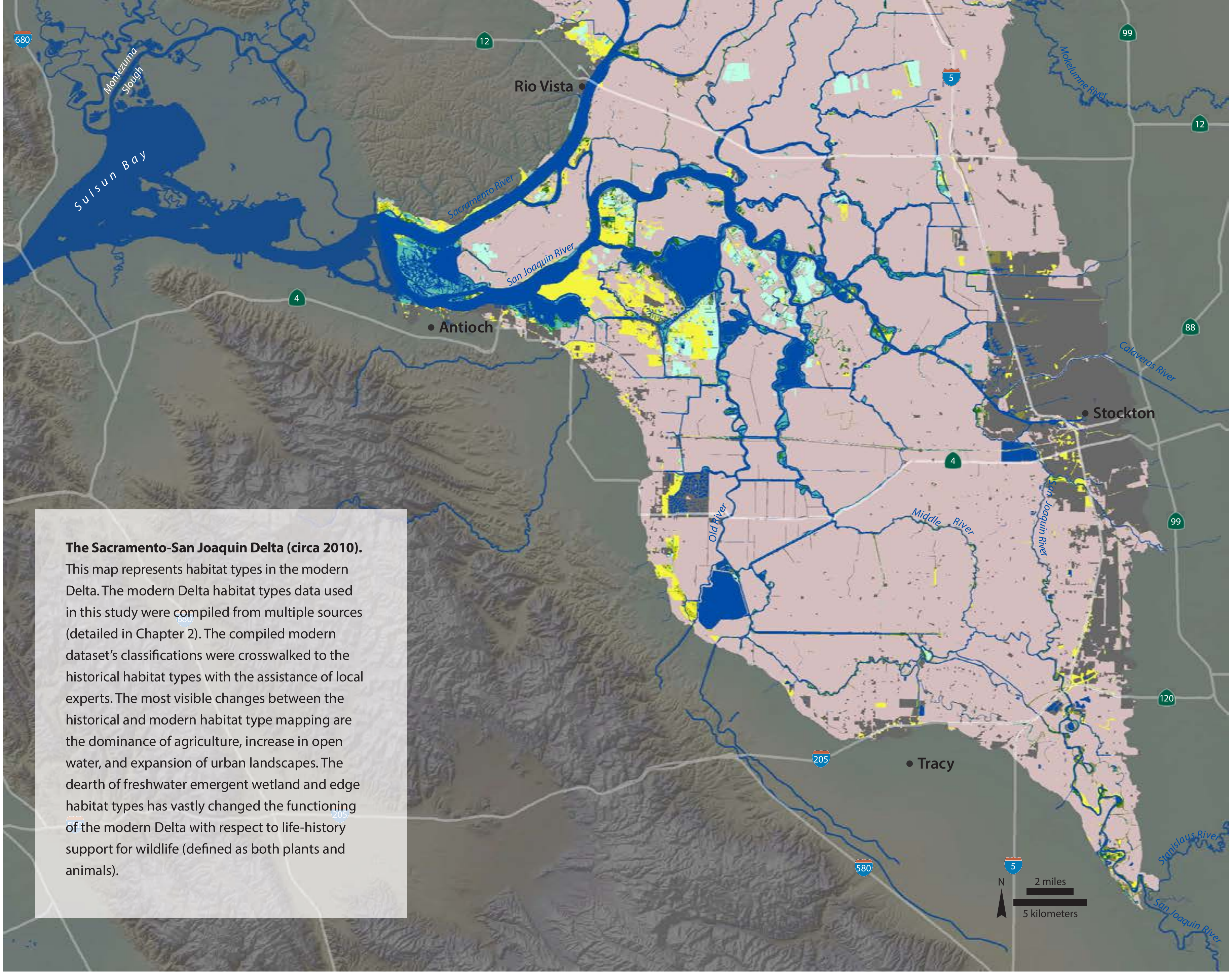
THE SACRAMENTO-SAN JOAQUIN DELTA
historical habitat types (circa 1800)
Tidal channel
Fluvial channel
Tidal or Fluvial channel
(lower confidence level)
Water
Intermittent pond or lake
Tidal freshwater emergent wetland
Non-tidal freshwater emergent wetland
Willow thicket
Willow riparian scrub or shrub
Valley foothill riparian
Wet meadow and seasonal wetland
Vernal pool complex
Alkali seasonal wetland complex
Stabilized interior dune vegetation
Grassland
Oak woodland or savanna
Sacramento
Napa
Fairfield
Antioch
San Francisco
Oakland
Stockton
Tracy
Modesto
San José
Feather River
Cache Creek
Sacramento River
American River
Cosumnes River
Davis
Sacramento
Fairfield
5
99
113
80
505
12



The Sacramento-San Joaquin Delta of the early 1800s. This map reconstructs the habitat types in the Delta region prior to the significant modification of the past 160 years. Extensive tidal wetlands and large tidal channels are seen at the central core of the Delta. Riparian forest extends downstream into the tidal Delta along the natural levees of the Sacramento River, and to a certain extent on the San Joaquin and Mokelumne rivers. To the north and south, tidal wetlands grade into non-tidal perennial wetlands. At the upland edge, an array of seasonal wetlands, grasslands, and oak savannas and woodlands occupy positions along the alluvial fans of the rivers and streams that enter the valley. Due to the map's scale, many smaller features, such as some ponds, sand mounds, and narrow riparian forest corridors, are difficult to show. Even smaller features and within-habitat type complexity (e.g., variation in vegetation communities) were not mapped due to the resolution of mapping sources, but are discussed in this report. Also, this map does not display channels mapped with the lowest level of certainty. Modern roads and cities are included for reference purposes. This map and caption are derived from Whipple et al. 2012.



THE SACRAMENTO-SAN JOAQUIN DELTA
modern habitat types (circa 2010)
Channel
Water
Freshwater emergent wetland
Willow thicket
Willow riparian scrub or shrub
Valley foothill riparian
Wet meadow and seasonal wetland
Vernal pool complex
Alkali seasonal wetland complex
Stabilized interior dune vegetation
Grassland
Agriculture/Ruderal/Non-native
Managed wetland
Urban/Barren
Sacramento
Napa
Fairfield
Antioch
Stockton
San Francisco
Oakland
Tracy
Modesto
San José
American River
Sacramento
Davis
Fairfield
Feather River
Cache Creek
Sacramento River
Putah Creek
Elk Slough
Cosumnes River
5
99
113
80
12



The Sacramento-San Joaquin Delta (circa 2010). This map represents habitat types in the modern Delta. The modern Delta habitat types data used in this study were compiled from multiple sources (detailed in Chapter 2). The compiled modern dataset's classifications were crosswalked to the historical habitat types with the assistance of local experts. The most visible changes between the historical and modern habitat type mapping are the dominance of agriculture, increase in open water, and expansion of urban landscapes. The dearth of freshwater emergent wetland and edge habitat types has vastly changed the functioning of the modern Delta with respect to life-history support for wildlife (defined as both plants and animals).

SUGGESTED CITATION

San Francisco Estuary Institute-Aquatic Science Center (SFEI-ASC). 2014. A Delta Transformed: Ecological Functions, Spatial Metrics, and Landscape Change in the Sacramento-San Joaquin Delta. Prepared for the California Department of Fish and Wildlife and Ecosystem Restoration Program. A Report of SFEI-ASC's Resilient Landscapes Program, Publication #729, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA.

REPORT AVAILABILITY

Report is available on SFEI's website at www.sfei.org/projects/delta-landscapes-project.

IMAGE PERMISSION

COVER CREDITS

Front cover, left to right, top to bottom: maps of historical and modern marsh in the Sacramento-San Joaquin Delta (developed for this report); Liberty Island (photo by Barbara Beggs, USFWS).

Back cover, left to right: NAIP 2005; detail from map of historical habitats of the Sacramento-San Joaquin Delta (Whipple et al. 2012); detail from map of historical inundation in the Sacramento-San Joaquin Delta (Whipple et al. 2012); Snow and Ross' geese (photo by Steve Emmons, USFWS); portion of map by WH Hall, ca. 1880, Grand Island and Suisun Bay to foothills and 1st Standard North (Hall ca. 1880, courtesy of California State Archives).

CONTENTS

Acknowledgments

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Executive Summary

While the decline of the Sacramento-San Joaquin Delta ecosystem is well recognized, relatively little is known about how the physical transformation of the Delta landscape—which took place more than a century ago—has affected its ability to support native plants and animals. The need for this understanding is urgent, as plans are being developed for substantial ecological restoration in the Delta. To fill this gap, we synthesized scientific knowledge about the Delta's native species with recent mapping of the pre-development (circa 1800) and contemporary Delta habitats to define ecologically relevant spatial metrics. We then analyzed the historical transformation of the Delta landscape from the perspective of these measures.

Based on scientific literature and input from experts, we identified aspects of the pre-development Delta landscape that contributed to the abundance and resilience of native wildlife populations. Habitats that dominated the landscape, such floodplains, marshes, and wide riparian forests, have declined precipitously in extent. For example, 98% of the freshwater emergent marsh in the Delta has been lost (from approximately 190,000 hectares to just over 4,000 hectares). Aquatic habitats have also undergone wholesale conversion. Underlying this habitat loss and degradation is the loss of the physical processes that create and maintain these habitats, conferring resilience upon the landscape, biological processes, and wildlife populations. The disconnection of floodwaters from marshes and riparian areas has not only altered habitats but also the exchange of materials and energy that affects the food web, water quality, and the future potential of these areas to be restored and provide habitat value. Thus, despite retaining some of the original system's template, with its sinuous channels and tidal flows, the Delta has been fundamentally transformed.

To improve the health and resilience of native wildlife populations in the Delta, another transformation will be required—one that restores greater habitat extent, connectivity, and diversity, as well as the physical processes that increase resilience and drive ecosystem function. This restoration must occur in the context of invasive species and changes in freshwater flow, necessitating a vision of the future that incorporates knowledge of the past and present but is completely new. This will require a landscape-scale framework for restoration that joins individual project "pieces" into a functional landscape "puzzle." The metrics presented here, as well as the landscape restoration conceptual models to be produced in the next phase of this project, can be useful tools to meet this challenge.

Recent state policy sets ambitious goals for ecosystem restoration in the Sacramento-San Joaquin Delta. *The Delta Plan and California Water Code, as well as other regional documents, identify the need to go beyond small-scale habitat restoration to create larger functional landscapes of interconnected habitats.*[1-6] *Yet there is little quantitative guidance available to help design the complex spatial systems that are likely to achieve these goals. This report provides the first analysis of landscape ecology metrics in the pre-disturbance and contemporary Delta to help define, design, and evaluate functional, resilient landscapes for the future.*

[1] *California Water Code, Section 85302 (e)(1). "The Delta Plan shall include measures that…restore large areas of interconnected habitats within the Delta and its watershed by 2100."*

[2] *Teal et al. 2009. "Restoration strategies must be designed from a systems perspective that the Delta is considered as an interconnected watershed-river-marsh-estuary-ocean landscape."*

[3] *The Delta Plan 2013. "Management plans and decisions need to be informed by a landscape perspective that recognizes interrelationships among patterns of land and water use, patch size, location and connectivity, and species success."*

[4] *California Department of Water Resources 2013, Bay Delta Conservation Plan (BDCP; Public Draft). "The BDCP will contribute to the restoration of Sacramento-San Joaquin River Delta (Delta) ecosystems largely by addressing ecological functions and processes on a broad landscape scale."*

[5] *Wiens et al. 2012. "Historical ecology can provide a tool for using the past to understand the foundations of the present landscape and to assess its future potential for restoration by considering landscape patterns, processes, and functions and the conditions to which species are adapted."*

[6] *Delta Independent Science Board 2013. "We suggest that successful restoration projects in the Delta will [recognize that]... spatial context is part of the design. Individual restoration projects, regardless of their size, are not isolated from the surrounding aquatic and terrestrial landscape, or from restoration or management actions undertaken elsewhere."*

1. Introduction

Delta Landscapes approach

Before modern development, almost half of California's coastal wetlands were found in the Sacramento-San Joaquin Delta. The Delta supported the state's most important salmon runs, the Pacific Flyway, and endemic species ranging from the delta smelt to the Delta tule pea. In the region's Mediterranean climate, the Delta's year round freshwater marshes were an oasis of productivity during the long dry season. Until reclamation, the Delta stored vast amounts of carbon in its peat soils. Today the Delta functions very differently, having undergone a massive and continuing transformation. Despite the dramatic changes, however, many native species are still found in the Delta, albeit in greatly reduced numbers. Some are threatened by extinction, and others may be soon.[1] The Delta no longer functions as a delta, spreading river and bay water and sediment across wetlands, floodplains, and riparian forests. Recovery of some of these lost ecological functions is considered crucial to ecosystem restoration in the Delta.[2]

Because of biological declines and regulatory challenges, Delta planning efforts often emphasize a few target species in habitat restoration and management. The Delta Landscapes project attempts to provide a "big picture" ecosystem perspective on how we reestablish ecosystem functionality for multiple suites of taxa. Our approach is to evaluate the landscape patterns and processes that supported native species in the historical Delta, measure how they have changed, and assess the potential for reestablishing smaller, modified, but ecologically functional deltaic landscapes in the future. The project contributes a missing dimension to Delta planning by providing a landscape-scale perspective on restoration opportunities that is founded in a sound understanding of how the Delta historically supported native species. This approach gives us the best chance at creating the new, reconciled landscapes of the future that integrate natural and cultural processes, maximizing resilience to climate change, invasive species, and other challenges.[3]

In order to imagine and plan for a functioning Delta ecosystem in the future, we must first understand how a healthy ecosystem looks.[4] Currently, we have no first-hand knowledge of how Delta landscapes functioned because there are no large areas typical of the historical Delta left. Such understanding is essential to evaluating the settings in which native wildlife (defined as plants and animals) evolved and designing future habitats that preferentially benefit these species. To develop this perspective, we analyzed early 1800s habitat mapping and other information from the Delta Historical Ecology Investigation,[5] completed in 2012, through a lens of key ecological functions that supported Delta wildlife. With a team of local and national experts in ecological and physical processes, we developed quantifiable metrics that represent different suites of functions

provided by different Delta settings. In order to evaluate change over time, the selected landscape metrics were also applied to the current Delta.

This first output of the Delta Landscapes project identifies important landscape-scale ecological functions that supported native species, and analyzes how they have changed. In subsequent project reports, these landscape metrics will be integrated with analyses of physical changes and existing constraints to explore the potential for future operational landscape units (OLUs) that would strategically link multiple projects over time into functional landscapes.[6]

Given the multiple uses of the Delta, diverse ecosystem stressors, and future challenges such as sea level rise and flooding, the future Delta will be a novel ecosystem,[7] likely to look very different from either the historical or the contemporary system. Today's Delta experiences multiple layers of impact, including freshwater flow diversions and alterations, contaminants, reduction in sediment supply, and non-native invasive species.[8] But while habitat mosaics cannot necessarily be reestablished in the same places or at the same scale at which they existed historically, they need to be designed to provide many of the same target functions at suitable scales. The challenge is to recognize of the potential resilience of disturbed physical and ecological systems, working in concert with underlying topographic and hydrological attributes to recover desired ecological functions.[9] By understanding how the landscape works and has changed, we can recognize the opportunities to strategically reconnect landscape components in ways that support ecosystem resilience to both present and future stressors.

Report structure

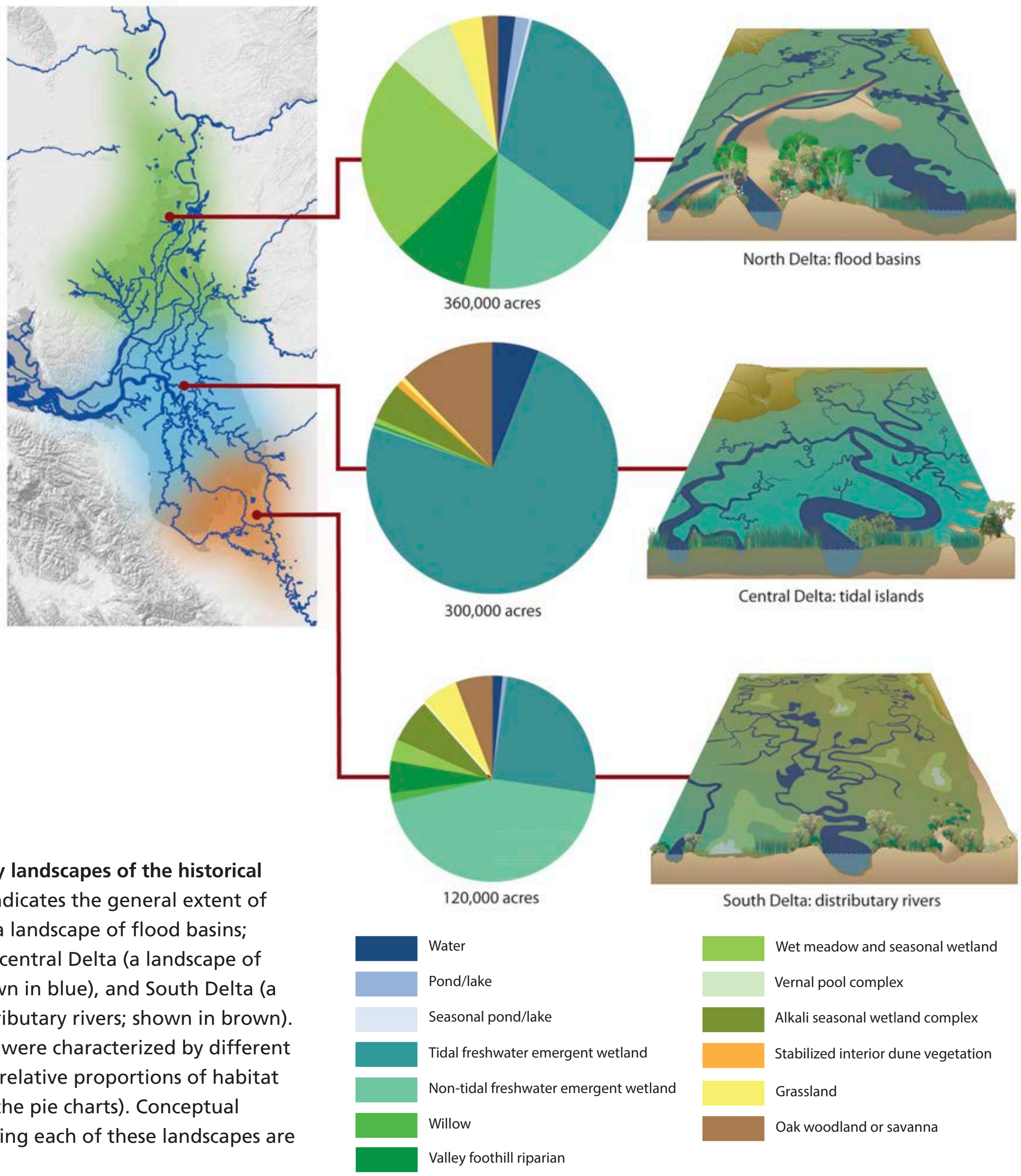
Following this Introduction, Chapter 2 presents a brief overview of the project framework and methods used (a longer, more detailed methods discussion is found in Appendix A). Chapter 3 discusses overall physical change in the Delta as it relates to ecological function. The next five chapters (Chapters 4-8) analyze different dimensions of life-history support for wildlife (animal and plants) in the Delta, focusing on particular habitat-associated guilds: fish, marsh wildlife, waterbirds, riparian wildlife, and marsh-terrestrial transition zone wildlife. Finally, Chapter 9 summarizes key findings and frames next steps in the Delta Landscapes project. The landscape analyses are presented as two-page spreads describing the selected ecological function, the spatial metrics used to evaluate that function, and analysis of that component of the landscape, past and present. Each of these chapters begins with several pages of preparatory background on the chapter topic.

The Delta landscape (below). Left to right: Nurse Slough, Sandhill Cranes at Stone Lake National Wildlife Refuge, giant garter snake, Sacramento River.

Photo Credits: Steve Martarano, USFWS; Justine Belson, USFWS; Brian Hansen, USFWS; Steve Martarano, USFWS

A short primer on the historical Delta landscape (summarized from Whipple et al. 2012)

The Sacramento-San Joaquin Delta historically served multiple physical and ecological functions. It was a perennial freshwater source in a Mediterranean climate, collecting, draining, and mixing water from the interior of the state (40% of the state's freshwater flows) to the ocean (see map on pages iv-v). It likewise served as an extended fluvial-tidal interface, with tidal influence extending past Sacramento. Saltwater influence was historically limited to the brackish Suisun marshes, and diminished towards Sherman Island, though the boundary was variable depending on the water year. Unlike coastal plain river deltas, the Sacramento-San Joaquin Delta is an inverted estuary that narrows at its outlet before opening to the San Francisco Bay.[10] It functioned as a sediment sink, slowing and settling coarser materials eroded from the granitic Sierras, while passing sands and silts downstream to replenish the salt marshes and beaches downstream. It was also the lungs of the region, sequestering carbon and releasing oxygen. The Delta was a highly productive system that provided abundant and diverse food resources to support robust food webs, including



The three primary landscapes of the historical Delta. The map indicates the general extent of the north Delta (a landscape of flood basins; shown in green), central Delta (a landscape of tidal islands; shown in blue), and South Delta (a landscape of distributary rivers; shown in brown). These landscapes were characterized by different assemblages and relative proportions of habitat types (as seen in the pie charts). Conceptual diagrams illustrating each of these landscapes are shown to right.

indigenous tribes. Many native wildlife species were able to exploit the complex and resource-rich landscape of the Delta, some thriving in astonishing numbers.

The historical reconstruction of the Delta reveals the large-scale patterns and heterogeneity that existed before major anthropogenic influences.[11] The central, northern, and southern parts of the Delta were diverse in their geomorphic and hydrologic settings, and in the ecological functions they provided. The central Delta consisted predominately of islands of tidal freshwater emergent wetland (marsh), which supported a matrix of tule, willows, and other species. These wetlands—topographically almost flat—were wetted by twice daily tides, and inundated monthly (if not more frequently) by spring tides. During high river stages in the wet season, entire islands were often submerged with several feet of water. The large tidal sloughs had low banks and, like capillaries, bisected into numerous, progressively smaller branching tidal channels which wove through the wetlands, bringing the tides onto and off of the wetland plain, promoting an exchange of nutrients and organic materials. Channel density in the central Delta was greater than in the less tidally dominated northern and southern parts of the Delta (but lower than the brackish and saline marshes of the estuary downstream). The edges or transition zones around the central Delta were composed of alkali seasonal wetlands, grassland, oak savannas, and oak woodlands. On the western edge of the central Delta, sand mounds (remnant Pleistocene dunes) rose above the marsh, providing gently sloping dry land in an otherwise wet landscape that served as a high tide refuge for terrestrial species.

The ecological functions provided by the north Delta were driven primarily by the great Sacramento River, which created large natural levees and flood basins. These flood basins, running parallel to the river, accommodated large-magnitude floods, which occurred regularly, with inundation often persisting for several months. They consisted of broad zones of non-tidal marsh that had very few channels and transitioned to tidal wetland towards the central Delta. Dense stands of tules over three meters (m) (~10 ft) tall grew in these basins. Large lakes occupied the lowest points in these flood basins.

The north Delta's natural levees, created pre-Holocene by the large sediment supply of the Sacramento River, were broad, sloping features that graded into the marsh. These supra-tidal levees supported dense, diverse, multi-layered riparian forests often up to a mile in width. They ran parallel to the Sacramento River and other large tidal sloughs that conveyed enough sediment to build them over time during high flow events. The levees provided migration corridors for birds and mammals, and allochthonous input (organic debris) and shade to the river systems for aquatic species. Some areas within tidal elevations were seasonally isolated from the tides due to the presence of these levees and complex fluvial and tidal interactions. The edge of the north Delta was lined by seasonal wetlands and willow thickets, or "sinks," at the distal end of tributaries as they entered the flood basins.

The south Delta, like the north, was shaped by a large river system. Here, the three main distributary branches of the San Joaquin River created a complex network of smaller distributary channels, oxbow lakes, tidal sloughs, and natural levees of varying heights which graded across the long fluvial-tidal transition zone. In contrast with the single main channel of the Sacramento and the parallel flood basins, the San Joaquin River had less power and sediment supply to build high natural levees, and thus had many channels branching from the mainstem and coursing through the marsh islands; these channels vacillated between being fluvially or tidally dominated, depending on the time of the year. Small lakes and ponds were scattered in the south Delta, and the marsh was intersected with willow thickets, seasonal wetlands, and grasslands, making it a very diverse place for wildlife. The edge of the south Delta was dominated by alkali seasonal wetland complex, grassland, and oak woodland. The eastern edge of the Delta was shaped by the alluvial fans of the Mokelumne and Calaveras rivers that spread into the marsh.

The Delta was not a static place. Though the positions of large tidal channels, natural levees, and lakes were relatively stable, the Delta would have looked very different depending on the year and season. Areas of marsh that were flooded with several feet of water by late winter could be dry at the surface by late fall. The Delta was a place of significant spatial and temporal complexity at multiple scales.

2. Project Framework and Methods

This chapter provides a brief summary of the project framework and tools developed to assess ecological functions in the historical and modern Delta. A more detailed discussion of the underlying mechanics of these tools (metrics) can be found in Appendix A.

The Landscape Interpretation Team

The challenging task of exploring landscape-scale Delta ecological functions, identifying and quantifying landscape metrics, and eventually generating restoration tools and principles necessitates the collective best professional judgment of a team of experts. For this reason, an interdisciplinary group of high-level scientists was assembled as part of the initial project conception to provide regular input and guidance. This group is referred to as the "Landscape Interpretation Team" (LIT) and was drawn from relevant fields of expertise (including geology,

Landscape Interpretation Team members who have advised this project since its start.

LIT member	Affiliation
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geomorphology, hydrodynamics, animal ecology, plant ecology, landscape ecology, and water resource management). Nineteen individuals have served on the LIT since the Delta Landscapes Project's initiation in 2012 (see table on previous page). LIT members have been consulted individually throughout the project and have met in plenary on five occasions. To date, the LIT has worked closely with SFEI-ASC staff to (1) identify ecological functions provided by the historical Delta's landscapes, (2) identify and prioritize landscape metrics that allow us to assess the extent and distribution of these key ecological functions (both historically and today) and (3) review/interpret initial results.

Identifying key ecological functions provided by historical Delta landscapes

Functions summary

Using the guidelines described below, SFEI-ASC staff first developed a draft list of ecological functions likely provided by the historical Delta. Next, via an iterative process, the draft list was reviewed, prioritized, and edited by the LIT. The result—a final list of key ecological functions for the project to assess—is provided below and in the diagram on page 8. In this section, we also discuss our use of the term "ecological function," how we arrived at the ecological functions list, and each individual function.

POPULATION-LEVEL FUNCTIONS

Functions related to life-history support for wildlife

1) Provides habitat and connectivity for fish
2) Provides habitat and connectivity for marsh wildlife
3) Provides habitat and connectivity for waterbirds
4) Provides habitat and connectivity for riparian wildlife
5) Provides habitat and connectivity for marsh-terrestrial transition zone wildlife

Functions related to wildlife adaptation potential

6) Maintains adaptation potential within wildlife populations

COMMUNITY-LEVEL FUNCTIONS

Functions related to food webs

7) Maintains abundant food supplies and nutrient cycling to support robust food webs

Functions related to biodiversity

8) Maintains biodiversity by supporting diverse natural communities

LEVEL	POPULATION						COMMUNITY	
THEME	Life-history support					Adaptation potential	Food webs	Biodiversity
FUNCTION	CHAPTER 4 **Provides habitat and connectivity for fish**	CHAPTER 5 **Provides habitat and connectivity for marsh wildlife**	CHAPTER 6 **Provides habitat and connectivity for waterbirds**	CHAPTER 7 **Provides habitat and connectivity for riparian wildlife**	CHAPTER 8 **Provides habitat and connectivity for marsh-terrestrial transition zone wildlife**	**Maintains adaptation potential within wildlife populations**	**Maintains food supplies and nutrient cycling to support robust food webs**	**Maintains biodiversity by supporting diverse natural communities**
METRICS	Inundation extent, duration, timing, and frequency *p. 38*	Marsh area by patch size (patch size distribution) *p. 50*	Ponded area in summer by depth and duration *p. 61*	Riparian habitat area by patch size *p. 64*	Length of marsh-terrestrial transition zone by terrestrial habitat type *p. 72*	To be addressed with qualitative conceptual models in next phase of project.	Expected to be addressed with a related project.	To be addressed with qualitative conceptual models in in next phase of project.
	Marsh to open water ratio *p. 44*	Marsh area by nearest neighbor distance *p. 52*	Wetted area by type in winter *p. 61*	Riparian habitat length by width class *p. 66*				
	Adjacency of marsh to open water by length and marsh patch size *p. 44*	Marsh core area ratio *p. 54*						
	Ratio of looped to dendritic channels (by length and adjacent habitat type) *p. 46*	Marsh fragmentation index *p. 56*						

The ecological functions provided by the historical Delta and the metrics used to assess the extent and distribution of these functions. Functions were identified at both the wildlife population and community level, and were grouped into four themes. Although we describe each of these themes, only functions related to life-history support for wildlife are analyzed in detail for this report (see chapters 4-8). The other functions (shown with transparent colors in this diagram) will be assessed in future tasks and related projects.

What are ecological functions?

Much has been written on the meaning of the word "function" as it is used in the discipline of ecology.[1] In this report we use "functions" to mean "processes or manifestations of processes."[2] Smith et al. (1995) expand upon this basic definition and write that "wetland functions" are "the normal or characteristic activities or actions that occur in wetland ecosystems, or simply, the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape and their interaction."[3] By choosing to focus specifically on "ecological" functions, we adopt the general framework of the above definitions, but alter their focus. We define "ecological" as the relationship of organisms to one another and to their surroundings. For the purposes of this project, then, "ecological functions" are defined as the processes or manifestations of processes that support organisms. When we identify key ecological functions we are, in effect, attempting to answer the question: "how did the historical Delta environment support life?"

How did we choose which ecological functions to assess?

Environmental processes that support organisms occur at multiple scales, from global to microscopic, and almost any individual function can be broken down into component sub-functions.[4] The function '*provides suitable nesting habitat for Least Bell's Vireo*,' for example, is contingent on the function '*supports riparian vegetation communities with dense shrub cover*,' which, in turn is based on functions like '*promotes successful Salix* spp. *reproduction*' and '*maintains groundwater levels.*' If every process that supported Delta species were called out as a separate ecological function, the number of possible ecological functions would be effectively infinite. We were therefore required to identify and group ecological processes that supported Delta organisms into a manageable number of meaningful functions. To accomplish this, we established the following guidelines:

- **Focus on landscape-scale ecological functions.** We focused on capturing the degree to which specific ecological functions were provided by the overall landscape, and where in the landscape those functions were provided.
- **Focus on functions at both the population level and community level**. We desired to capture functions at both the population and community levels. For example, although food availability is a critical component of the ecological functions relating to population-level life-history support, we also sought to address Delta-wide productivity at the community level. Constraints on primary production and the relative importance of different production sources to the food web are major sources of uncertainty for Delta management today.
- **Focus on key ecological functions.** To keep this task manageable, we were required to focus on a limited number of key ecological functions—those that would have likely and collectively supported healthy wildlife communities in the Delta.
- **Focus on ecological functions for native wildlife.** Our focus on wildlife (which we define here as native plants and animals) is guided by the Delta's regional regulatory framework. The draft Bay Delta Conservation Plan (BDCP), for example, is designed in part to provide for the conservation and management of 56 covered plant and animal species. We focus much of our attention on vertebrates, since they tend to be better researched, are near the top of food webs, and are generally of greater interest to humans.
- **Consider life-history support functions for wildlife groups rather than for individual species.** For functions related to life-history support, we felt it necessary and useful to focus on specific ecological groupings. Ultimately, the ecological groupings we delineated for analyses were fish, marsh wildlife, waterbirds, riparian wildlife, and marsh-terrestrial transition zone wildlife. These groupings are largely based on habitat associations, which we felt was a sensible way to group species given the habitat-based GIS data we use for our analyses.
- **The extent and distribution of functions should be assessable through landscape metrics and supported by the available data**. We prioritized ecological functions for which appropriate landscape metrics and datasets were available to assess the function's extent and distribution (ideally both historically and today).
- **Focus on functions relevant to regional restoration efforts**. We prioritized ecological functions aimed to increase performance of the entire ecosystem, and used the framework of increased resilience and biodiversity to support the Delta's threatened and endangered species as specified by BDCP.

Function descriptions

Through a careful consideration of the historical habitat type map and discussions with the LIT, we identified eight key ecological functions of the historical Delta to focus on for this project (see the box on page 7 and the diagram on page 8). Functions can broadly be divided into four groups: those related to (1) wildlife life-history support, (2) wildlife adaptation potential, (3) food, or (4) biodiversity.

FUNCTIONS RELATED TO WILDLIFE LIFE-HISTORY SUPPORT The majority of this report focuses on wildlife life-history support functions. We define "life-history support" as the processes and characteristics of the Delta that supported the life histories of specific native taxa. Life-history support for wildlife encompasses many smaller species-specific functions, far more than could be detailed in this report. We therefore chose to focus on major wildlife groups: resident and migratory fish, marsh wildlife, waterbirds, riparian wildlife, and marsh-terrestrial transition zone wildlife. We assume that if the landscape provided broad life-history support for these groups then a majority of the related sub-functions were also being provided. Each of the functions related to wildlife support is described in the table below.

FUNCTIONS RELATED TO WILDLIFE ADAPTATION POTENTIAL For this report, "wildlife adaptation potential" is defined as the potential ability of native plant and animal populations to adapt to changing conditions. Wildlife adaptation potential encompasses adjusting to new or increased

The five functions related to wildlife life-history support. Each function relates to a specific wildlife group and is defined here with example sub-functions.

Function	Wildlife group	Description
Provides habitat and connectivity for fish	Native resident and migratory fish	Defined as the processes and the characteristics of the Delta that support the life histories of native resident and anadromous fish. Example sub-functions include '*provides sufficient floodplain inundation to support splittail spawning and rearing*' and '*provides adequate prey to support delta smelt*.'
Provides habitat and connectivity for marsh wildlife	Native marsh wildlife	Defined as the processes and the characteristics of the Delta that support the life histories of obligate and transitory marsh wildlife. Example sub-functions would include '*Black Rail refuge from predation*' (which would have been provided by dense vegetation) or '*tule seed germination*' (which would have been supported by inundation).
Provides habitat and connectivity for waterbirds	Native waterbirds	Defined as the processes and the characteristics of the Delta that support the life histories of waterbirds (which are defined as "birds that are ecologically dependent upon wetlands"[5]). Example sub-functions would include '*provides areas suitable for Sandhill Crane roosting*,' '*provides food for wintering waterfowl*,' and '*provides nesting habitat for breeding ducks*.'
Provides habitat and connectivity for riparian wildlife	Native riparian wildlife	Defined as the processes and the characteristics of the Delta that support the life histories of riparian wildlife, including riparian residents and transients, particularly Neotropical songbirds. Example sub-functions would include '*provides nesting structures for riparian birds*,' '*facilitates movement of terrestrial mammals*,' '*provides food to avian fall migrants*,' '*supports establishment of large valley oaks*,' and '*provides cover to anadromous fish in the form of large woody debris*.'
Provides habitat and connectivity for marsh-terrestrial transition zone wildlife	Native terrestrial-transition zone wildlife	Defined as the processes and the characteristics of the Delta that support the life histories of wildlife that utilize the transition zone between marshes and terrestrial habitats or these terrestrial habitats themselves. Example sub-functions would include '*provides tule elk with access to fresh water during the summer*,' '*provides refuge to Black Rails during spring tides*,' '*provides breeding pond habitat for California tiger salamanders*.'

disturbances and stressors, utilizing newly available resources, and moving as the locations of suitable conditions shift. Wildlife adaptation potential is particularly important in the face of climate change, sea-level rise, and changing water management in the Delta. Species distributions, habitat associations, and life-history strategies are likely to change over time in ways that are difficult to predict. Promoting wildlife adaptation potential at the landscape scale can help to manage for an uncertain future. The large population sizes with high genetic and phenotypic diversity that help drive adaptation potential require extensive, heterogeneous habitats. The ability of species to move along physical gradients (in elevation, salinity, and other parameters) as conditions change requires habitat connectivity. Metrics to characterize wildlife adaptation potential were not developed for this report, because this complex concept could not be adequately quantified with the resolution of data available. However, the drivers behind adaptation potential, namely habitat extent, connectivity, heterogeneity, and diversity, are integrated throughout this report (for example, the importance of alternative life-history support strategies for salmon is discussed in Chapter 4) and will inform future work on this project.

FUNCTIONS RELATED TO FOOD WEBS The amount of food within a system, and the ability of nutrients to be cycled and exchanged throughout that system, are critical to determining the degree to which that system can support wildlife. Constraints on primary production and the relative importance of different production sources to the food web are a major ecological uncertainty in the Delta system. We consider the size and location of high productivity habitats such as tidal marshes and shallow-water areas with high residency time to be important features for maintaining this function, and these are discussed in the related "life-history support" chapters. Estimating primary productivity in different parts of the Delta system was determined to be beyond the scope of this project, given the careful analysis of uncertainties that would be required. However metrics developed for this project may be appropriate to support such calculations in the future.

FUNCTIONS RELATED TO BIODIVERSITY For this project, we define biodiversity as the diversity of plants and animals supported by the Delta. Since biodiversity is the aggregate result of all the life-history support functions provided by the Delta, we do not devote a discrete chapter to biodiversity in this report. However, to understand changes in biodiversity at a landscape scale we make the following assumptions: 1) greater extent and diversity of habitat types will support greater diversity of species, 2) areas of key importance to endemic and rare native species are disproportionately important to overall biodiversity, and 3) preserving processes under which endemic species evolved may favor native over invasive species.

Identifying landscape metrics to assess ecological functions

What are landscape metrics?

Landscape metrics are commonly described as quantitative indices that describe spatial patterns of landscapes based on data from maps, remotely sensed images, and GIS layers.[6] McGarigal (2002) notes that "real landscapes contain complex spatial patterns in the distribution of resources that vary over time" and that "landscape metrics are focused on the characterization of the geometric and spatial patterns."[7] Landscape metrics are traditionally algorithms that quantify specific spatial characteristics of categorical data such as patches, classes of patches, or entire landscape mosaics. We broaden the term to use landscape metrics to quantify particular aspects of the physical landscape, including channel length, width and area, and habitat adjacencies in addition to analysis of patch dynamics. We use these landscape metrics to assess the extent and distribution of ecological functions. As such, the aspect of the landscape that the metric measures must somehow relate to the provision of the relevant ecological function.

Choosing landscape metrics

We used a series of rules to choose metrics that could be correlated to ecological functions and were feasible given the available data.

- **Landscape metrics are derived from the available data.** The selection of metrics was guided by the available data on the historical and present day Delta. The primary data sources for the historical Delta include a categorical map of historical habitat types and a linear network of historical channels and streams. Metrics were limited to those that could be derived from these and related contemporary data sources and were appropriate given the data's spatial extent and resolution.
- **Landscape metrics should be functional.** McGarigal (2002) uses the terms "functional" and "structural" to distinguish between metrics that measure landscape patterns with and without explicit reference to a particular ecological process.[8] Specifically, he defines functional metrics as "those that explicitly measure landscape pattern in a manner that is functionally relevant to the organism or process under consideration."[9] Since we are using landscape metrics to assess the extent and distribution of specific ecological functions, we selected only functional metrics. We conducted reviews of the available literature to parameterize our metrics for specific species/guilds of wildlife and to define how exactly the metrics relate to the functions they are meant to quantify. That said, some metrics intended to describe the physical landscape of the historical Delta are purely structural.

Metrics to assess the function 'Provides habitat and connectivity for fish'

1) Inundation extent, duration, timing, and frequency

2) Marsh to open water ratio

3) Adjacency of marsh to open water by length and marsh patch size

4) Ratio of looped to dendritic channels (by length and adjacent habitat type)

Metrics to assess the function 'Provides habitat and connectivity for marsh wildlife'

1) Marsh area by patch size (patch size distribution)

2) Marsh area by nearest neighbor distance

3) Marsh core area ratio

4) Marsh fragmentation index

Metrics to assess the function 'Provides habitat and connectivity for waterbirds'

1) Ponded area in summer by depth and duration

2) Wetted area by type in winter

Metrics to assess the function 'Provides habitat and connectivity for riparian wildlife'

1) Riparian habitat area by patch size

2) Riparian habitat length by width class

Metrics to assess the function 'Provides habitat and connectivity for marsh-terrestrial transition zone wildlife'

1) Length of marsh-terrestrial transition zone by terrestrial habitat type

Using the guidelines described above, SFEI-ASC staff first developed a draft list of landscape metrics that could be used to assess the extent and distribution of the ecological functions described above in both the historical and contemporary Delta. Next, via an iterative process, the draft list was reviewed, prioritized, and edited by the LIT and specialized expert groups. In addition to our meetings with the LIT, we also met separately with groups of regional experts to help review, vet, and parameterize the metrics chosen to assess specific functions. The result—a final list of landscape metrics for the project to analyze—is provided in the diagram on page 8 and in the box on page 12. For detailed descriptions of each metric and the methods used to execute them, please see Appendix A.

Calculating landscape metrics

Metrics were developed using spatial datasets of habitat types and channels/water bodies, both for the historical Delta (ca. 1800) and the modern Delta (ca. 2010). We used these layers to assess the chosen metrics for the entire Delta, both for the modern and historical periods. For more information on these datasets, please see the table and images on pages 14-15.

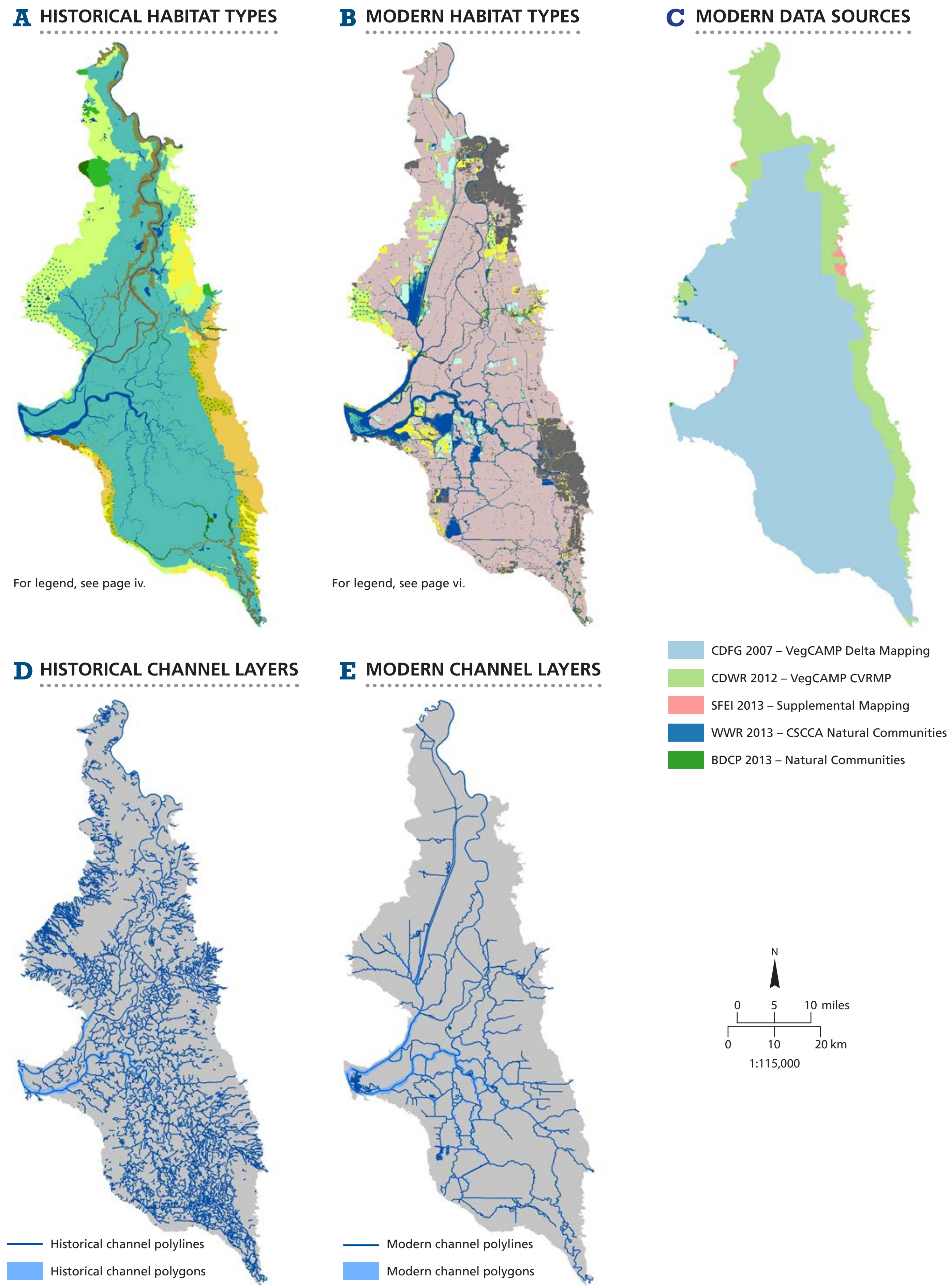
To best correlate our landscape metrics with ecological functions, we parameterized them based on relevant ecological thresholds and data identified in the available scientific literature (see table below). For certain metrics, categories or thresholds were identified to help make the results more easily interpretable in terms of ecological function. Examples of this include patch size, "large" patch size, and definition of "core" vs. "edge" habitat for marsh habitat. Although parameters are based on values from the literature, landscape metrics are inevitably simplifications of the complex relationships between habitat fragmentation and wildlife support, and do not necessarily account for important variables such as population demographics and habitat quality. Detailed information on sources and assumptions used to develop the metrics can be found in Appendix A.

Examples of sources and assumptions used to parameterize metrics (below). For each metric we present the parameter and the rationale used to justify it.

Metric	Parameter	Rationale
Marsh area by patch	When defining marsh patches, discrete marsh polygons were considered part of the same patch if they were located within 60 m of one another	This distance is derived from the rule set for defining intertidal resident rail (e.g. Black Rails) patches developed by Collins and Grossinger (2004), which is based on the best available data on rail habitat affinities and dispersal distances.[10] We assume that the rule set developed for intertidal rails in the South Bay (including Clapper Rails, which are not found in the Delta) is generally applicable to the Delta and non-tidal marsh. Additionally, this simplistic model of a binary landscape (marsh and non-marsh) assumes that all patches of marsh are equally suitable for rails, that the routes of travel between patches are linear, and that the only barrier to rail movement is distance.[11]
Marsh area by nearest "large" neighbor distance	Nearest "large" neighbor distance was calculated for each marsh patch as the linear distance to the nearest neighboring marsh patch of at least 100 ha.	This size threshold is based on (1) regression models of Spautz and Nur (2002) and Spautz et al. (2005), which show a significant negative correlation between Black Rail presence and distance to the nearest 100 ha marsh[12] and (2) the work of Liu et al. (2012), which found that Clapper Rail densities decrease in patches <100 ha.[13]
Marsh core area ratio	Core area ratio is defined as the percent of a marsh patch's total area that is greater than 50 m from the patch edge.	This distance is based on the work of Spautz and Nur (2002) and Spautz et al. (2005) indicating a significant positive relationship between Black Rail presence and marsh area >50 m from the marsh edge.[14]
Riparian habitat length by width class	We determined the length of riparian habitat in three width classes: <100 m wide, 100 – 500 m wide, and >500 m wide.	The 100 m width threshold is based in part on the work of Gaines (1974), who found that Western Yellow-billed Cuckoos were only present in patches at least 100 m wide.[15] Kilgo et al. (1998) found that riparian forest areas at least 500 m wide were necessary to maintain the "complete avian community" in bottomland hardwood forests in South Carolina.[16] These widths largely agree with the findings of Laymon and Halterman (1989) who (based on occupancy and nest predation rates) define riparian habitat <100 m wide as "unsuitable," habitats 100-600 m wide as "marginal" to "suitable," and habitats at least 600 m wide as "optimal" for cuckoo nesting.[17]

Datasets used to run landscape metrics. Data include habitat type layers, channel polygons, channel polylines, and channel bathymetry rasters. These layers were obtained or developed for both the historical and modern time periods.

Type of data	Time period	Notes
Habitat type (polygons)	Historical	The historical Delta habitat type data (A, right) used in this study were obtained from SFEI-ASC's *Sacramento-San Joaquin Delta Historical Ecology Investigation*.[18] The dataset classifies the historical Delta into 17 habitat types, the majority of which are based on modern classification systems. Some of these classifications were grouped to facilitate comparison with the modern Delta habitat types layer.
	Modern	The modern Delta habitat type data (B, right) used in this study were compiled from multiple sources, including the CDFW Vegetation Classification and Mapping Program's 2007 Sacramento-San Joaquin River Delta dataset[19] and the 2012 Central Valley Riparian Mapping Project Group Level dataset.[20] Together, these two sources covered greater than 99% of the project's study extent (C, right). The compiled modern dataset's classifications were crosswalked to the historical habitat types (or groups of historical habitat types) with the assistance of local experts.[21]
Channels (polygons & centerlines, bathymetry rasters)	Historical	Historical channel polygons (D, right) were obtained from SFEI-ASC's *Sacramento-San Joaquin Delta Historical Ecology Investigation* historical habitats layer by selecting polygons classified as 'fluvial low order channel,' 'fluvial mainstem channel,' 'tidal low order channel,' or 'tidal mainstem channel.'[22] Historical channel polylines were obtained from the *Delta Historical Ecology Investigation*'s historical creeks layer.[23]
		Historical bathymetry was derived from a variety of historical sources, including mid-19th century surveys of the Sacramento and San Joaquin rivers.[24] The task of developing a historical topographic-bathymetric digital elevation model of the Delta from these data is the focus of a separate project (a collaboration between the San Francisco Estuary Institute and researchers at the UCD Center for Watershed Sciences). This report utilizes interim data from that project.
	Modern	Modern channel polygons (E, right) were derived from the National Hydrography Dataset (NHD)[25] by clipping the dataset to the project study extent and selecting features classified as 'StreamRiver' or 'CanalDitch.' Additional channels that were not included in the NHD but are apparent in contemporary aerial photographs were either incorporated from other datasets (such as CDFW Delta LiDAR hydrography breaklines) or manually digitized by SFEI staff. Modern channel polylines were generated from the polygon dataset (described above) with a custom centerline generation tool.
		Modern bathymetry was extracted from a continuous topographic-bathymetric DEM of the San Francisco Bay-Delta Estuary.[26]


A HISTORICAL HABITAT TYPES
For legend, see page iv.
B MODERN HABITAT TYPES
For legend, see page vi.
C MODERN DATA SOURCES
CDFG 2007 – VegCAMP Delta Mapping
CDWR 2012 – VegCAMP CVRMP
SFEI 2013 – Supplemental Mapping
WWR 2013 – CSCCA Natural Communities
BDCP 2013 – Natural Communities
D HISTORICAL CHANNEL LAYERS
Historical channel polylines
Historical channel polygons
E MODERN CHANNEL LAYERS
Modern channel polylines
Modern channel polygons
N
0 5 10 miles
0 10 20 km
1:115,000

Key project assumptions, limitations, and uncertainties

Inevitably, using available data sources for analyses of an ecosystem as complex as the Delta involves significant assumptions and uncertainties. Here we list the largest assumptions, uncertainties, and limitations associated with the use of our data. For more details, please refer to Appendix A.

General assumptions

Records of what wildlife were present in the historical Delta are sparse and inconsistent. Accounts of how wildlife used the landscape are even more so. Therefore, inferring the ecological functions provided by the historical landscape requires us to make many assumptions, with varying levels of confidence, combining disparate sources to develop a picture of the functioning landscape as a whole. Assumptions made and sources used are referenced in endnotes in the back of the report. Types of information, sources and assumptions used to interpret ecological functions in the historical landscape fell into several broadly defined categories:

- Assumptions based on well-established ecological theory.
- Assumptions based on ecological theory, but that required us to make major assumptions about Delta functioning. For these assumptions, the endnotes provide added detail on our rationale and sources.
- Assumptions based on ecological functions in less disturbed systems (e.g., salmon support in Pacific Northwest wetlands).
- Assumptions based on knowledge of natural history, physiological tolerance, and current habitat associations of Delta species.
- Assumptions based on records of historical occurrence. We did not go back to primary sources to look for incidents of species observations, but where these observations are summarized by other sources we cite them.
- Assumptions based on understanding of first principles of physical processes.
- Landscape metrics are a proxy for ecological function.
- Historical and modern habitat types are directly comparable.

Uncertainties (see Appendix A, pages 95-97 for additional details)

- **Uncertainty associated with the historical spatial data.** For the *Delta Historical Ecology Investigation*, each feature in the historical habitat types and channels layers was assessed for certainty. Overall, certainty of the features' interpretation/location was characterized as fairly high.[27]
- **Uncertainty associated with the modern spatial data.** Some degree of uncertainty is associated with each of the individual datasets compiled to generate our modern habitat types map. Additional uncertainty is associated with the process of crosswalking each of these data sources to the single classification system used in the historical dataset.
- **Uncertainty associated with historical and modern data fidelity.** When making comparisons between the historical and modern landscape, it was important that we compared the same things, at the same scale, using the same measurements. While, for certain analyses, differences in data resolution increased the uncertainty surrounding the precise magnitude of measured changes, we do not believe that these differences impacted the direction of changes or the overall stories told by the analyses.[28]

Limitations

- **The methods do not assess all of the functions that were performed by the historical Delta.**[29] Our high-level list of key ecological functions provided by the historical Delta is meant to broadly capture the functions that would have—likely and collectively—supported healthy wildlife communities in the Delta. Other high-level functions (such as primary productivity) are not addressed, while multitudes of lower-level functions (such as providing roosting habitat for certain bird species) are not specifically or directly identified in the body of this document. The project team decided which ecological functions to address using guidance from the LIT, who reviewed and edited a draft master list of possible ecological functions.

- **The metrics do not assess the landscape quantitatively for fine-scale heterogeneity.** Some historical and modern habitat types are mosaics that encompass smaller features (e.g., small ponds, beaver cuts, large woody debris, and willow-fern patches). We sometimes attempt to generally quantify these but do not discretely map or specifically analyze them.

- **The methods do not assess cultural, recreational, educational, or aesthetic functions of the historical (or contemporary) Delta.**[30] While there is limited information known about indigenous uses of the historical Delta, we recognize that humans had a significant impact on its ecological functioning. This is not a focus of this analysis.

- **Landscape metrics do not represent a direct measurement of the performance of a function.** Landscape metrics to represent ecological function are based on literature on conditions in California and elsewhere, but are not direct measurements of ecological function. As stated above as an assumption, metrics create a proxy for, or a hypothesis about expected ecological outcomes, based on observations elsewhere. The metrics do not include statistical validation/field testing.

- **Metrics do not capture interannual (or in some cases seasonal) variability in hydrology or temperature.** The data used for this analysis create a snapshot in time, from which we have inferred some seasonal and interannual variability. While seasonal variability is captured in timelines of available habitat through a water year for fish and waterbirds, the longer term interannual hydrologic patterns typical of our Mediterranean climate are not quantitatively assessed due to data limitations. Measurements of flow or sediment are not included.

- **The metrics do not acknowledge the limitations of private versus public land in terms of providing ecological function.** The analysis presented here does not distinguish between private or public land in the Delta. For restoration plans to eventually be made from these data, the details and constraints of land holdings must be considered.

- **The metrics do not differentiate between types of agriculture.** We recognize that certain types of wildlife-friendly agriculture are practiced in the Delta currently, and that certain crops and crop patterns provide more ecological benefit than others. At this scale of analysis, our report does not differentiate between types of agriculture, though further research could be done on this topic.

- **The report does not analyze the impact of invasive species or changes to groundwater levels on ecological functions.**

- **The metrics do not weight the modern land surface in terms of severity of subsidence.** During future stages of the Delta Landscapes project which involve integrating the results of the metrics into landscape units, these physical constraints will be considered.

Habitat type	Description
Water	**Tidal mainstem channel:** Rivers, major creeks, or major sloughs forming Delta islands where water is understood to have ebb and flow in the channel at times of low river flow. These delineate the islands of the Delta. **Fluvial mainstem chanel:** Rivers or major creeks with no influence of tides. **Tidal low order channel:** Dendritic tidal channels (i.e., dead-end channels terminating within wetlands) where tides ebb and flow within the channel at times of low river flow. **Fluvial low order channel:** Distributaries, overflow channels, side channels, swales. No influence of tides. These occupy non-tidal flood-plain environments or upland alluvial fans. **Freshwater pond or lake:** Permanently flooded depressions, largely devoid of emergent Palustrine vegetation. These occupy the lowest-elevation positions within wetlands. **Freshwater intermittent pond or lake:** Seasonally or temporarily flooded depressions, largely devoid of emergent Palustrine vegetation. These are most frequently found in vernal pool complexes at the Delta margins and also in the non-tidal floodplain environments.
Freshwater emergent wetland	**Tidal freshwater emergent wetland:** Perennially wet, high water table, dominated by emergent vegetation. Woody vegetation (e.g., willows) may be a significant component for some areas, particularly the western-central Delta. Wetted or inundated by spring tides at low river stages (approximating high tide levels). **Non-tidal freshwater emergent wetland:** Temporarily to permanently flooded, permanently saturated, freshwater non-tidal wetlands dominated by emergent vegetation. In the Delta, occupy upstream floodplain positions above tidal influence.
Willow thicket	Perennially wet, dominated by woody vegetation (e.g., willows). Emergent vegetation may be a significant component. Generally located at the "sinks" of major creeks or rivers as they exit alluvial fans into the valley floor.
Willow riparian scrub or shrub	Riparian vegetation dominated by woody scrub or shrubs with few to no tall trees. This habitat type generally occupies long, relatively narrow corridors of lower natural levees along rivers and streams.
Valley foothill riparian	Mature riparian forest usually associated with a dense understory and mixed canopy, including sycamore, oaks, willows, and other trees. Historically occupied the supratidal natural levees of larger rivers that were occasionally flooded.
Wet meadow or seasonal wetland	Temporarily or seasonally flooded, herbaceous communities characterized by poorly-drained, clay-rich soils. These often comprise the upland edge of perennial wetlands.
Vernal pool complex	Area of seasonally flooded depressions, characterized by a relatively impermeable subsurface soil layer and distinctive vernal pool flora. These often comprise the upland edge of perennial wetlands.
Alkali seasonal wetland complex	Temporarily or seasonally flooded, herbaceous or scrub communities characterized by poorly-drained, clay-rich soils with a high residual salt content. These often comprise the upland edge of perennial wetlands.
Stabilized interior dune vegetation	Vegetation dominated by shrub species with some locations also supporting live oaks on the more stabilized dunes with more well-developed soil profiles.
Grassland	Low herbaceous communities occupying well-drained soils and composed of native forbs and annual and perennial grasses and usually devoid of trees. Few to no vernal pools present.
Oak woodland or savanna	Oak dominated communities with sparse to dense cover (10-65% cover) and an herbaceous understory.
Agriculture/Ruderal/Non-native	Cultivated lands, including croplands and orchards. This habitat type also includes areas dominated by non-native vegetation and ruderal lands.
Managed wetland	Areas that are intentionally flooded and managed during specific seasonal periods, often for recreational uses such as duck clubs.
Urban/Barren	Developed, built-up land often classified as urban, barren or developed. Includes rock riprap bordering channels.

Modern only

Habitat types descriptions and images. The mapping developed and used in this report includes twenty habitat types. With the exception of three types unique to the modern Delta, the classification was first developed for the *Sacramento-San Joaquin Delta Historical Ecology Investigation*.[31] The table **(opposite)** describes each habitat type. Representative images are shown to illustrate what these landscapes may have looked like. Not shown: alkali seasonal wetland complex, agriculture/non-native/ruderal, urban/barren, managed wetlands.

Photo by Daniel Burmester

Tidal mainstem channel

Photo by Daniel Burmester

Fluvial mainstem channel

Photo by Bill Miller

Fluvial low order channel

Photo by Bill Miller

Freshwater pond or lake

Photo by Daniel Burmester

Freshwater pond or lake

Photo by Bill Miller

Freshwater emergent wetland

Photo by Daniel Burmester

Freshwater emergent wetland

Photo by Bill Miller

Willow thicket

Photo by Bill Miller

Valley foothill riparian

Photo by Daniel Burmester

Valley foothill riparian

Photo by Daniel Burmester

Wet meadow/seasonal wetland

Photo by Marc Hoshovsky

Vernal pool complex

Photo by Jean Pawek

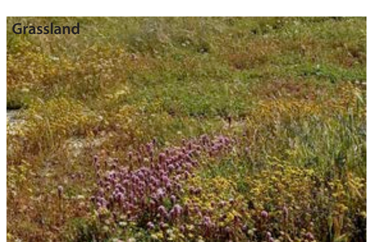
Stabilized interior dune vegetation

Photo by Christopher Thayer

Stabilized interior dun3 vegetation

Photo by Ingrid Taylar

Oak woodland or savanna

Photo by Jean Pawek

Grassland

3. Overall Delta Landscape Changes

This chapter describes systemic changes to the Delta ecosystem since the historical period (prior to the analyses of ecological function in the subsequent chapters).

The historical Delta is gone. The defining characteristic of the historical Delta was its extensive wetland landscape, formed over time as floodwaters met the tides. Modern land management has increasingly disconnected floodwaters from the wetlands by widening and deepening channels, diking and draining wetlands for agriculture, and building levees for flood protection. The consequences of this disconnection include a nearly complete loss of Delta wetlands, along with the processes that sustain them, and a dramatic altering of the remaining aquatic habitats. The Delta has become more susceptible to invasive species, and the consequences of those invasions are magnified as a result of habitat loss and alteration. The ecological impacts of these transformations have been dire; the Delta food web has collapsed, wildlife populations have been drastically reduced in size, and the resilience of many remaining populations has been impaired.

The Delta once supported numerous wildlife species, some in great abundance, many of which are now species of concern. Tricolored blackbirds formed the largest breeding colonies of any landbird in North America,[1] Chinook salmon runs were among the largest on the Pacific Coast,[2] despite being at the southern end of the species distribution, and millions of waterfowl wintered in the Central Valley, in concentrations unmatched anywhere in California.[3] Many regionally endemic species inhabited the Delta, including plants (Mason's lilaeopsis, Delta tule pea), insects (Lange's metalmark butterfly, valley elderberry longhorn beetle), fish (delta smelt, longfin smelt, thicktail chub), reptiles and amphibians (giant garter snake, California tiger salamander), and mammals (riparian brush rabbit, riparian woodrat). At least one species endemic to the Delta, the thicktail chub, is now extinct, while several more have been extirpated in the Delta (including the Western Yellow-billed Cuckoo and Sacramento perch). Many more Delta species are at risk of being lost in the future; the draft Bay Delta Conservation Plan (BDCP) lists 56 species as being of immediate management concern.[4]

Six interrelated drivers of change are implicated in the loss of ecological function in the Delta. These drivers interact in a complex physical and biological system, where one driver may tip the scales toward ecosystem collapse, but only because the other drivers have brought the system to that tipping point.[6] The drivers of change are (1) reduction in habitat extent, (2) loss of heterogeneity within habitats, (3) loss of connectivity within and among habitat types, (4) degradation of habitat quality, (5) disconnection of habitats from the physical processes that form, sustain, and confer resilience upon them, and (6) invasion by ecosystem engineers such as Brazilian waterweed and invasive clams, and other predatory fish. Other drivers of change, particularly reductions and alterations in freshwater inflow and contaminants, are also responsible for the loss of ecological function.[5]

The habitats that dominated when the Delta was a functionally intact ecosystem have been reduced to small fractions of their former extent. For example, 15,608 hectares of Valley foothill riparian forest throughout the historical Delta have been reduced to 4,010 hectares: a reduction of 74%. There were at least 3,217 km of small channels (<15 m wide) in the Delta historically (not including an estimated 1,931 km of additional unmapped channels; see Appendix A, page 85), but only 144 km of small channels exist in the modern Delta: a 96-97% loss of channels in this size class. This decrease has most likely reduced the population viability of native wildlife in these habitats by eliminating the large, widely distributed, and connected populations. The reduced extent of high-endemism habitats, such as vernal pools and alkali wetlands, may have significant consequences for biodiversity in the region (see Chapter 8). The effects of habitat loss, fragmentation, and degradation on marsh and riparian wildlife are discussed in Chapters 5 and 7. As a result of the diking of marshes, dendritic channel networks have been lost, with ecological consequences for native fish (see Chapter 4). The reduction of high-productivity marsh habitat has reduced the food resources available for fish and waterfowl (discussed in Chapter 4 and Chapter 6). In general, the scale-dependent effects of habitat loss on food resources are not well understood. Marsh production, from the marsh plain and the shallow, high-water-residence-time dendritic channels, was undoubtedly consumed and sequestered within the marsh, as well as being consumed by transient and edge wildlife, with some productivity ultimately being exported in one form or another to the broader estuarine and adjacent terrestrial ecosystems.[7]

Historically there was considerable geomorphic and hydrological heterogeneity within Delta habitats, creating diverse options for wildlife. This heterogeneity grew from the complex and variable hydrology, water and air temperature gradients, and differences in geomorphic setting, including topography and soils.[8] These differences manifested as diversity in plant communities and water chemistry, which provided a variety of options for wildlife. The riparian shrub habitats of the south Delta supported different species than the wide riparian gallery forests of the north Delta (see Chapter 7). Likewise, the dense tule marshes of the north Delta, willow-interspersed marshes of the central Delta, and complex marsh mosaics of the south Delta likely supported somewhat different communities of marsh wildlife (see Chapter 5 and Chapter 6). Yet some broadly distributed species with an ability to exploit diverse habitats, like Song Sparrows and Virginia Rails, were likely present across all these types of marsh, as large and diverse populations. Heterogeneity within habitats provided niche opportunities and increased habitat complexity, which is one way to create and maintain the genotypic and phenotypic diversity necessary for adaptation to change. Thus, heterogeneity supported the adaptation potential of wildlife and, in some cases, the development of alternative life-history strategies.[9] Heterogeneity within the Delta allowed different runs of Chinook salmon to exploit different resources at different times of year, supporting the diversity in salmon life-history strategies present today (see Chapter 4).

The modern Delta has lost connectivity within and among habitat types. Once-continuous populations of marsh species are now dispersed metapopulations or small, isolated populations at risk of extirpation. Riparian forests that once were unbroken corridors for terrestrial wildlife movement are now small, isolated, narrow patches often disconnected from the flooding that sustains them. Other habitat types in the Delta are also disconnected from one another, bounded by levees and separated by a matrix of agriculture. Approximately 1,770 km of levees exist in the modern Delta, separating channels and marshes from adjoining habitats. Historical flooding moved sediment, nutrients, and organisms between adjacent habitats, replenishing less productive areas

Damming a Delta slough.

Unknown ca. 1900, MS 229, Dyer Photograph Album, courtesy of Holt-Atherton Special Collections, University of the Pacific Library

on a regular basis and maintaining geomorphic structure. Loss of connectivity in the modern Delta disrupts these water and energy flows, impacting productivity[10] and resilience. Loss of habitat connectivity also reduces the viability of wildlife populations by restricting gene flow and limiting the ability of individuals and species to move conditions change.[11] One exception is that connections between large channels have increased over time as a result of channel cuts and dredging. The over connectivity of the channel network, and abundance of looped channels (combined with altered flow regimes) results in flow paths and chemical signals that are unpredictable for aquatic species.[12]

The quality of remaining habitats within the Delta has been degraded by a loss of complexity and the addition of anthropogenic stressors. The channels that now characterize the Delta are wider, straighter, deeper, and simpler than historical channels, and generally lack the fine-scale structure and micro-topography (e.g., from pools, vegetated banks, channel cut-offs, and backwaters) that once increased habitat value for aquatic wildlife. High nutrient loads and contaminants impair water quality and can reduce wildlife survival and reproductive success.[13] Invasive species have altered food-web dynamics, particularly the Asian clam, which reduces phytoplankton availability.[14] Introduced predatory fish, like bass and sunfish, directly compete with and prey upon native fish.[15] Wetland and upland habitats have also suffered the effects of introduced species such as *Arundo* and Himalayan blackberry, both of which can dramatically alter habitat structure and diversity. Grasslands along the edge of the Delta have been almost entirely converted from perennial grasses and forbs to non-native annual grasses (see Chapter 8).

Habitat types are now disconnected from the processes that created and sustained them. Rivers and sloughs are separated from their floodplains by artificial levees, so flood waters do not deliver the sediment and nutrients to adjacent lands. Most leveed agricultural land has subsided to well below sea level. Similarly, riparian forests are no longer inundated by the floods that maintained the natural levees they grow upon. Upland habitat types now occupy topographic lows. The naturally dynamic and seasonal hydrology of the Delta has been greatly simplified and constrained. Lakes, ponds and basins are now often disconnected from the larger channel network, and no longer fill with floodwaters during the winter and then drain over the summer. Instead, they have become perennial warm-water habitat that favors invasive fish.[16] Though not historically a delta of actively migrating meanders,[17] tidal channels have been deepened, widened, and straightened- their edges hardened- limiting their ability to adjust and respond to environmental changes. The rivers that feed the Delta have been almost uniformly dammed and their channels armored and leveed, simultaneously cutting off peak flows, reducing sediment supply, and altering seasonal hydrology.

These and other interruptions or constrictions of physical processes have contributed to the development of a brittle skeleton of the former Delta, pinned in place by roads and levees, and unable to benefit from the processes that created it. Thus, the changes in physical processes mirror the changes in habitat. Both have been so severely altered and reduced that the dominant features of the historical Delta – extensive marshes nourished with seasonal flooding and supporting vast wildlife populations – are no longer present. The Delta today is a network of deep, engineered channels within a matrix of leveed agriculture, supporting declining native wildlife and increasing invasive species populations.

The following pages describe overall change in habitats and the channel network. These changes are the easiest to quantify, given the available historical and contemporary datasets. Changes in habitat quality, habitat heterogeneity, and physical processes are often described qualitatively, since the datasets necessary for quantification are not available. These overarching analyses provide context for understanding the changes in ecological functions which are assessed in the subsequent chapters.

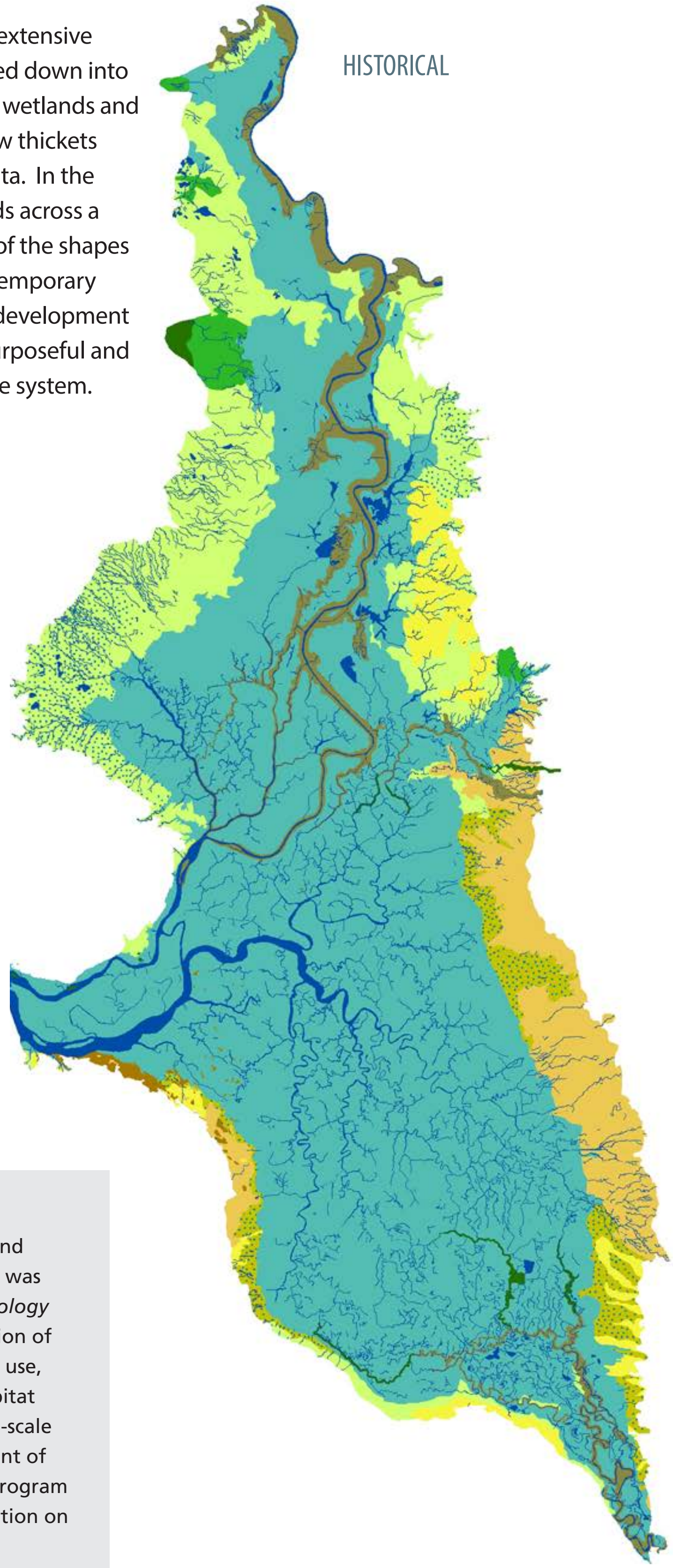
(top) Riprap and oaks on artificial levee, Lindsey Slough. (bottom) Dredges creating meander cuts on the San Joaquin.

Top: Erin Beller, SFEI; Bottom: Covella & Farichild ca. 1910, courtesy of Bank of Stockton Historical Photograph Collection

The extent of habitat type conversion has been extreme

The Delta has been converted from a marsh-dominated landscape to an agriculture-dominated landscape

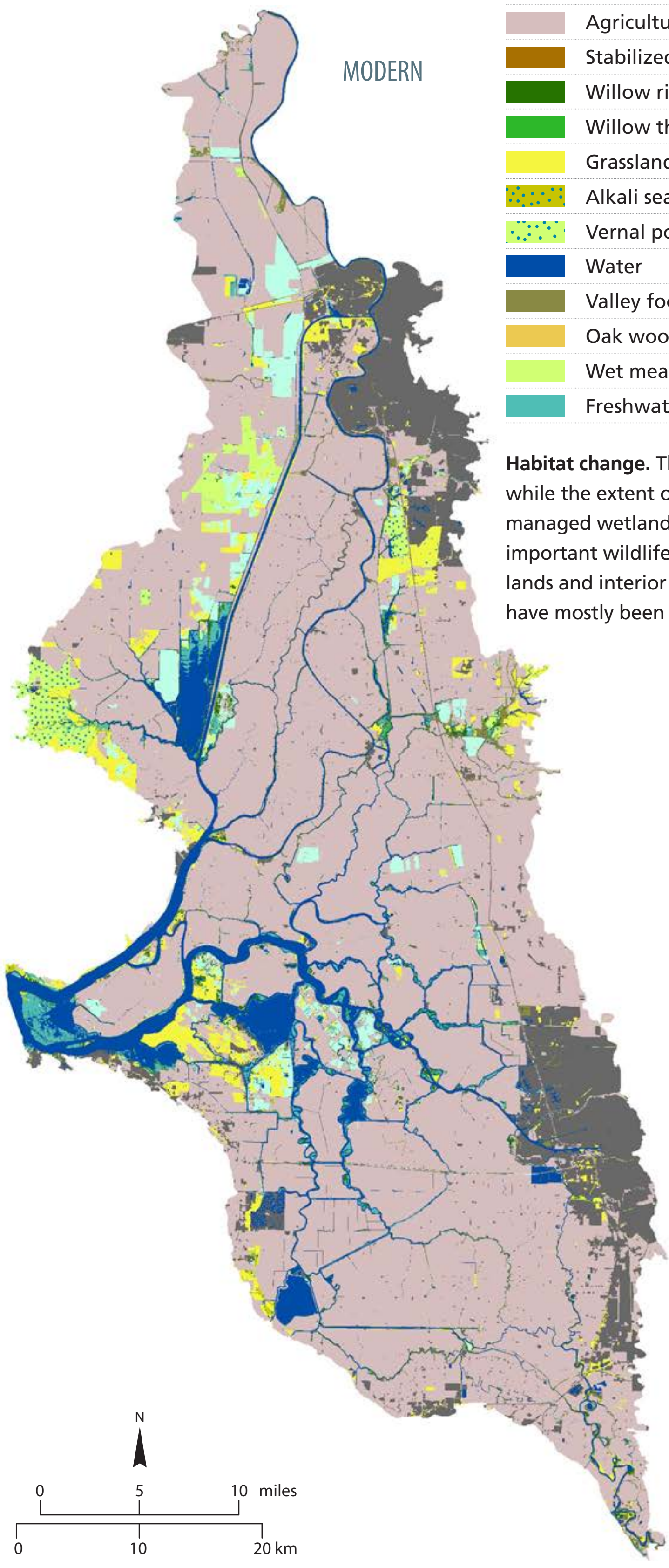
The historical Delta was characterized by a complex and extensive marshland matrix. Broad corridors of riparian forest snaked down into the marsh along major rivers and distributaries. Seasonal wetlands and vernal pools lined the periphery of the north Delta. Willow thickets were interspersed throughout the tules in the central Delta. In the south Delta, tidal wetlands graded into non-tidal wetlands across a long, heterogeneous fluvial-tidal interface. While many of the shapes of these former features can still be identified in the contemporary Delta, habitat type conversion to agricultural and urban development has been extreme. Small remnants and restored (both purposeful and accidental) habitats can be seen scattered throughout the system.



Delta habitat types, past (right) and present (far right). Historical habitat types and channels for the historical Delta ca. 1800 are shown to the right. Modern habitat type mapping ca. 2007 is shown to the far right.

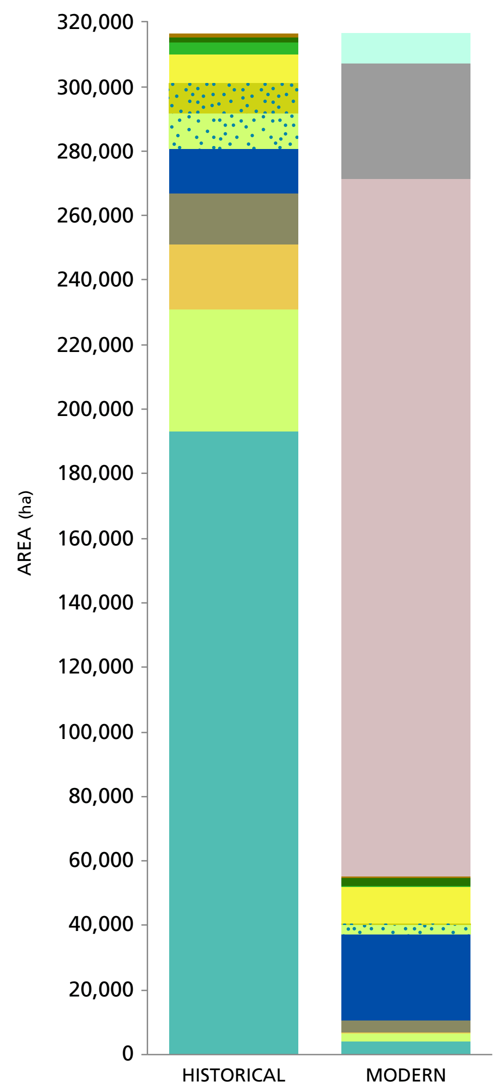
Methods: Habitat type extent

Habitat type acreages were calculated from the historical and modern habitat type maps. The **historical habitat type map** was taken from the *Sacramento-San Joaquin Delta Historical Ecology Investigation.*[18] The **modern habitat type map** is a compilation of several spatial datasets detailing Delta vegetation and land use, with each vegetation type crosswalked to the historical habitat types. The majority of the modern map is derived from fine-scale vegetation mapping produced in 2007 by the CA Department of Fish and Wildlife's Vegetation Classification and Mapping Program (VegCAMP).[19] Please see Appendix A for additional information on developing the historical and modern habitat type layers.



Habitat Type	Area (ha) Historical	Modern	% Change
Managed wetlands	0	9,454	∞
Urban/Barren	0	35,517	∞
Agriculture/Non-native/Ruderal	0	216,085	∞
Stabilized interior dune veg.	1,032	4	-99
Willow riparian scrub/shrub	1,637	2,878	+76
Willow thicket	3,567	132	-96
Grassland	9,108	11,800	+30
Alkali seasonal wetland complex	9,193	238	-97
Vernal pool complex	11,262	3,007	-73
Water	13,772	26,530	+93
Valley foothill riparian	15,608	4,010	-74
Oak woodland/savanna	20,460	0	-100
Wet meadow/Seasonal wetland	37,561	2,445	-93
Freshwater emergent wetland	193,224	4,253	-98

Habitat change. The extent of wetland habitats has decreased in the modern Delta while the extent of open water and grasslands has increased. Agriculture and managed wetlands take up a large portion of the modern Delta and provide some important wildlife support but are not equivalent to historical habitats. Oak woodlands and interior dune scrub have mostly been eliminated.

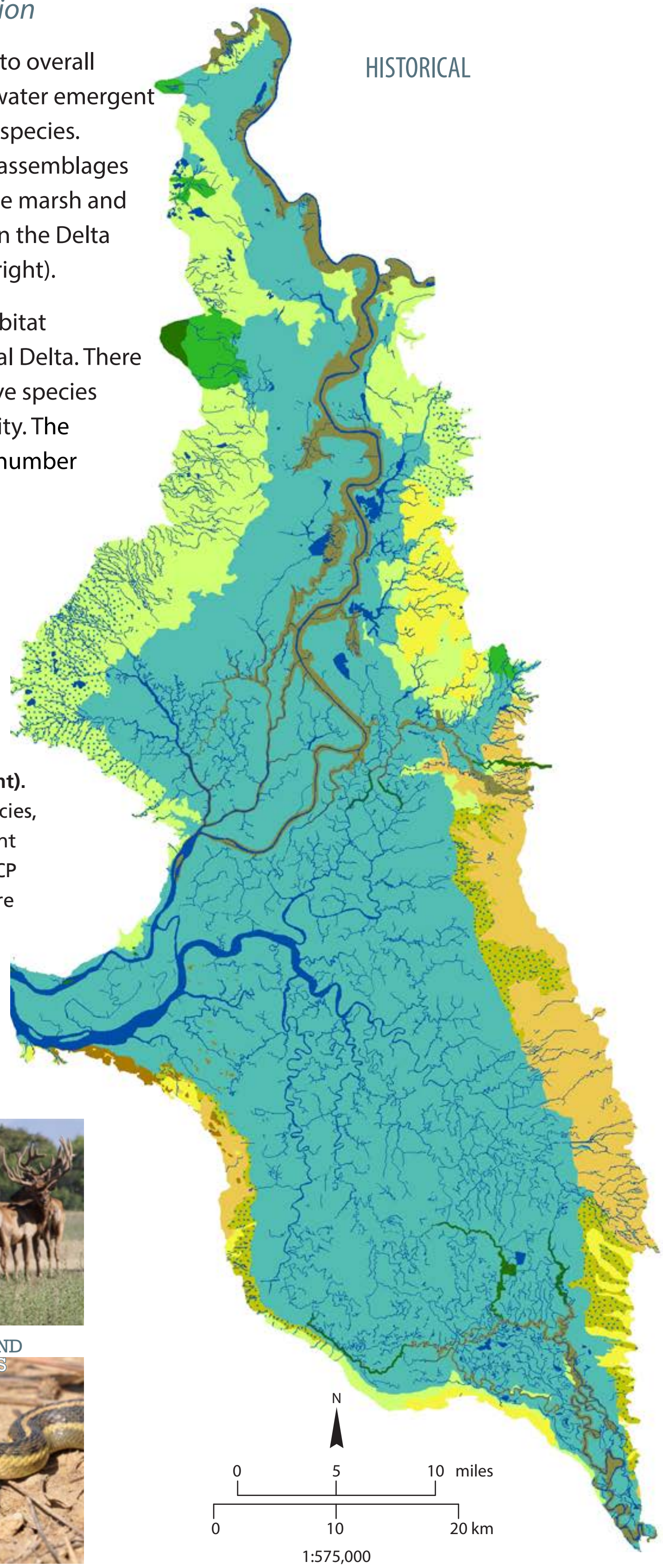


The variety of Delta habitats supported native wildlife diversity

The historical Delta supported a unique assemblage of species, contributing to the overall biodiversity of the region

Habitat diversity within the historical Delta contributed to overall species diversity. Much of the historical Delta was freshwater emergent marsh and aquatic habitat, which supported numerous species. Adjacent habitat types each supported distinct species assemblages and provided additional support to species that used the marsh and aquatic habitats. Many of the protected species found in the Delta today relied on varied habitat types historically (see far right).

Abundant resources from multiple habitat types and habitat adjacencies led to significant biodiversity in the historical Delta. There were also areas of importance to endemic and rare native species that disproportionately contributed to overall biodiversity. The introduction of invasive species has increased the total number of species in some areas, likely at the expense of native species diversity.[20]



Delta habitat types (right) and their affiliated species (far right). Each habitat type in the Delta supported specific suites of species, though several species used multiple habitat types for different phases of their lives. The species listed to the far right are BDCP Covered Species. Historical species-habitat type associations are based on modern species-habitat associations and life-history characteristics.[21]

Photo Credits (clockwise from top left): Dan Cox, USFWS; Steve Emmons, USFWS; Lee Eastman, USFWS; Brian Hansen, USFWS; Jon Katz and Joe Silveira, USFWS; Steve Martarano, USFWS

FISH

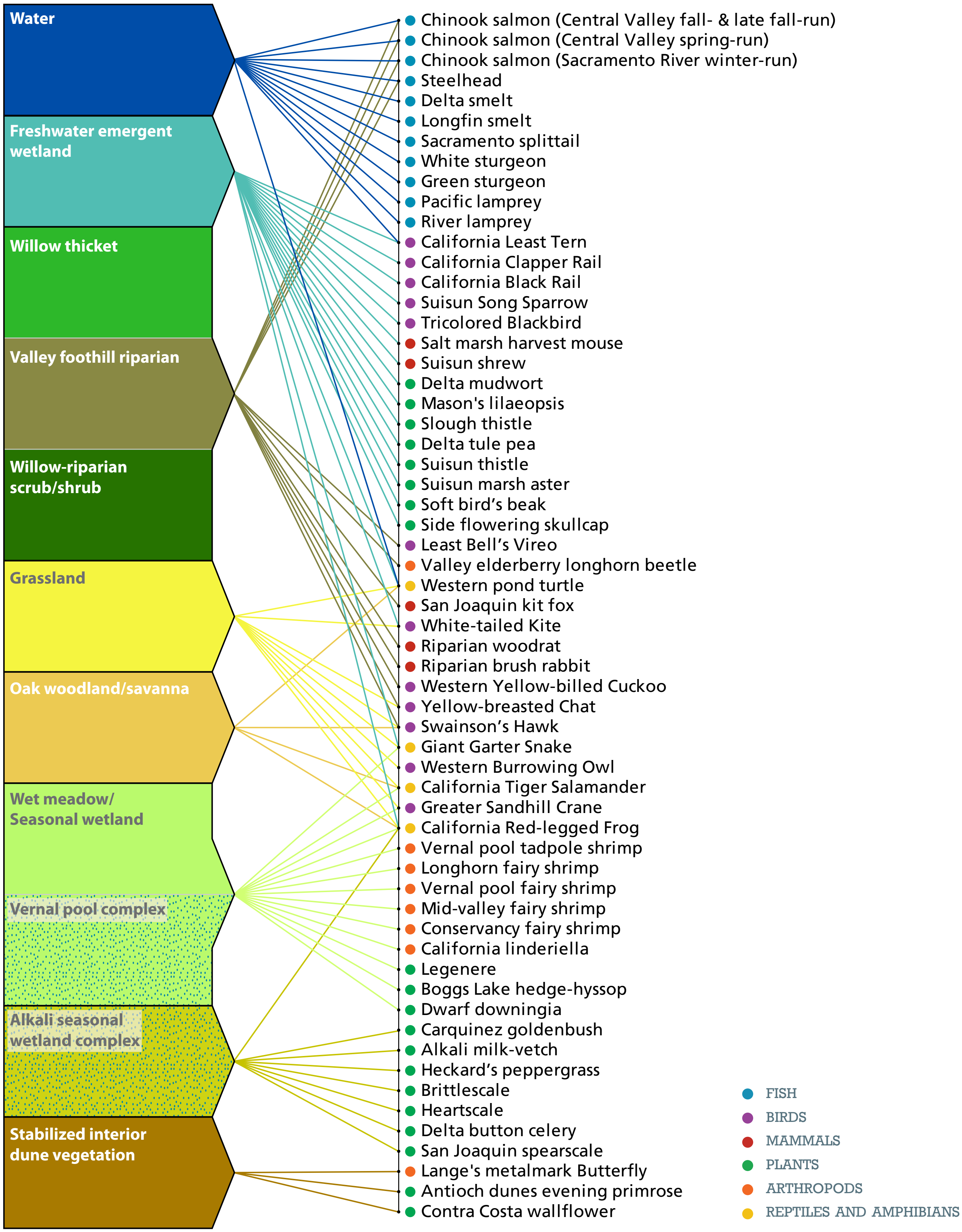
BIRDS

MAMMALS

PLANTS

ARTHROPODS

REPTILES AND AMPHIBIANS


Water
Freshwater emergent wetland
Willow thicket
Valley foothill riparian
Willow-riparian scrub/shrub
Grassland
Oak woodland/savanna
Wet meadow/ Seasonal wetland
Vernal pool complex
Alkali seasonal wetland complex
Stabilized interior dune vegetation
Chinook salmon (Central Valley fall- & late fall-run)
Chinook salmon (Central Valley spring-run)
Chinook salmon (Sacramento River winter-run)
Steelhead
Delta smelt
Longfin smelt
Sacramento splittail
White sturgeon
Green sturgeon
Pacific lamprey
River lamprey
California Least Tern
California Clapper Rail
California Black Rail
Suisun Song Sparrow
Tricolored Blackbird
Salt marsh harvest mouse
Suisun shrew
Delta mudwort
Mason's lilaeopsis
Slough thistle
Delta tule pea
Suisun thistle
Suisun marsh aster
Soft bird's beak
Side flowering skullcap
Least Bell's Vireo
Valley elderberry longhorn beetle
Western pond turtle
San Joaquin kit fox
White-tailed Kite
Riparian woodrat
Riparian brush rabbit
Western Yellow-billed Cuckoo
Yellow-breasted Chat
Swainson's Hawk
Giant Garter Snake
Western Burrowing Owl
California Tiger Salamander
Greater Sandhill Crane
California Red-legged Frog
Vernal pool tadpole shrimp
Longhorn fairy shrimp
Vernal pool fairy shrimp
Mid-valley fairy shrimp
Conservancy fairy shrimp
California linderiella
Legenere
Boggs Lake hedge-hyssop
Dwarf downingia
Carquinez goldenbush
Alkali milk-vetch
Heckard's peppergrass
Brittlescale
Heartscale
Delta button celery
San Joaquin spearscale
Lange's metalmark Butterfly
Antioch dunes evening primrose
Contra Costa wallflower
FISH
BIRDS
MAMMALS
PLANTS
ARTHROPODS
REPTILES AND AMPHIBIANS

The Delta is a highly invaded system

Invasive species have altered the functions and quality of Delta habitats

The Delta has been inexorably altered by the introduction of numerous non-native species. These species have changed not only the community composition of Delta wildlife, with non-native species outnumbering native species in some instances, but have also affected the structure, functions, and processes the Delta can support. The alteration of physical processes and habitats in the Delta has undoubtedly facilitated some of these invasions, and the invasions themselves have further altered and degraded habitats within the Delta. The proliferation of non-native species within the Delta places considerable constraints on the extent to which restoration and other management actions can benefit native species. Non-native species affect the ability of the Delta to support native wildlife through several mechanisms, including habitat alteration, changes in food web structure, competition, and predation (see examples below).

ALTERED HABITAT STRUCTURE

Egeria (shown left) changes flow patterns and turbidity in shallow aquatic habitats. *Arundo* and Himalayan blackberry form dense thickets, impenetrable to some wildlife, in both marsh and riparian habitats.

CHANGED FOOD WEB STRUCTURE

The high filtration rate of the now abundant overbite clam has substantially reduced phytoplankton availability in the Delta. The invasion of the Delta by this clam is correlated with a stepwise decline in fish abundance (Pelagic Organism Decline).

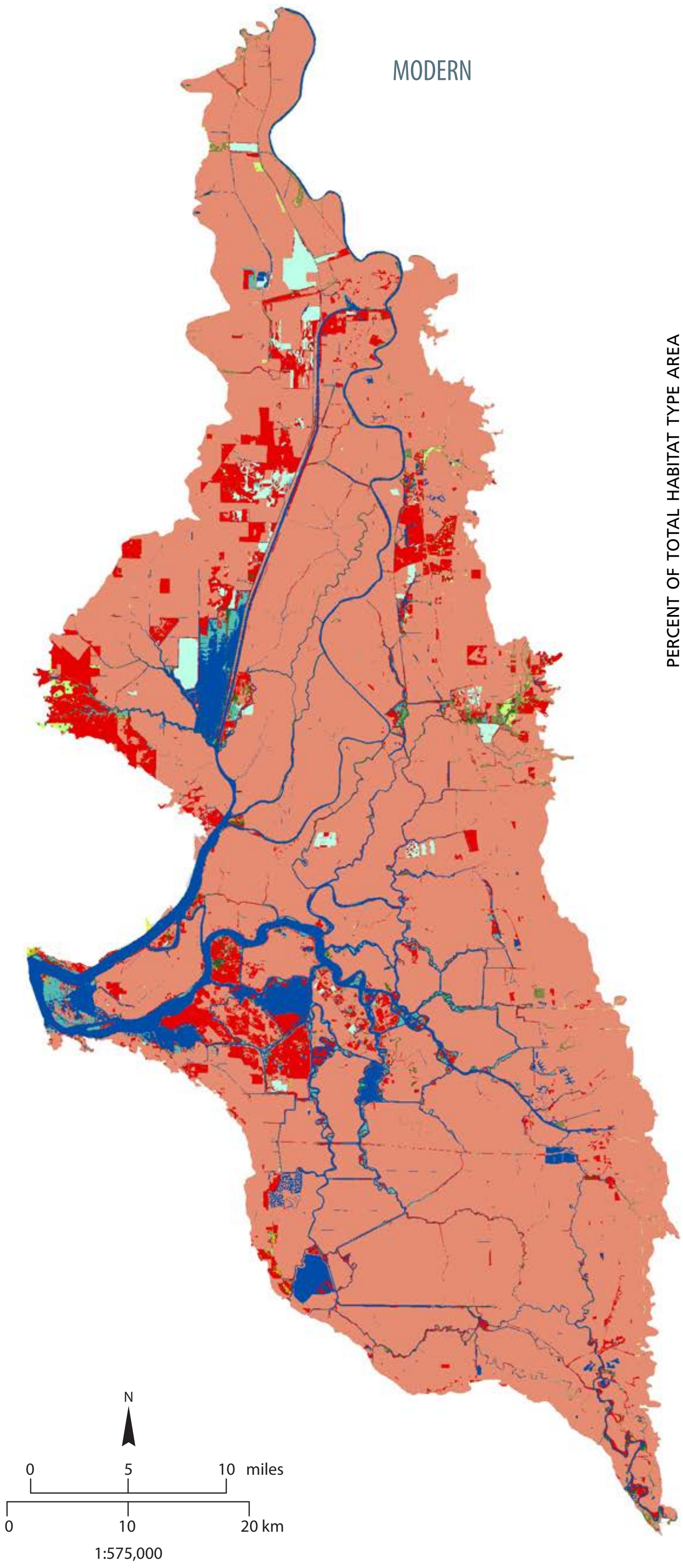
Photo Credits: California Department of Boating and Waterways; Delta Stewardship Council; Dave Giordano, Cal Fish

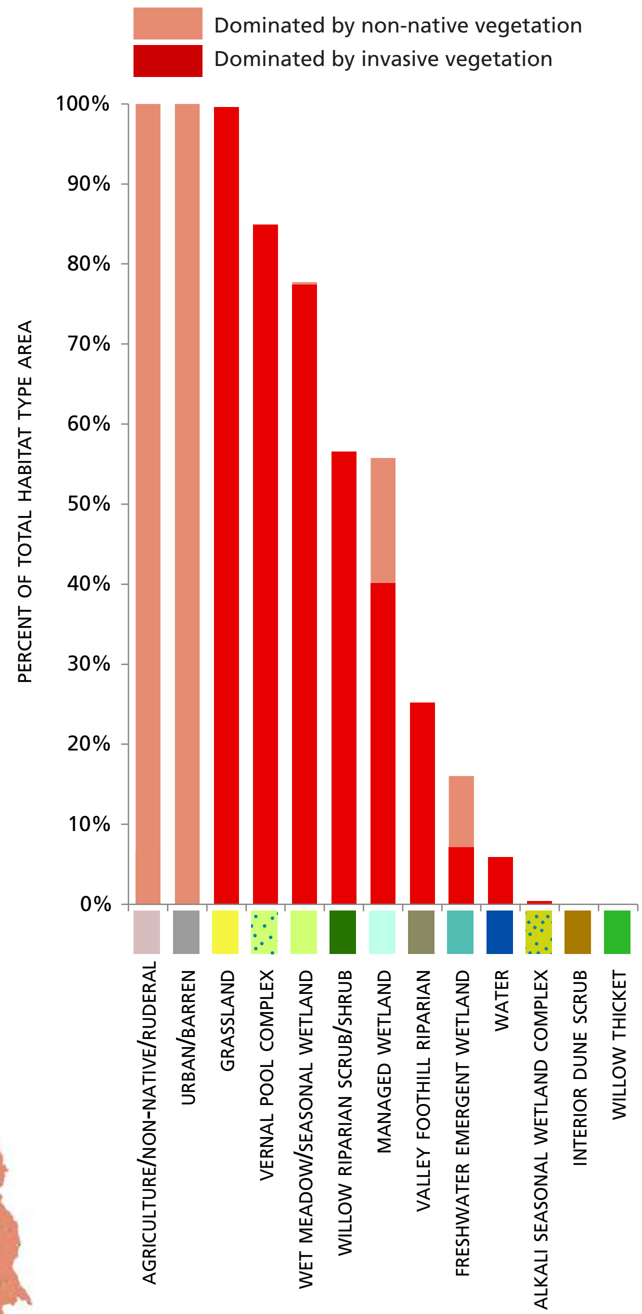
INCREASED PRESSURE ON NATIVE SPECIES

Non-native fish introduced to the Delta for sport, including striped bass (shown left) and bluegill, compete with native species for limited resources. Non-native predators, including feral pets and nuisance species such as house mice and introduced rats, increase predation pressure on native wildlife.

Methods: Areas dominated by non-native and invasive plants

Individual polygons were marked as dominated by non-native/invasive vegetation if their specific alliance/association-level vegetation mapping unit featured a non-native (as defined by CalFlora)[22] or invasive species (as defined by the California Invasive Plant Council).[23] Where these fine scale classifications were not available, the non-native/invasive designation was determined based on group-level mapping units and best professional judgement. Areas with a habitat type of Agriculture/Non-native/Ruderal or Urban/Barren were classified by default as non-native. See pages 106-109 of Appendix A for a list of the mapping units classified as dominated by non-native/invasive vegetation. Invasive submerged aquatic vegetation is included in the mapping, but may be underrepresented depending on the year and season.



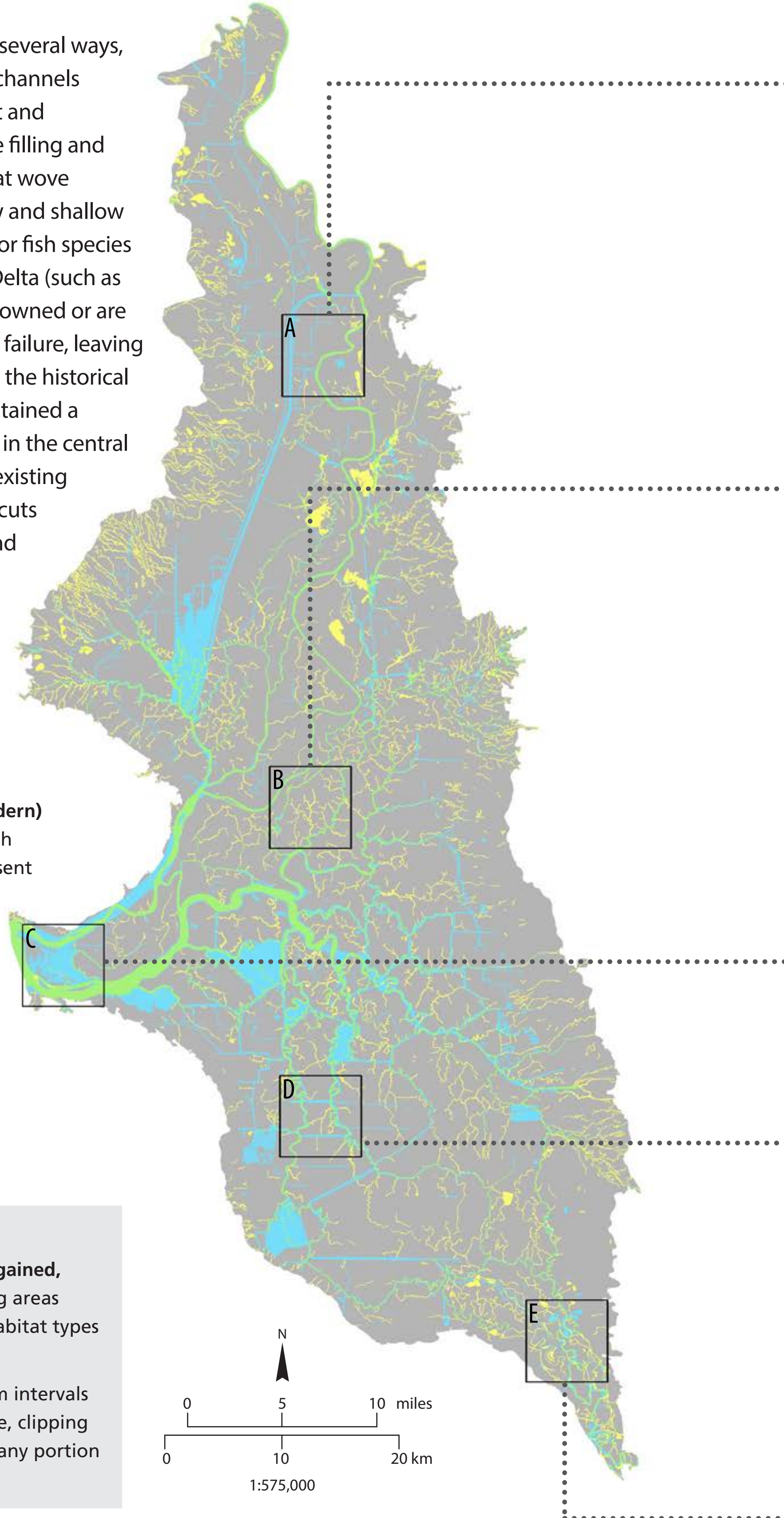


Areas dominated by non-native or invasive plants. The map **(left)** shows areas where non-native (in pink) and invasive (in red) plants are dominant over or co-dominant with native vegetation. The chart **(above)** quantifies the total proportion of each habitat type dominated by non-native/invasive vegetation.

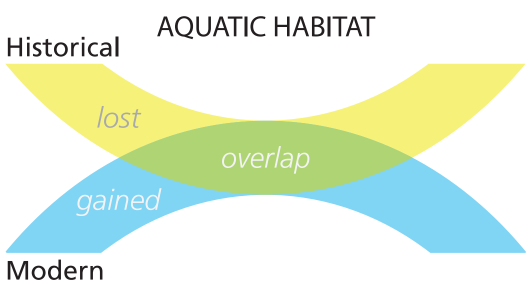
The Delta's channel network and lakes have been fundamentally altered

Some dominant native aquatic habitat types have been nearly eliminated, while other novel types have been created

The aquatic habitats of the Delta have been changed in several ways, all of which are significant to ecological functions. New channels have been dug for shipping, creating new, often straight and leveed waterways (A). Perhaps most severe has been the filling and elimination of the branching dendritic tidal channels that wove through the marshes. These channels were often narrow and shallow with high residence times providing important habitat for fish species (B). Several previously farmed and diked islands in the Delta (such as Sherman Island, Franks Tract, and Liberty Island) have drowned or are in the process of drowning due to subsidence and levee failure, leaving in their wake more open and deep water than existed in the historical Delta (C). While much of the Sacramento River has maintained a consistent width due to its natural levees, many reaches in the central Delta have been widened (A, C). Throughout the Delta, existing channels have been hyper-connected through channel cuts and meander cut-offs (D). This lowers residence times and often increases average velocities, thereby providing less nutrients, shelter, and habitat complexity for aquatic species. Finally, while the San Joaquin River has continued to migrate (more than the Sacramento), off-channel aquatic habitat such as floodplain and oxbow lakes and distributary channels has been filled (E).



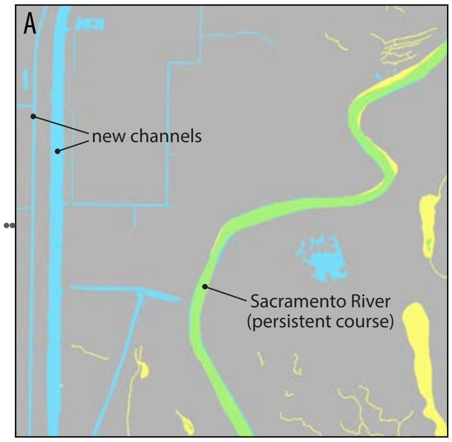
Reconfiguration of the aquatic landscape (historical and modern) (right). Historical aquatic habitats (in yellow) are overlaid with modern aquatic habitats (in blue). Areas where past and present aquatic habitat overlap are displayed as green.



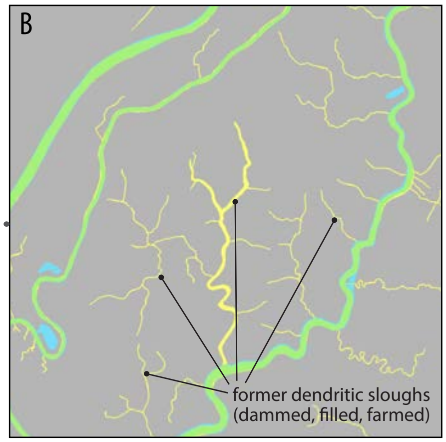
Methods: Changes in channel planform

Determining areas of aquatic habitat that have been **lost, gained, or have not changed (overlap)** was achieved by intersecting areas classified as aquatic habitat in the historical and modern habitat types layers.

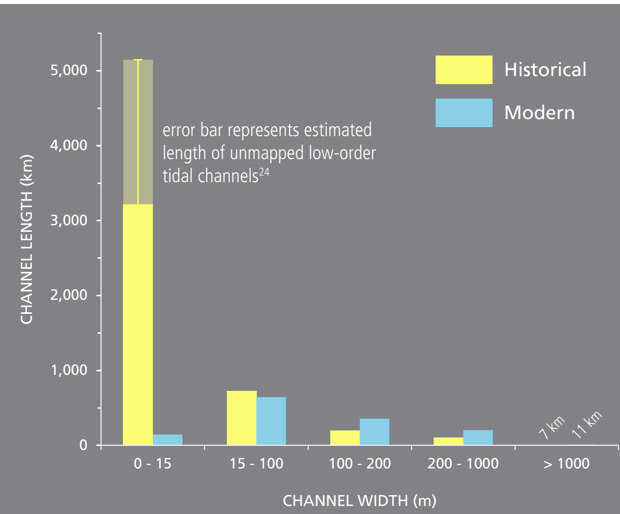
Channel width (top of facing page) was calculated at 100 m intervals by casting transects perpendicular to the channel centerline, clipping the transects to the banks of the channel, and subtracting any portion of the width associated with in channel islands.



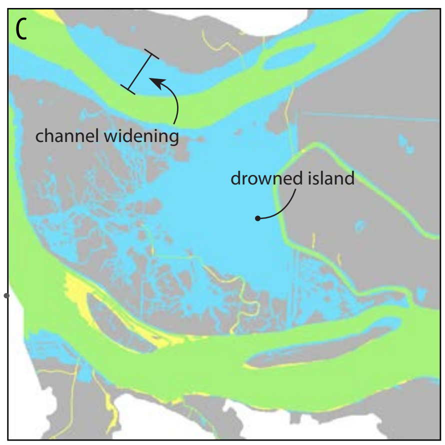
Confined by large natural levees, the course and width of the Sacramento River (here in green) is largely unchanged, but new straight channels have been created (blue).



The smaller, dendritic, dead end sloughs of the Delta (here in yellow) have almost all been diked and filled.

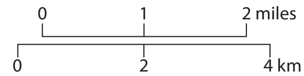


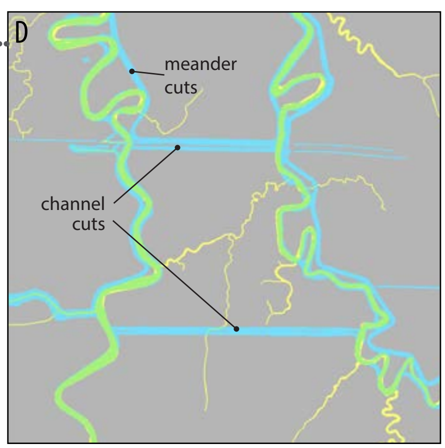
The loss of narrow channels and increase in wide channels (above). The most significant change when comparing channel widths is seen in the lowest width category (0-15 m). The length of narrow channels in the Delta has decreased by two orders of magnitude, effectively eliminating more than 5,000 km of channels. The length of channels in the wider size classes (between 100-1,000 m) has essentially doubled.



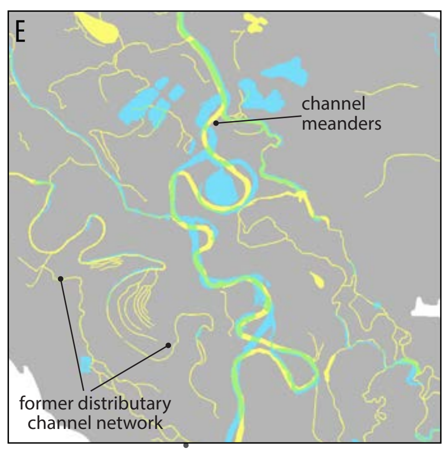
Some channels, like the lower Sacramento, have been substantially widened. Levee breaches flood subsided islands, creating extensive new areas of open water.

Several types of reconfiguration of aquatic habitats (A-E, left and below). Small channels have been diked and filled. Large channels have been straightened, leveed, and artificially connected. Since the geometry of the Delta largely controls the dispersion and trapping of tidal waters,[25] these changes have likely had significant impacts on key physical processes and gradients (e.g., tidal flows, sediment transport and deposition, salinity transport, water residence time, water temperature, terrestrial linkages).





Meander cuts (between bends in a channel) and channel cuts (between separate sloughs) effectively straighten and short-circuit tidal channel networks.

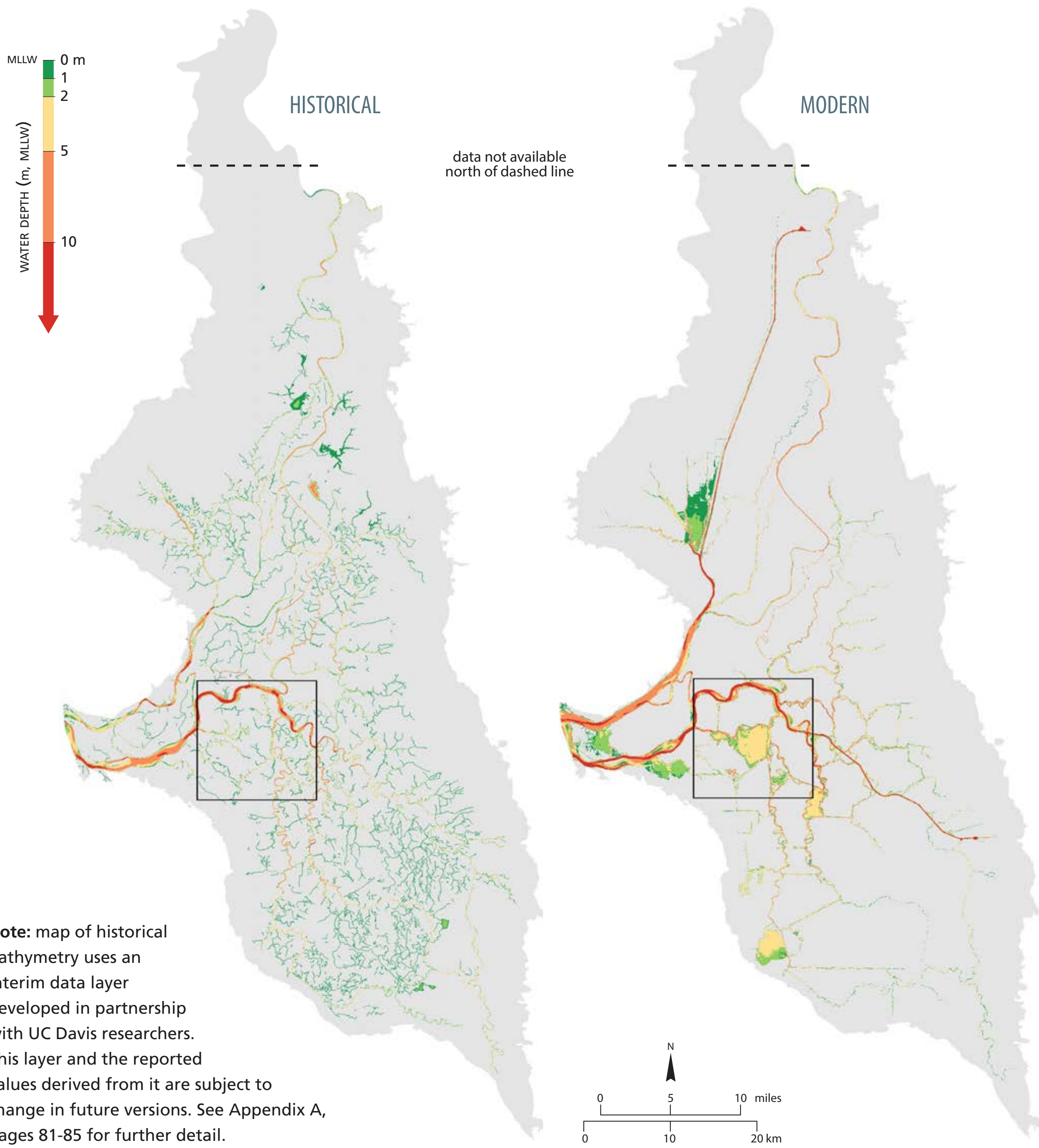


The main course of the San Joaquin has meandered over time. Its smaller floodplain channels have been mostly filled.

There is twice as much tidal shallow-water habitat in the Delta today as there was historically

Shallow dendritic channels and lakes have been exchanged for novel flooded island habitats

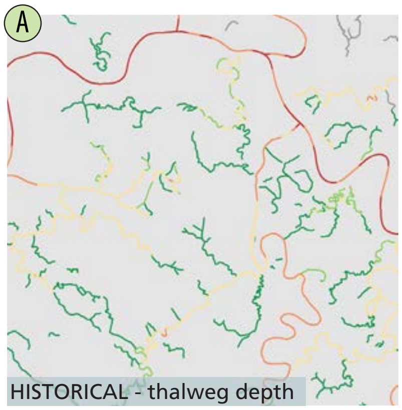
Existing tidal shallow-water habitat types are different than they were historically. The majority of areas <2 m deep today is part of large open water expanses rather than the historical small marsh channels. Shallow channel habitat is now found mainly along the edges of larger channels and flooded islands, adjacent to deep water. In fact, because of the widening of large channels, construction of new channels, and accidental flooding of subsided islands, there is more tidal aquatic habitat today in all depth classes, despite the near total loss of small marsh channel networks.



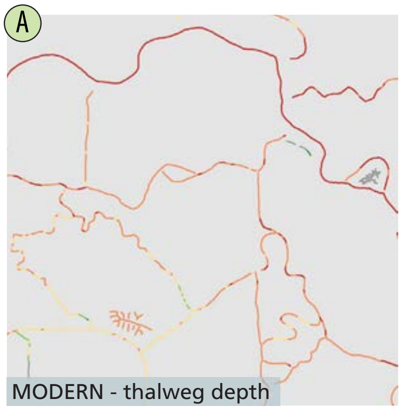
Note: map of historical bathymetry uses an interim data layer developed in partnership with UC Davis researchers. This layer and the reported values derived from it are subject to change in future versions. See Appendix A, pages 81-85 for further detail.

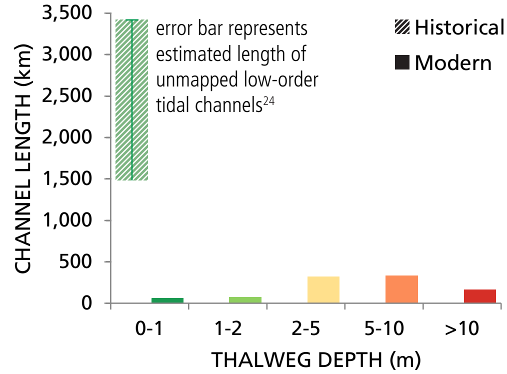
Near elimination of shallow channels; near doubling of deep channels. In the historical Delta, the vast majority of tidal channels (by length) were shallow (0-1 m). Nearly 1,500 km of low order dendritic channels in tidal channel networks likely had high water residence times and low velocities (see green channels below). These channels were almost completely eliminated during reclamation of the marshes. Large channels (the deepest classes: 5-10 m and >10 m) have greatly increased in extent, likely due to dredging and other modifications.

A



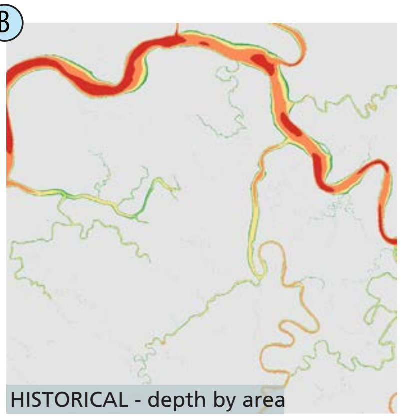
A



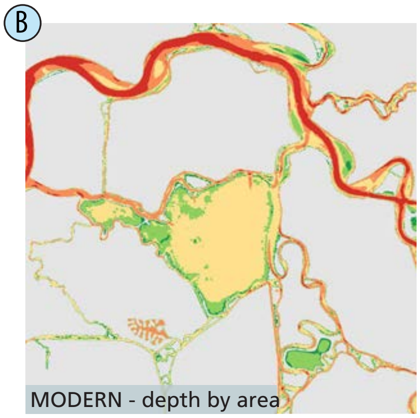


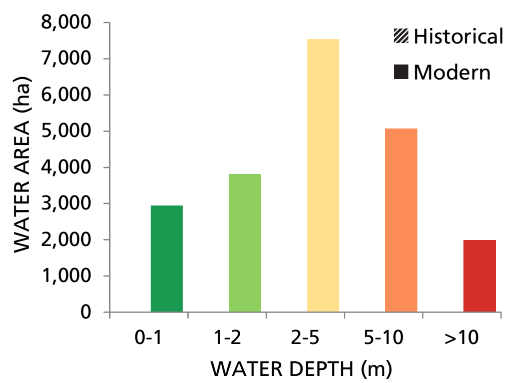
Loss of lakes; creation of novel flooded islands. There has been an overall increase in the area of aquatic habitat and, in particular, shallow water in the modern Delta. Shallow-water habitat is now mainly found in flooded islands, and widened channels. Yet shallow flooded islands are not equivalent to the historical lakes, with different hydrologic patterns, they have been largely overtaken by invasive submerged aquatic vegetation and invasive species. The shallow water on the edges of large, deep channels in the modern Delta may provide refuge for some fish, but these areas also harbor invasive aquatic species and likely do not provide the same benefits to fish as small, dendritic channels.

B



B

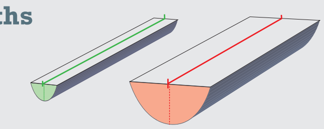




Methods: Two ways to summarize extent of aquatic habitats of different depths

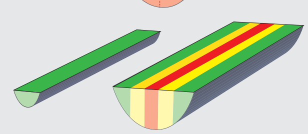
A **By length:** we summed the linear extent of channels based on their thalweg depth (taken at ~100 m intervals). The thalweg is the deepest part of the channel. For all analyses on this page, depth was measured from an approximate mean lower-low water (MLLW) elevation.[26]

A



B **By area:** We summed the areal extent of aquatic habitat at each depth class (water column depth).

B



4. Life-History Support for Resident and Migratory Fish

Aquatic habitats in the historical Delta were complex and dynamic, providing many resources and opportunities for native fish. The rivers and sloughs that wove through the Delta displayed wide variation in width, depth, and sinuosity, creating heterogeneity in local hydraulics, residence time, and water chemistry. These characteristics provided diverse food resources and refuge for fish populations.[1] Historically, large channels flanked by riparian forest or marshes served as migration corridors for fish and provided resting places and refuge in undercut banks, deep pools, and inner bends.[2] Off-channel ponds and lakes were characterized by extensive shallow, slow-moving waters, which facilitated primary and secondary production for rearing populations.[3] Dendritic tidal channels that terminated in the marsh were backwaters with high residence times, and were characterized by temperature gradients beneficial for juvenile fish.[4] Delta channels were hydrologically connected to floodplains and marshes, and expanded in times of high water. Seasonally inundated floodplains offered a rich source of food and habitat for rearing and spawning.[5] Tidal flooding allowed fish access to the vegetated marsh and facilitated exchange of nutrients and organic matter between wetlands and open water habitats.[6] While the position of the large tidal channels, natural levees, and lakes in the Delta remained relatively unchanged from year to year, the seasonal and interannual variability in hydrology and weather created a complex and ever-changing portfolio of aquatic habitat available to fish through time.[7]

Historically the Delta supported an abundant and diverse fish community that included several species of anadromous fish and numerous endemic species, including two locally endemic species of smelt. The fish community included both freshwater stenohaline (narrow salinity tolerance) and euryhaline (broad salinity tolerance) species.[8] Fish confined to freshwater included hardhead, hitch, roach, Sacramento pikeminnow, and Sacramento sucker. These species also inhabited the tributaries that fed into the Delta.[9] Freshwater euryhaline species, associated primarily with freshwater but more tolerant of brackish conditions, included tule perch, Sacramento splittail, and both the longfin and delta smelt.[10] These species were found in Suisun Bay as well as the Delta. Euryhaline marine species such as staghorn sculpin and starry flounder were commonly associated with higher salinities but were able to tolerate freshwater conditions in the Delta.[11] Large numbers of anadromous fish passed through the Delta historically, taking advantage of the productive and protected Delta environment while migrating from freshwater to the ocean and back. These species included the Pacific and river lamprey, green and white sturgeon, Chinook salmon, and steelhead.[12] Chinook salmon were particularly abundant in the Delta, with four distinct runs and an estimated overall population of 1-2 million spawners per

year.[13] Many of the fish species that occupied the Delta were adapted to slower moving shallow waters and floodplains (habitats that have been largely eliminated in the modern Delta); these include the Sacramento perch (extirpated), thicktail chub (extinct), hitch, Sacramento blackfish, and Sacramento splittail.[14] Freshwater conditions predominated throughout the Delta, though high tides late in the season and during times of drought occasionally brought brackish water to the Delta mouth.[15]

Interpreting how the historical Delta supported fish is challenging because the current understanding of their natural history and ecology is based on their use of a heavily altered modern landscape. This difficulty is compounded by the dynamic nature of these aquatic habitats, which experienced tremendous temporal variability in the past. However, we can take a landscape-scale approach to understanding how the Delta historically supported fish and other aquatic wildlife. Within aquatic systems, as in terrestrial systems, different areas provide different habitat qualities, and boundaries between those areas affect the connectivity between them. These interactions take place at multiple scales.[16] Using this landscape-scale approach several aspects of the historical Delta stand out as particularly important for fish: (1) habitat heterogeneity, (2) presence of high-productivity habitats, and (3) connectivity among habitats.

Aquatic habitats were heterogeneous at multiple scales, providing support to wildlife at the individual, species, and community levels. Small-scale heterogeneity allowed individuals to escape unsuitable conditions. For example, channels, swales and microtopography on floodplains reduced stranding risk for rearing Chinook and splittail, while pockets of slow moving water, such as along inner undercut banks and submerged trees, allowed tule perch to occupy otherwise fast-flowing channels.[17] Large-scale heterogeneity allowed species to occupy different niches, preferentially occupying different positions along salinity, temperature, and turbidity gradients. While species such as thicktail chub may have been specifically adapted to slow-moving backwaters and lakes, species such as Sacramento splittail were able to take advantage of floodplain habitats, using these areas to spawn.[18] The heterogeneity of aquatic habitats allowed some species to develop multiple life-history strategies, each likely to be favored in different years and under different conditions. Chinook salmon, for example, exhibited a wide range of variability in the timing and location of spawning and rearing. This diversity in life-history strategies likely stabilized the population via portfolio effects, increasing resilience because different segments of the population were less likely to experience declines at the same time.[19]

Resident and migratory fish (below). Left to right: Sacramento splittail; Chinook salmon; Chinook salmon; tule perch.

Photo Credits: Unknown, USFWS; Dan Cox, USFWS; Blaine Bellerud, NOAA; Unknown, UC Davis

The Delta had several types of high-productivity habitats that supported the base of the food web. Within the water column, shallow water depths and high residence times likely supported high densities of phytoplankton.[20] Dendritic channels that terminated in the marsh and other backwater areas may have been particularly important in this regard.[21] Within open water habitats such as lakes, submerged and floating aquatic vegetation supported high densities of invertebrates that were important food sources for fish.[22] Periodically inundated marshes and floodplains contributed organic matter to fuel the food web. In the modern San Francisco Bay Delta Estuary, fish food webs are dependent upon autochthonous marsh materials,[23] and this dependence was likely even greater historically when more marsh habitat was available.[24] Delta fish likely varied their diet seasonally to take advantage of shifts in prey availability, while maintaining minimal dietary overlap among species, as has been observed in native fish in the modern Delta.[25] This ability to take advantage of diverse and dynamic food resources would have been beneficial to the fish community in the historical Delta.

Wetlands, including floodplains, were connected to aquatic habitats by regular, unimpeded flooding from tides, precipitation, and snowmelt. Water moved slowly through vegetated landscapes, allowing exchange between the channels and wetlands to occur and providing variation in water depths and velocities.[26] The pattern of wetland flooding, with pulses of inundation and slower recession, allowed fish to take advantage of these habitats while still being able to pass back into the river channels once floodplains began to dry. Floodplains were inundated for both short and long durations, providing temporally variable benefits to fish.[27] Connections to off-channel habitats affected water chemistry within the channels themselves.[28] Organic matter contributed by marshes would have increased turbidity.[29] Exchange of primary productivity and export of invertebrates would have affected the food web.[30] Riparian trees and shrubs contributed woody debris that altered flows, channel dynamics, and sedimentation processes, particularly in the south Delta.[31]

Floodplains were critical for fish migration, spawning, and rearing. Floodplains served as important rearing habitat for several species of resident and migratory fish.[32] Floodplain habitats provided fish with refuge from predation as well as from energetic demands and physiological stressors. These habitats had high turbidity and increased the extent of shallow-water habitat where certain species could hide.[33] The increased foraging space provided by floodplains may have reduced competition and the likelihood of encountering certain predators.[34] Native fish may have been vulnerable to predation by abundant birds, but this additional risk was likely offset by for increased growth on the floodplain and reduced predation risk later in the ocean.[35] Estuarine rearing in marshes and floodplains is important to Chinook salmon because it can reduce size-dependent mortality upon ocean entry by increasing the variation in the size and timing at which individuals reach the ocean.[36]

In the modern Delta, aquatic habitats are characterized by wider, deeper, straighter channels that are leveed off from adjacent habitats. There is now much less seasonal and spatial variation in hydrology and habitat. Connectivity between large channels has increased through connecting canals, meander cutoffs, cross-levees, and dredged and widened channels. This has homogenized conditions (e.g., salinity, temperature, nutrients, and flows) and altered tidal and flood routing through the Delta. The modern channel network no longer predictably leads to fluvial sources or dendritic channels, making the Delta a much less coherent landscape for native fish to navigate.[37] Channel systems with coherent gradients allowed fish in the historical Delta to position themselves where conditions were most suitable, despite the dynamic nature of these conditions. Delta smelt, for example, track the low salinity zone as it moves upstream and downstream seasonally. These fish use vertical migration and other behavioral adaptations to stay in favorable areas.[38] Native fish key in on changes in flow, water temperature, and turbidity to cue their movement.[39] Furthermore, where once fish could predictably travel a short distance between one habitat (e.g., a large fluvial channel with high velocities and low residence time) and another quite different one (e.g., a small marsh channel with low velocities and high residence time), now these distances are much greater, and the path to get from one habitat to another is much less predictable.[40]

Most of the slow-water habitat, highly productive floodplains, and marsh-influenced habitats in which Delta fish species evolved are lost. The loss of wetlands, development of artificial levees, and the increase in the size and connectedness of channels has increased the speed at which water moves through the Delta. Most of the channels in the Delta today are lined by steep artificial levees that isolate the channels from adjacent habitats, and much of the habitat that was once marsh has been converted to agriculture. Flooding occurs, though in very limited areas, and is predominantly short-duration. Between 1935 and 1995, for instance, the frequency with which the Yolo Bypass experienced at least seven days of overflow in the spring decreased from ~80% of years to ~20% of years.[41] While remnants of several lakes persist, today most of the large areas of open water in the Delta are drowned islands. These deep water habitats, primarily in the central Delta, did not have functional equivalents in the historical Delta.[42]

The modern Delta is characterized by a suite of threats not faced by Delta fish communities historically. Highly managed hydrology, including diversions and pumps, alters directional flows often entraining fish.[43] Agricultural runoff and water discharges impact water quality.[44] In addition, introduced invasive species have restructured food webs, altered habitats, and directly outcompete native fish. The invasive *Corbicula* clam has dramatically reduced planktonic food resources available to fish.[45] Invasive submerged aquatic vegetation (SAV) species, such as Brazilian waterweed and water hyacinth, provide different structure and reach higher densities than native SAV species, and thus are not functionally equivalent.[46] Invasive SAV species provide habitat for non-native predatory fish and support invertebrates that are less favored in the diets of native fish species.[47]

The Delta fish community is now dominated by non-native species including sunfish, bass, catfish, and common carp.[48] Native species are generally associated with higher river flows and lower temperatures, although a few non-natives, including striped bass, white catfish, channel catfish, and American shad are also associated with high flows.[49] While floodplain inundation is critical for native fish migration, breeding, and rearing, floodplains are currently heavily used by non-native species.[50] However, native fish, adapted to the Delta's flood cycle, have been found to spawn and leave the Cosumnes floodplain earlier than non-native fish (thus avoiding stranding), and may be able to quickly take advantage of newly flooded habitats.[51] Food limitation in the modern Delta likely intensifies competition with non-native fish, as well as non-native predation on natives.[52]

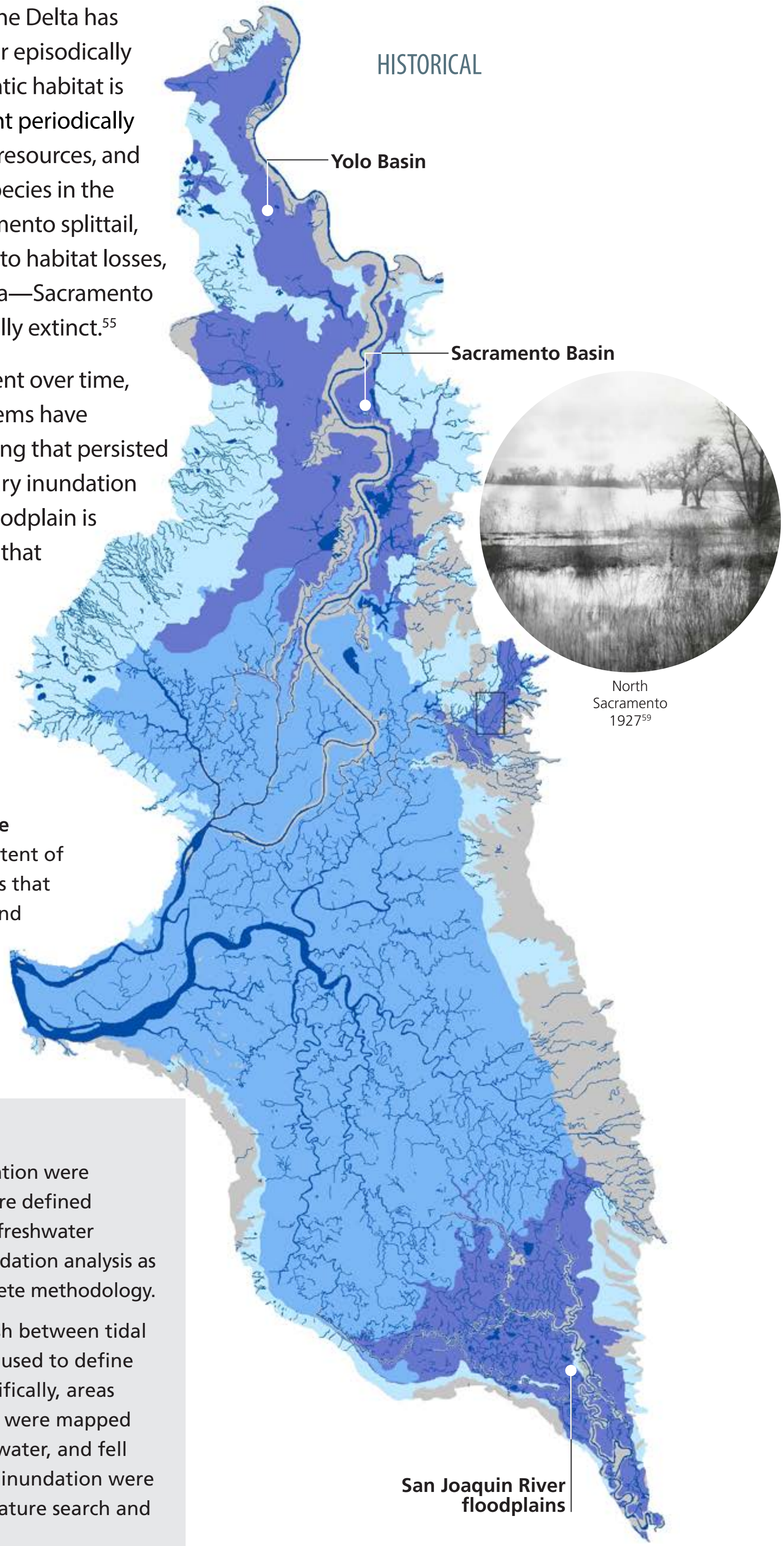
The future of threatened fish species is uncertain and threats and stressors may continue to worsen. Restoration of habitat for native fish is difficult. Competing water interests make it challenging to re-establish historical flows that favor native fish, and improvements to water quality and habitat will likely favor non-native fish to some degree. Marsh and floodplain restoration have the potential to preferentially help native fish, though restoration would need to be implemented on a large scale to increase the likelihood of success due to the large variability in fish response to restoration activities.[53]

Fish likely benefited from dynamically inundated landscapes

Most of the temporarily flooded habitat available to fish has been lost in the modern Delta

By comparing the past and present, it is apparent that the Delta has shifted from a mosaic of subtidal, tidal, and seasonally or episodically flooded habitats to a landscape where most of the aquatic habitat is permanently subtidal. Historically, fish utilized abundant periodically available habitat for spawning, rearing, additional food resources, and refuge from predators. Specific floodplain-associated species in the Delta included Sacramento perch, thicktail chub, Sacramento splittail, and juvenile Chinook salmon.[54] Today, likely in part due to habitat losses, two of these species can no longer be found in the Delta—Sacramento perch are locally extirpated and thicktail chub are globally extinct.[55]

Although all types of inundation have decreased in extent over time, altered flow regimes, artificial levees, and drainage systems have effectively eliminated the seasonal long-duration flooding that persisted for months at a time in the historical Delta. Contemporary inundation associated with the Yolo Bypass and Cosumnes River floodplain is more akin to the shallow, seasonal short-term flooding that was common to the seasonal wetlands of the historical Delta.[56] This has important consequences for species like Sacramento splittail whose life-history strategies require longer periods of sustained inundation (and potentially enables alternate rearing strategies for juvenile salmon).[57]



North Sacramento 1927[59]

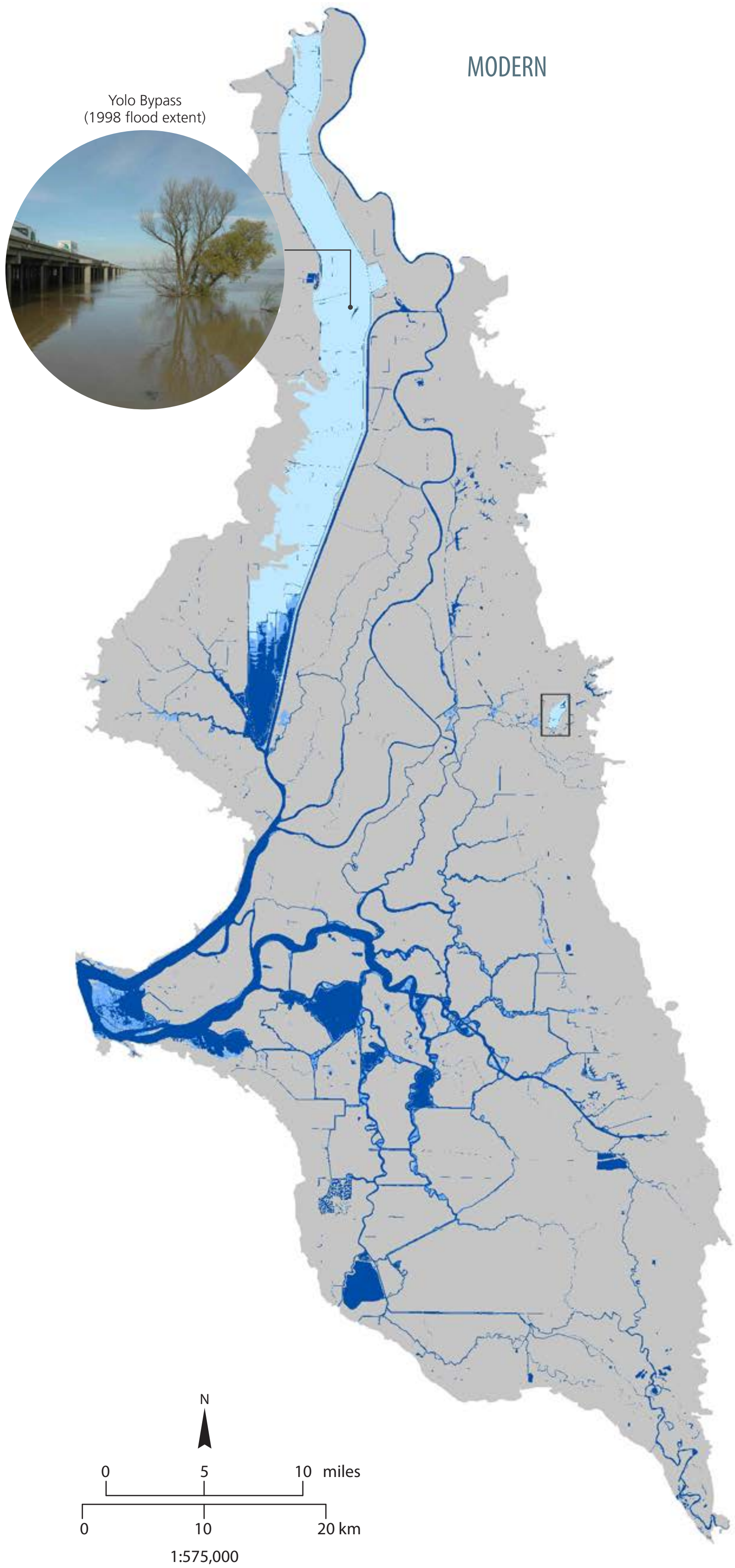
Approximate maximum extent and type of inundation in the historical (right) and modern (far right) Delta. While the extent of perennial open water features has increased over time, areas that experience tidal inundation, seasonal short-term flooding, and seasonal long-duration flooding (defined at far right) have all decreased in extent (by 144,000, 40,000, and 59,000 ha, respectively).

Photo Credits: McCurry, courtesy of California History Room, California State Library, Sacramento; Yolodave, Wikipedia Commons

Methods: Type and extent of flooding

For the historical Delta, areas regularly subjected to inundation were derived from the map of historical habitat types, which were defined in part, by their typical hydrology.[58] Areas mapped as tidal freshwater emergent wetland, for instance, were classified in the inundation analysis as areas of "tidal inundation." See Appendix A for our complete methodology.

Since the modern habitat type dataset does not distinguish between tidal and non-tidal freshwater emergent wetland, a proxy was used to define the areas that currently experience tidal inundation. Specifically, areas were assigned the "tidal inundation" classification if they were mapped as freshwater emergent wetland, were adjacent to open water, and fell within the historical extent of tidal marsh. Other areas of inundation were identified, mapped, and classified after conducting a literature search and consulting with regional experts.



SEASONAL SHORT-TERM FLOODING

Short-term fluvial inundation

- intermediate recurrence (~10 events per year)
- low duration (days to weeks per event)
- generally shallower than seasonal long-duration flooding

SEASONAL LONG-DURATION FLOODING

Prolonged inundation from river overflow into flood basins

- low recurrence (~1 event per year)
- high duration (persists up to 6 months)
- generally deeper than seasonal short-term flooding

TIDAL INUNDATION

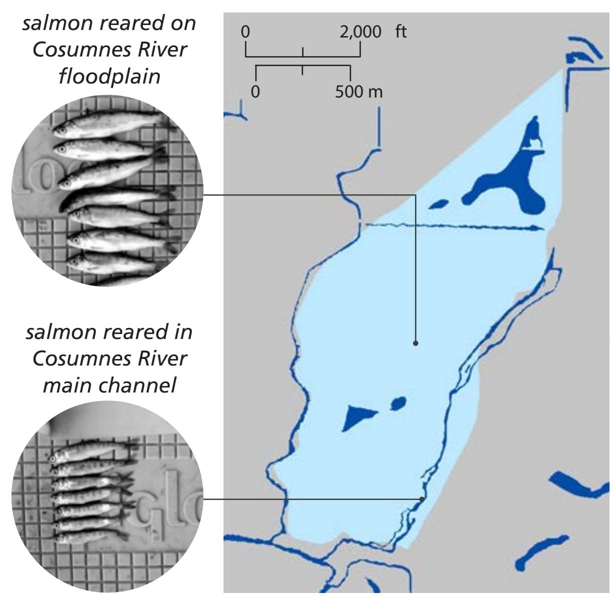
Diurnal overflow of tidal sloughs into marshes

- high recurrence (twice daily)
- low duration (<6 hrs per event)
- low depth ("wetted" up to 0.5 m)

PONDS, LAKES, CHANNELS, & FLOODED ISLANDS

Perennial open water features (with the exception of historical intermittent ponds and streams)

- recurrence not applicable (generally perennial features)
- high duration (generally perennial features)
- variable depth



Floodplains support rearing salmon. Juvenile Chinook reared in seasonal floodplain habitats of the Cosumnes River have been found to grow significantly larger than those reared only within the river's main channel.[60] Although seasonally flooded habitat once totalled more than 117,000 ha in the Delta,[61] it is now largely restricted to parts of the Yolo Bypass and Cosumnes River floodplain and totals less than 19,000 ha (a decrease of approximately 85%).

Images of juvenile salmon courtesy Springer Science+Business Media, originally published in Jeffres et al. (2008).

Dramatic loss of seasonally flooded habitats

Native fish are adapted to a complex, variable landscape with extensive aquatic resources throughout the year

The historical Delta exhibited dramatic seasonal variation in flooding (right, top). Seasonal basin flooding in the north Delta, driven by lower-elevation, rain-fed Coast Range streams, tended to occur between December and April. In contrast, elevated flows and flooding in the south Delta were driven by snowmelt, generally began in April, and continued into the summer. This seasonal variation in flooding is reflected in the life histories of the native fish species that evolved here (see bottom of this page and the chart on page 42). Today, a decrease in the extent of inundation across the Delta has been accompanied by a decrease in the spatial-temporal variability of inundation (right).

SEASONAL SHORT-TERM FLOODING

Short-term fluvial inundation

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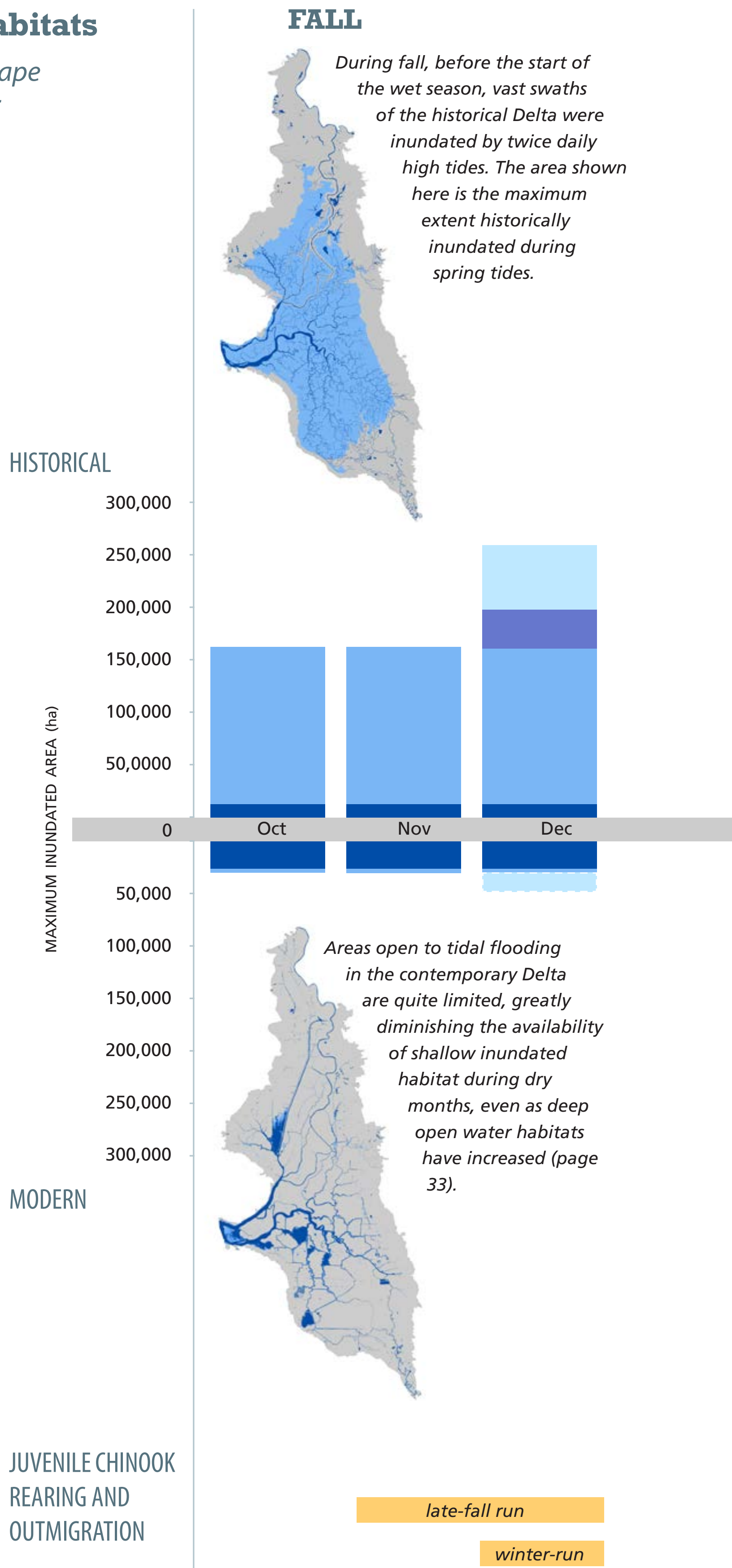
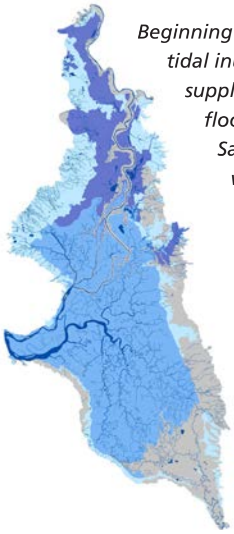
- variable depth



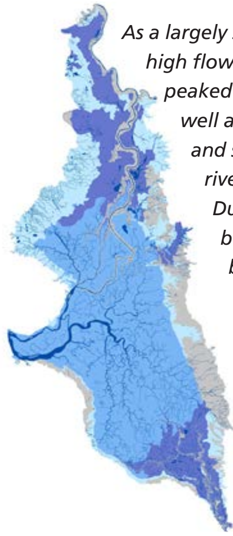
Temporal distribution of juvenile Chinook rearing and outmigration (right). The colored bars depict the periods of juvenile rearing and outmigration for each of the four runs of Central Valley Chinook salmon (named for when adults migrate into freshwater; also see page 42). The distinct salmon populations display diverse life-history characteristics that reflect the temporal variability in available habitat across a year **(above)**.[62]

WINTER



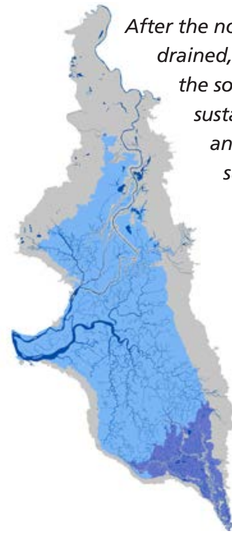
Beginning in the winter, tidal inundation was supplemented with flooding from the Sacramento River, which frequently passed much of its flow into the Sacramento and Yolo Basins. Cache and Putah creeks and also contributed floodwaters.

SPRING

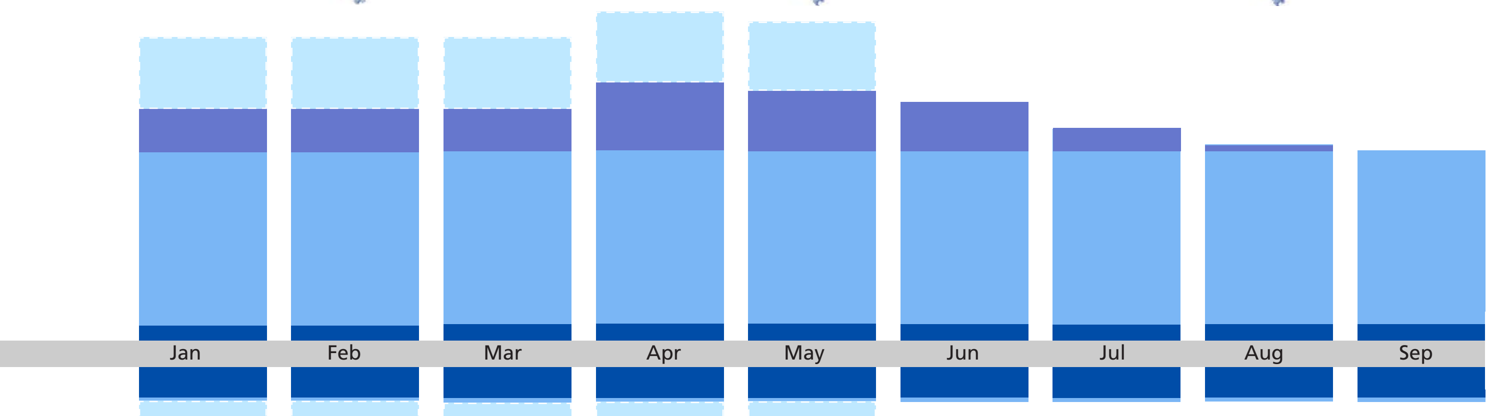


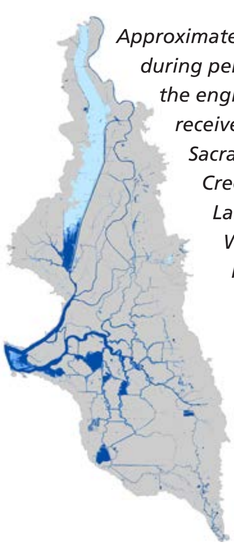
As a largely snowmelt-fed river, high flows on the San Joaquin peaked during the spring, well after winter storms, and spread across the river's floodplain. During wet years, both the north Delta basins and south Delta floodplains would have been inundated during mid-spring, creating a maximum flood extent.

SUMMER

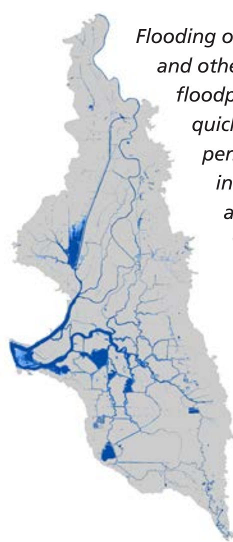


After the north Delta basins drained, inundation in the south Delta was sustained by snowmelt and persisted into the summer, extending the availability of floodplain resources.

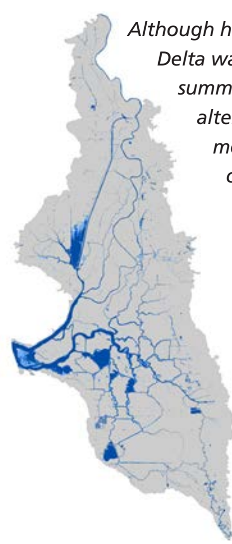




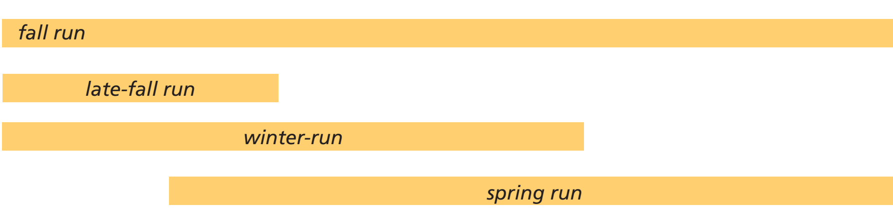
Approximately every three years, during periods of high flow, the engineered Yolo Bypass receives water from the Sacramento River, Cache Creek, the Knight's Landing Ridge Cut, Willow Slough, and Putah Creek. The floodway is designed to divert this water away from major cities and to quickly deliver it downstream to the Cache Slough Complex.



Flooding on the Yolo Bypass and other modern Delta floodplains drains quickly and does not persist for as long into the spring and summer as was common historically.



Although historically the South Delta was wettest during early summer, 160 years of flow alterations and channel modifications have changed the timing and magnitude of inundation events in the region. Aquatic habitat in the late spring and summer is now generally limited to small areas of tidal inundation and extensive areas of perennial open water habitats.



Simple life-history periodicities of BDCP Species of Special Concern (below). Habitat needs vary across fish life-history stages and, therefore, across time. Over the course of a single year, the historical Delta exhibited a great deal of spatial-temporal variability in physical processes/gradients and habitat availability. This variability is reflected in the temporal distributions of fish species that utilize the Delta during one or more phases of their lives. The table reflects modern use of the Delta by fish—it is possible that the historical temporal distributions differed. Migrating adult spring-run Chinook, for example, ascended the San Joaquin River well into the late summer—a pattern that is tied to the availability of snowmelt runoff and sufficient flows from the south Delta to upstream tributaries.[63] There may also once have been (now extinct) summer runs of Chinook and steelhead that migrated in July and August.[64] The table does not include life-history stages that occur predominantly outside of the Delta (like salmonid spawning, which occurs upstream).

■ Life-history stage present in Delta

		Month											
Species	**Life-history stage**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**
Chinook salmon[65]	Fall run adult migration	■	■	■								■	■
	Fall run juvenile rearing and migration				■	■	■	■	■	■			
	Late-fall run adult migration		■	■	■								
	Late-fall run juvenile rearing and migration		■	■	■	■							
	Winter run adult migration				■	■	■	■	■				
	Winter run juvenile rearing and migration			■	■	■	■	■					
	Spring run adult migration						■	■	■				
	Spring run juvenile rearing and migration					■	■	■	■	■			
Steelhead[66]	Adult migration	■	■	■	■	■	■	■	■		■	■	■
	Rearing		■	■	■	■	■	■	■				
	Juvenile emigration			■	■	■	■	■	■	■			
Sacramento splittail[67]	Adult upstream migration towards spawning areas		■	■	■	■	■	■					
	Floodplain/river spawning					■	■	■					
	Eggs/embryo and larvae (floodplain/channel margin)					■	■	■	■				
	Juvenile floodplain use					■	■	■	■	■			
	Juvenile downstream migration						■	■	■	■			
Green sturgeon[68]	Juveniles (Delta/Bay)	■	■	■	■	■	■	■	■	■	■	■	■
	Spawning migration (Bay/Delta)					■	■	■	■	■	■		
	Post-spawn adults (River/Delta)	■	■	■	■				■	■	■	■	■
	Mature adults (Ocean/Delta)	■	■	■	■	■	■	■	■	■	■		
White sturgeon[69]	Juveniles	■	■	■	■	■	■	■	■	■	■	■	■
	Spawning migration		■	■	■	■	■	■	■				
Pacific lamprey[70]	Adult migration		■	■	■	■	■						
	Ammocoetes (larval lamprey)	■	■	■	■	■	■	■	■	■	■	■	■
	Metamorphosis to juveniles							■	■	■	■	■	
	Juvenile outmigration	■	■	■	■							■	■
River lamprey[71]	Adult upmigration	■	■										■
	Juvenile outmigration (congregation in Delta)								■	■	■		
Delta smelt[72]	Egg/embryo (sandy-gravel channel edge)					■	■	■	■	■			
	Yolk-sac/First-feeding larvae (offshore tidal freswater)					■	■	■	■	■			
	Fin-fold larvae (offshore tidal freswater)						■	■	■	■	■		
	Metamorphosing larvae (offshore tidal freshwater & LSZ)							■	■	■	■		
	Juveniles (offshore tidal freshwater & LSZ)	■	■	■					■	■	■	■	■
	Migrating adults (offshore tidal freshwater)			■	■	■	■	■					
	Spawning (tidal freshwater)					■	■	■	■	■			
Longfin smelt[73]	Spawning		■	■	■	■	■						
	Eggs			■	■	■	■	■					
	Larvae				■	■	■	■	■	■			
	Juveniles (primarily in San Francisco and Suisun bays)	■	■	■	■	■	■	■	■	■	■	■	■

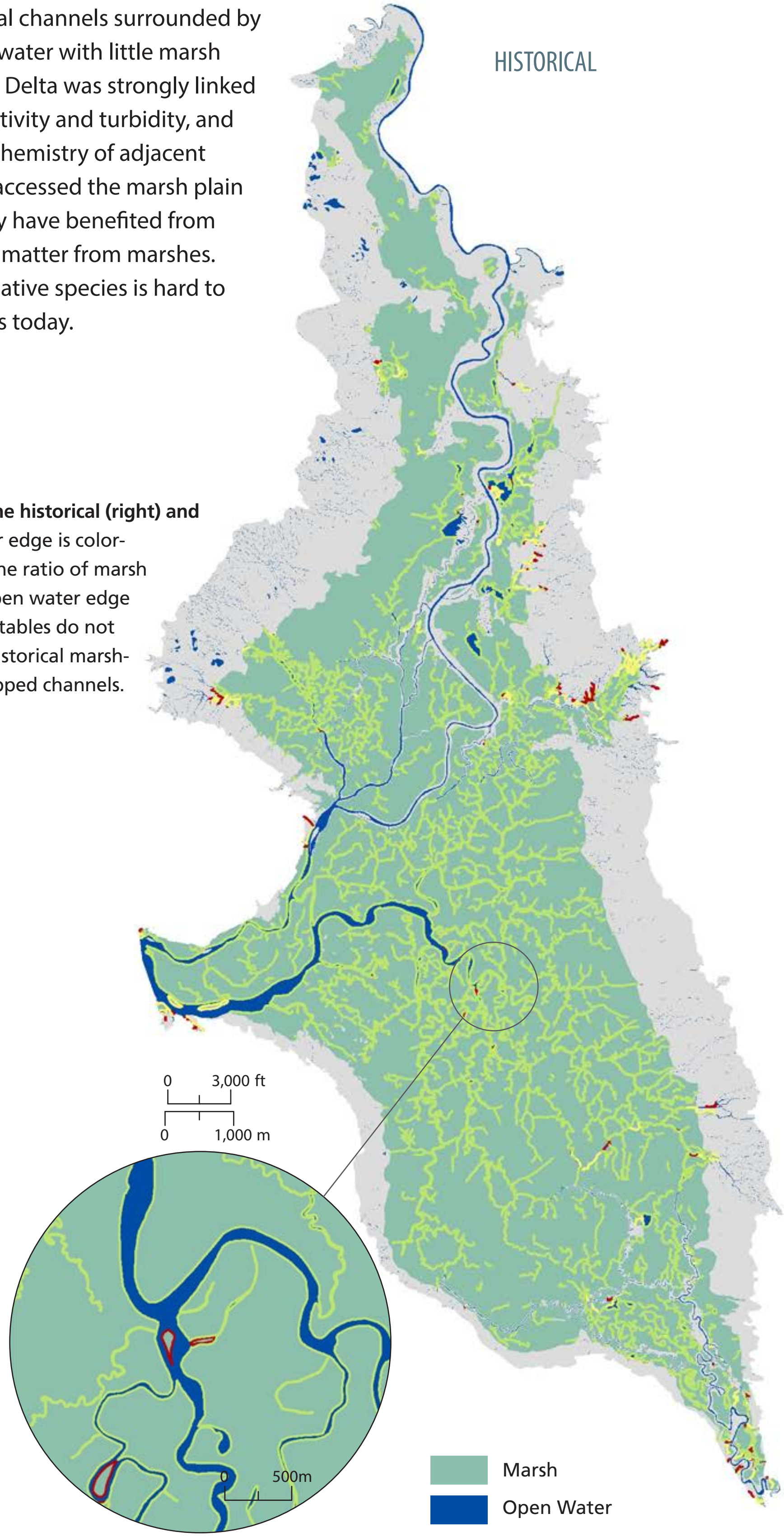
Chinook salmon in the lower American River **(top)** and at a fish hatchery **(bottom)**.

Photo Credits: Dan Cox, USFWS; Steve Martarano, USFWS

Marshes directly influenced the character and quality of aquatic habitats

There has been a 73-fold reversal in the ratio of marsh to open water area in the Delta

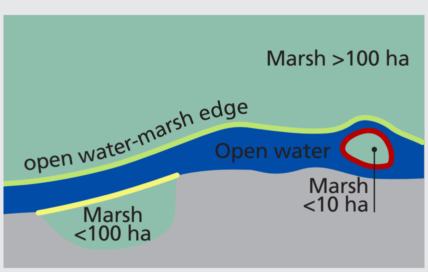
The Delta has shifted from a system of tidal channels surrounded by marsh to one dominated by leveed open water with little marsh influence. Aquatic habitat in the historical Delta was strongly linked to wetlands, which contributed to productivity and turbidity, and influenced the hydrology, structure, and chemistry of adjacent aquatic habitats. Some fish species likely accessed the marsh plain and marsh edge directly, while others may have benefited from the export of nutrients, food, and organic matter from marshes. The extent to which marshes benefitted native species is hard to determine because so little marsh remains today.

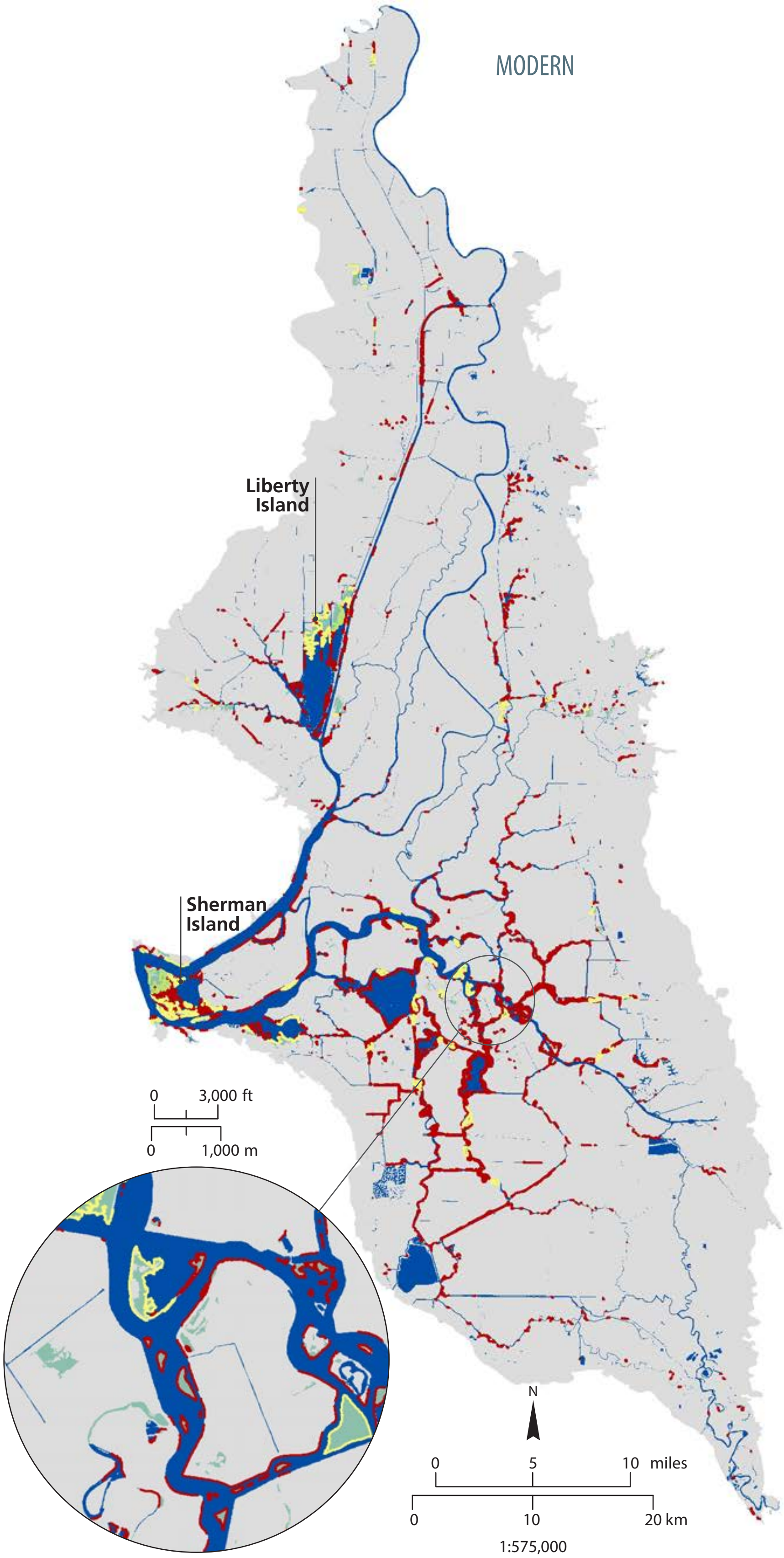


Marsh and open water habitat adjacencies in the historical (right) and modern (far right) Delta. The marsh-open water edge is color-coded by the size of the adjacent marsh. Both the ratio of marsh to open water and the total length of marsh-open water edge have decreased dramatically. These figures and tables do not include an estimated additional ~3,800 km of historical marsh-water edge associated with the smallest, unmapped channels.

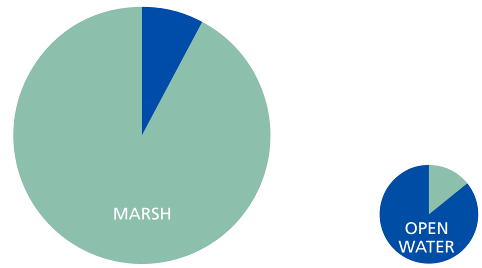
Methods: Marsh to open water ratio and edge

For the analyses on this page, we isolated all areas mapped as open water and marsh, regardless of their tidal status, connectivity, or form. Since habitat type maps represent average dry-season conditions, seasonally and tidally inundated areas are not included within the area mapped as open water. Linear areas where the two habitat types were mapped as adjacent to one another are identified as the open water-marsh edge. This edge was then classified by the size of the contiguous area of marsh from which it was drawn.





Habitat type	Total area (ha) Historical	Modern
Marsh	193,224	4,296
Open water	16,344	26,554

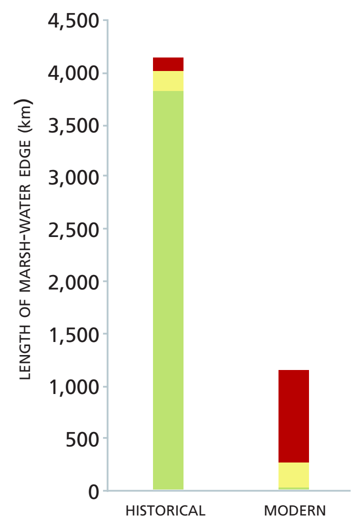


HISTORICAL
100 : 1,182

MODERN
100 : 16

The reversal in marsh to open water area ratio over time (above) is the result of a 98.7% decrease in the area of marsh and a 62.5% increase in the area of open water. Where historically the Delta was characterized by narrow channels embedded within large areas of marsh, today we find tiny marshes embedded within large areas of open water.

Marsh-water edge marsh size class (ha)	Marsh-water edge length (km) Historical	Modern
>100 ha	3,823	31
10 - 100 ha	202	236
0 - 10 ha	112	874
TOTAL	4,137	1,142

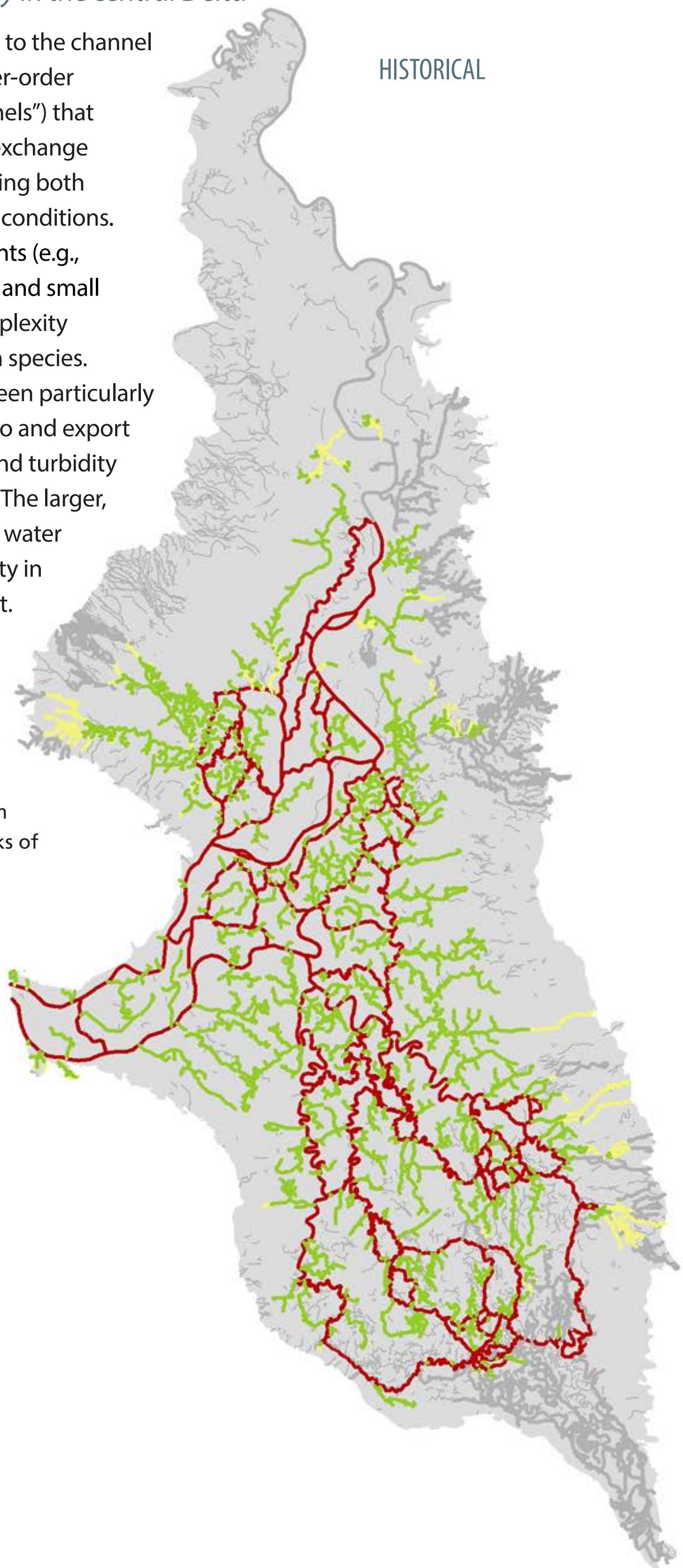


Despite fragmentation (which increases marsh edge length), the length of marsh-water edge has decreased by more than 72%. Historically there was over 3500 km of interface between open water and large (>100 ha) marsh patches The present day edge is largely associated with marsh patches <10 ha in size.

Complex dendritic channel networks likely provided high productivity habitat for fish

Most dendritic channels are now gone, especially in the central Delta

As Delta marshes were diked, connections were severed to the channel networks that wove through them. These dendritic lower-order tidal channels (also known as "dead-end" or "blind channels") that terminated within the wetland were once the capillary exchange system between the wetland and aquatic areas, promoting both food web productivity and spatial complexity in habitat conditions. They provided native fish species with a range of gradients (e.g., temperature, turbidity, and water velocity) at both large and small scales. Dendritic channel networks offered channel complexity and higher turbidities, which provided refuge for certain species. Channels that branched through the marsh may have been particularly important for salmonids because they provided access to and export of invertebrates from the marsh plain,[68] physical cover and turbidity for refuge, and slow moving water for energetic refugia. The larger, looped channels that characterize the Delta today allow water to move through and mix more quickly, with less diversity in residence time and less heterogeneity in channel habitat. The lack of large wetlands connected to channels means that there is little exchange of organic matter, organisms, or sediment between these ecosystems.



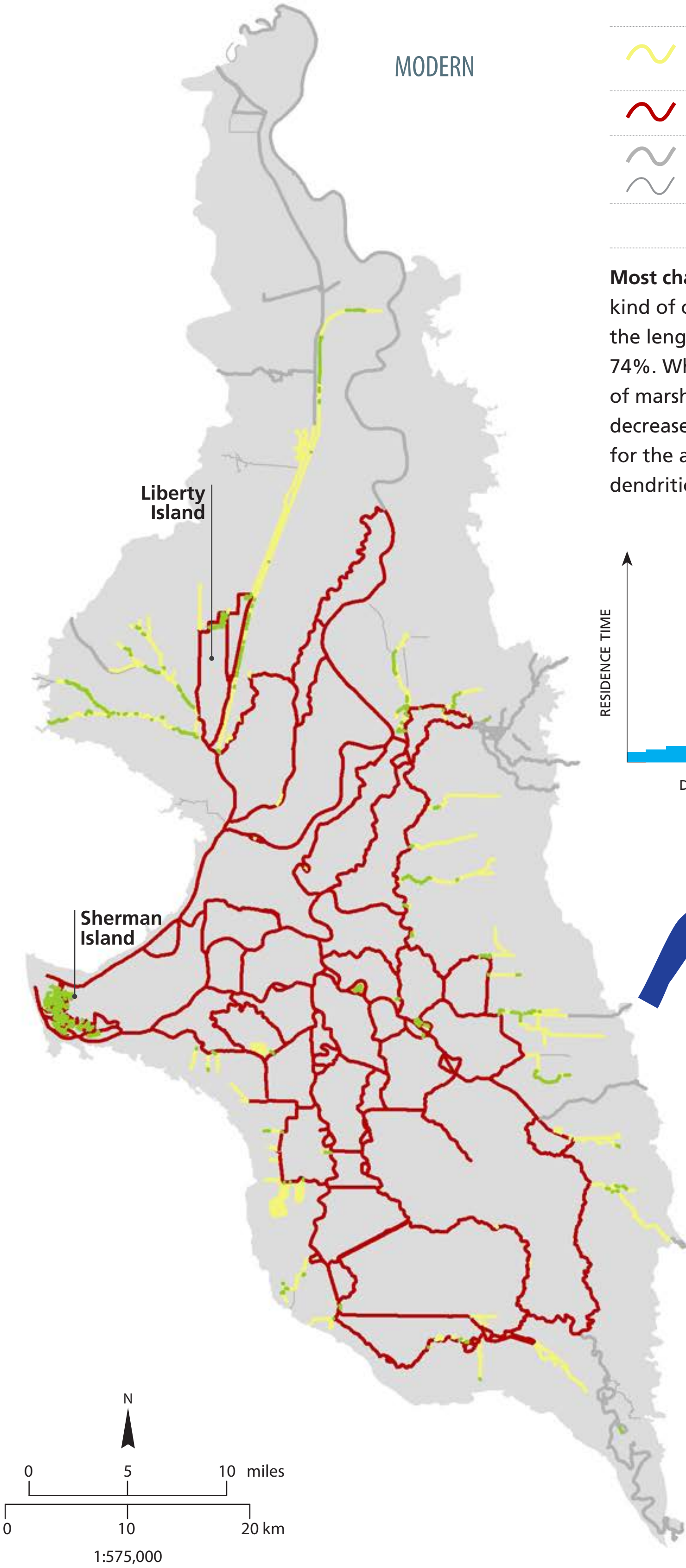
Comparing the historical (right) and modern (far right) landscape. While the skeletal framework of looped mainstem channels remains largely similar (red), the branching networks of dendritic channels (green and yellow) are mostly gone.

Methods: Classifying channel types

Channel reaches were manually classified using the following definitions:

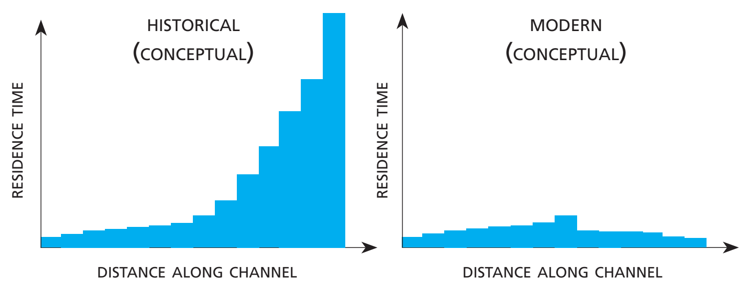
- Dendritic: tidal channel reaches connected to the tidal source by only one non-overlapping path
- Looped: tidal channel reaches connected to the tidal source (the Delta mouth) by two independent and non-overlapping paths
- Fluvial: channel reaches connected to the tidal source, but upstream of the approximate limit of bidirectional tidal flows (during spring tides in times of low river stages) AND tidal reaches between upstream perennial fluvial reaches and downstream looped reaches
- Detached: channel reaches without a direct connection to the tidal source (through the larger channel network)

Dendritic channels (segmented at 100 m intervals) were classified into those adjacent to marsh and those non-adjacent to marsh, based on the habitat-type polygon closest to the channel centerline.



Channel classification	Channel length (km) Historical	Modern
Dendritic channels adjacent to marsh	1,151	84
Dendritic channels not adjacent to marsh	153	255
Looped Channels	754	768
Fluvial Detached	2,225	298
TOTAL	4,283	1,404

Most channels in the Delta today are looped. The length of this kind of channel has slightly increased (due to channel cuts), while the length of dendritic tidal channels has decreased by more than 74%. Where dendritic channels do exist, they are generally not part of marshes—the length of dendritic channels adjacent to marsh has decreased by 93%. These figures and tables do not show or account for the approximately 1,900 km of estimated unmapped, low-order dendritic channels in the historical Delta.



Historically, the complex structure of Delta channels established gradients in residence time, a pattern heavily altered in the modern Delta (after Chris Enright, Delta Science Program). Historically, small low-order tidal creeks had high residence times, which allowed phytoplankton to accumulate and created net autotrophic conditions. Deeper sloughs, by contrast, had shorter residence times which created net heterotrophic conditions. The increased connectivity of modern channels in the Delta has led to homogenization of residence time across channel networks, increasing the reach of tidal excursion within channel networks and decreasing the occurrence of small channels with high residence time. The relationship between residence time and primary productivity in the modern Delta has been additionally complicated by the introduction of the overbite clam.

5. Life-History Support for Marsh Wildlife

Freshwater marshes dominated the Delta landscape historically. Enormous expanses of regularly inundated, highly connected, productive, and structurally complex marsh sustained large wildlife populations. Although much of the marsh was dominated by tules, overall the marsh supported a rich assemblage of both perennial and annual plant species that added to the marsh structure and complexity.[1] In this report, we use the word "marsh" to describe both tidal and non-tidal freshwater emergent wetlands, which can include non-herbaceous species, such as willows. Diverse plant species produced large quantities of seeds that accumulated as extensive seed banks in the sediment.[2] In tidal freshwater marshes both larval and adult insects were key primary consumers.[3] The amount of plant production directly influenced the potential to support secondary consumer populations by providing organic matter for detritivores, contributing to habitat structure, and other mechanisms.[4] The abundant food resources of Delta marshes supported many wetland and terrestrial vertebrates. Some terrestrial and semi-terrestrial species were restricted to the freshwater marsh, while others used it as one of several habitat options, as a migration corridor, or for a part of their life history (such as for dry-season foraging).[5]

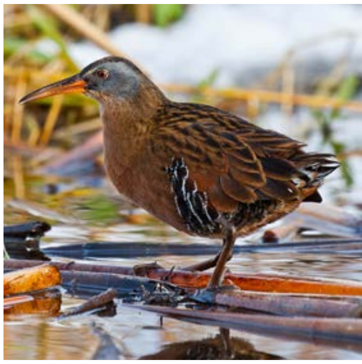
A diverse and dynamic community of native wildlife, including humans, flourished within the marshes of the historical Delta. This community included resident birds and mammals such as rails, herons, bitterns, songbirds, mice, shrews, and voles.[6] Tidal freshwater marshes are thought to support the largest and most diverse populations of birds of any wetland type.[7] Waterbirds such as coots, moorhens, grebes, ducks, geese, and swans inhabited the channels and ponds within the Delta marshes, taking advantage of the food and shelter that marsh proximity provided. Some waterbirds also used the marsh to forage, rest, or breed (see Chapter 6). The Delta supported abundant beavers, river otters, and mink and was a major population center for these species.[8] The shallow ponds, blind channels, and backwaters of the marsh provided slow-moving habitat for littoral fish such as tule perch and the now extinct thicktail chub. Some fish inhabited the smaller marsh channels and may have ventured further into the marsh as flooding conditions allowed (see Chapter 4).[9] Tree frogs, pond turtles, California red-legged frogs, and giant garter snakes that used the marsh were likely limited to areas close to upland and seasonal wetland habitats.[10] In addition many terrestrial species, notably tule elk, but also antelope, deer, coyotes, and bears, used the marsh opportunistically to supplement foraging or escape predation and extreme conditions (see Chapter 8).[11] Raptors, including Northern Harriers and White-tailed Kites, hunted in the marsh. Compared to high salinity tidal marshes, freshwater marshes are thought to have high wildlife diversity, but low endemism.[12] However the Delta did support several endemic plants and a few regionally restricted vertebrates including the giant garter snake and Modesto Song Sparrow.[13] Finally, indigenous people benefited from and managed for this wildlife diversity, relying on the extensive marshes for food and materials.[14]

Marsh wildlife (right). Top to bottom: North American river otter, Delta tule pea, Virginia Rail, giant garter snake.

Photo Credits: Unknown, USFWS; Mark Fogiel, CalPhotos; Tom Talbott, Creative Commons; Dave Feliz, Wikipedia Commons

The considerable heterogeneity expressed by Delta marshes provided structural complexity and niche diversity to support different species. Gradients in physical characteristics such as tidal energy, river flow, and salinity, as well as subtle local variations in topography and microclimate, provided a variety of habitat features that supported wildlife under different conditions (e.g., seasonal cycles, floods, drought, temperature extremes, turbidity). These gradients also supported different species in different places, and fostered genotypic and phenotypic diversity within species. The character of the Delta marsh was particularly variable along its latitudinal gradient. Largely due to its distance from the mouth of the Delta and to riverine influences, the north Delta flood basins contained broad zones of both tidal and non-tidal freshwater marsh that were relatively free of channels and supported dense stands of tules over ten feet tall. Channel density and sinuosity in the central Delta was greater than in the less tidally dominated northern and southern parts of the Delta because of the gradation in tidal prism. Willows were a significant component of the western-central Delta marshes, which were characterized by willow-fern-tule associations. The marshes of the south Delta were a mosaic of small ponds, patches of tule, willow thickets, rushes, grasses, and sedges[15] dependent on fluvial geomorphic influences from the San Joaquin River and tributaries. In addition to gradients, disturbances (including flood, drought, animal damage, and fires) maintained heterogeneity within the marsh. By knocking back vegetation, these disturbance mechanisms allowed disturbance-tolerant plants to grow and created small open water habitats (duck puddles) that supported waterfowl and littoral fish. The north Delta in particular supported many such small ponds.

The staggering loss of marsh in the Delta, combined with changes in connectivity and habitat quality, has led to tremendous loss of wildlife support. Over 97% of the historical marsh is now gone. What little marsh remains consists primarily of small patches surrounded by deep channels, artificial levees, and agriculture. Much of the marsh in the modern Delta is the result of accidental restoration via levee failure, and is relatively young in age (decades old rather than centuries). Marshes in the Delta no longer span broad, continuous gradients; instead, isolated patches occupy narrow spots along these gradients. Many modern marsh patches are small islands—often the cut-off tips of once larger marshes—now surrounded by riprapped levees and deep channels. The size and isolation of existing marsh patches severely limits the wildlife populations the marsh can support. The Delta's waters no longer inundate surrounding wetlands, limiting exchange of nutrients, organic matter, and dry-season freshwater input.



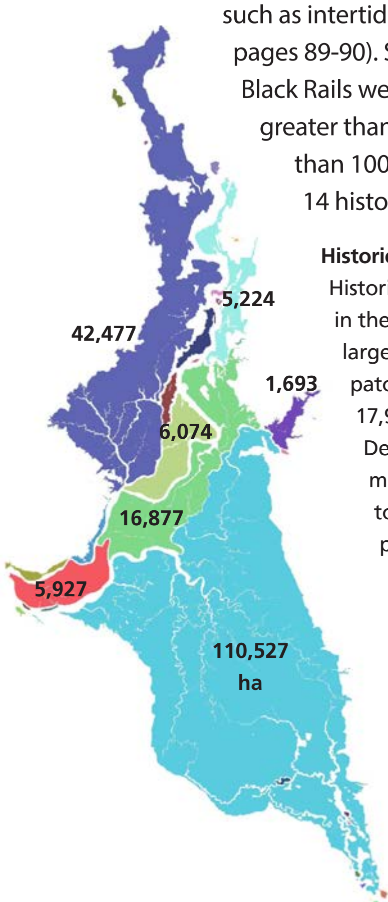
Fragmented wetlands support smaller wildlife populations because of increased edge effects, with reduced population viability and greater probability of extirpation within habitat fragments.[16] With few patches large enough to support self-sustaining populations, marsh wildlife in the Delta is particularly vulnerable to catastrophic events. The complex channel networks that were associated with these marshes historically cannot be adequately expressed in the small remaining habitat patches. In addition to these effects of fragmentation, the habitat quality of the remaining marsh patches has been altered by non-native invasive species, which compete with and prey upon native species, and by changes in water quality due to agricultural and urban runoff and habitat alteration.[17] Species that relied on the marsh historically, including waterfowl, giant garter snakes, and Tricolored Blackbirds, now increasingly rely on other habitats, including agricultural fields and blackberry thickets. Managed wetlands are critical to wildlife support in the Delta, providing habitat for wintering and nesting waterfowl (see Chapter 6) but they do not support the full native marsh wildlife community, and are often not hydrologically connected to the larger Delta system.

The freshwater marshes of the Delta were unique and extraordinarily valuable to wildlife. As part of an interior inverted delta in a Mediterranean climate, unparalleled in size within the state, the freshwater marsh in the Delta offered unique benefits to wildlife. Because so little of this habitat remains intact it is difficult to comprehend what has been lost. The majority of the Delta historically supported native marsh wildlife; now few places in the Delta do.

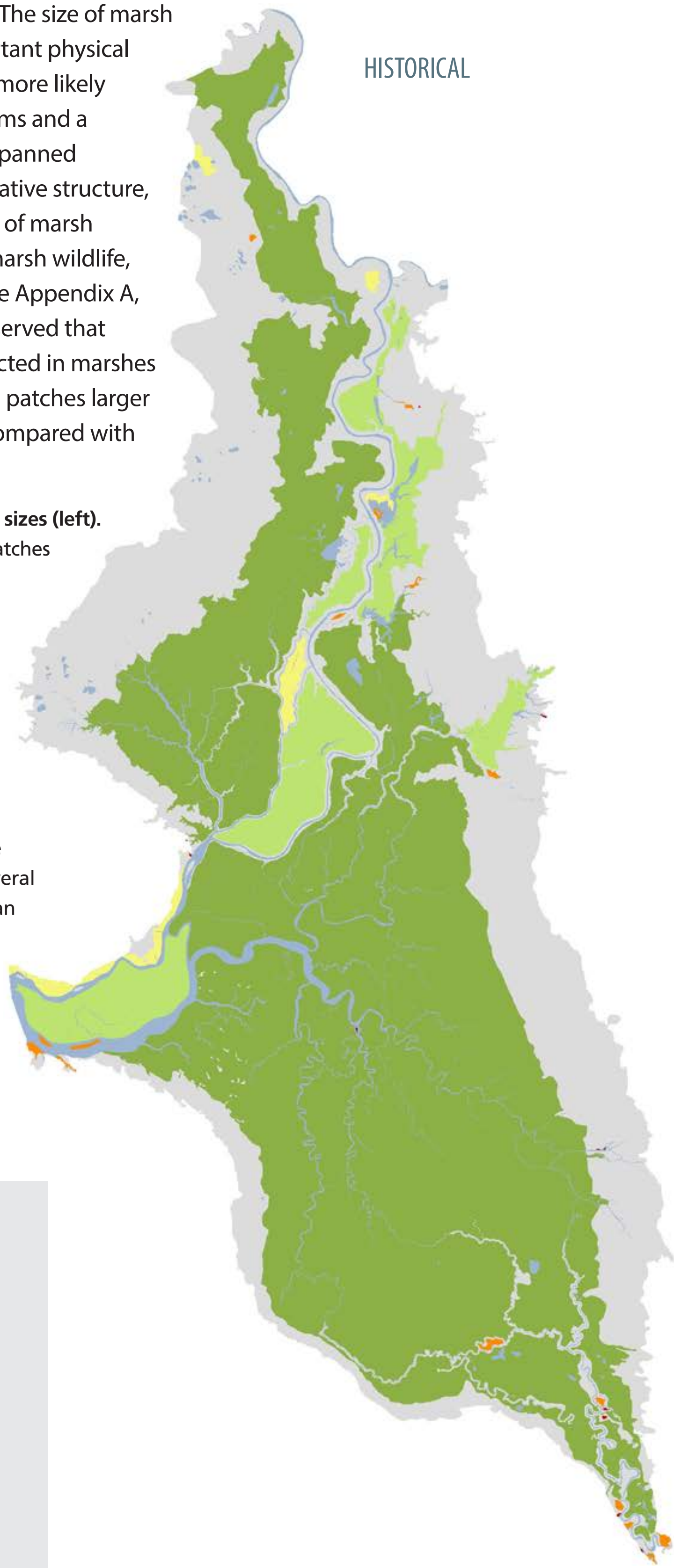
The few marshes left in the Delta are small

The current average patch size is several hundred times smaller than in the historical Delta

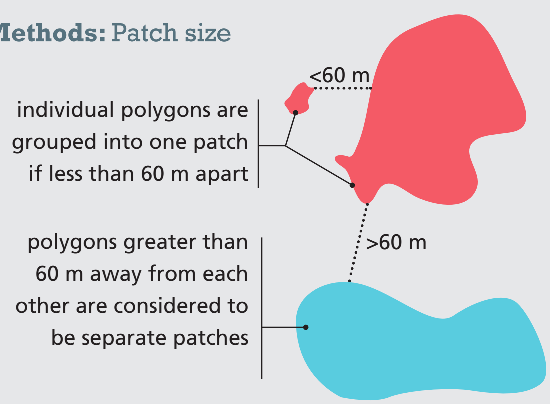
The area of marsh in the Delta has been reduced by 97%. The size of marsh patches today is small relative to the scale at which important physical and ecological processes occur. Large marsh patches are more likely than small patches to have well-developed channel systems and a range of physical and ecological features. Large patches spanned considerable heterogeneity in inundation patterns, vegetative structure, and geomorphic setting. Here we look at spatial patterns of marsh patches based on parameters relevant to marsh wildlife, such as intertidal rails (for more details see Appendix A, pages 89-90). Spautz and Nur (2002) observed that Black Rails were more consistently detected in marshes greater than 100 ha. Only three marsh patches larger than 100 ha remain in the Delta (compared with 14 historically).

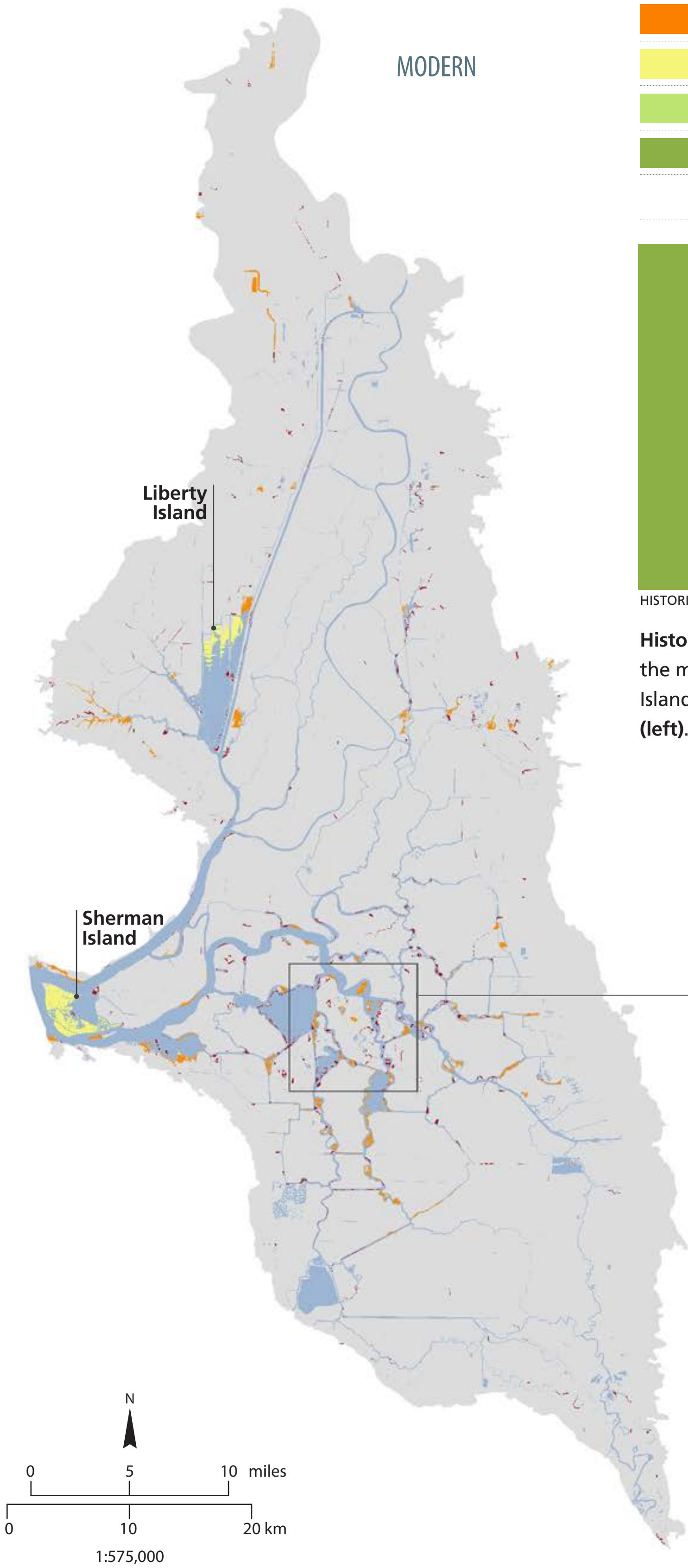


Historical marsh patches with patch sizes (left). Historically, there were 43 marsh patches in the Delta (14 of which were larger than 100 ha), with a mean patch size of 4,494 ha (SD = 17,956 ha). In the modern Delta there are many more marsh patches (1,211 in total), but they have a mean patch size of only 4 ha (SD = 24 ha), and only three are larger than 100 ha. Average patch size today is thus several hundred times smaller than it was historically. The largest single historical patch (110,527 ha) spanned the entire south and much of the central Delta.



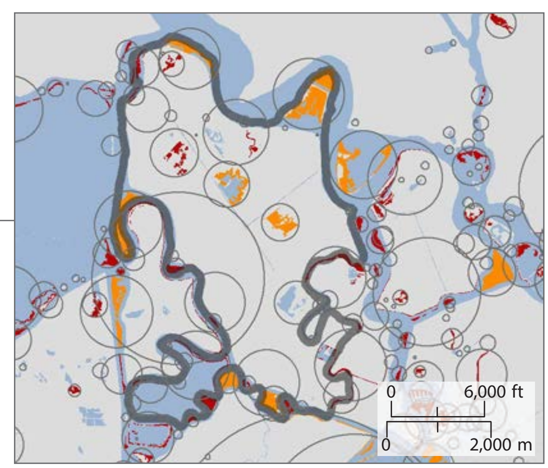
Methods: Patch size





Marsh patch size class (ha)	Total area (ha) Historical	Modern
<= 10 ha	46	1,427
10 - 100	702	1,757
100 - 1,000	2,489	1,154
1,000 - 10,000	20,105	0
>10,000	169,881	0
TOTAL	193,224	4,338

Historical marsh was composed of large patches, unlike marsh in the modern Delta **(above)**. Even today's largest patches—Liberty Island and Sherman Island—are not very big by historical standards **(left)**. The total extent of marsh is <3% of the historical area.

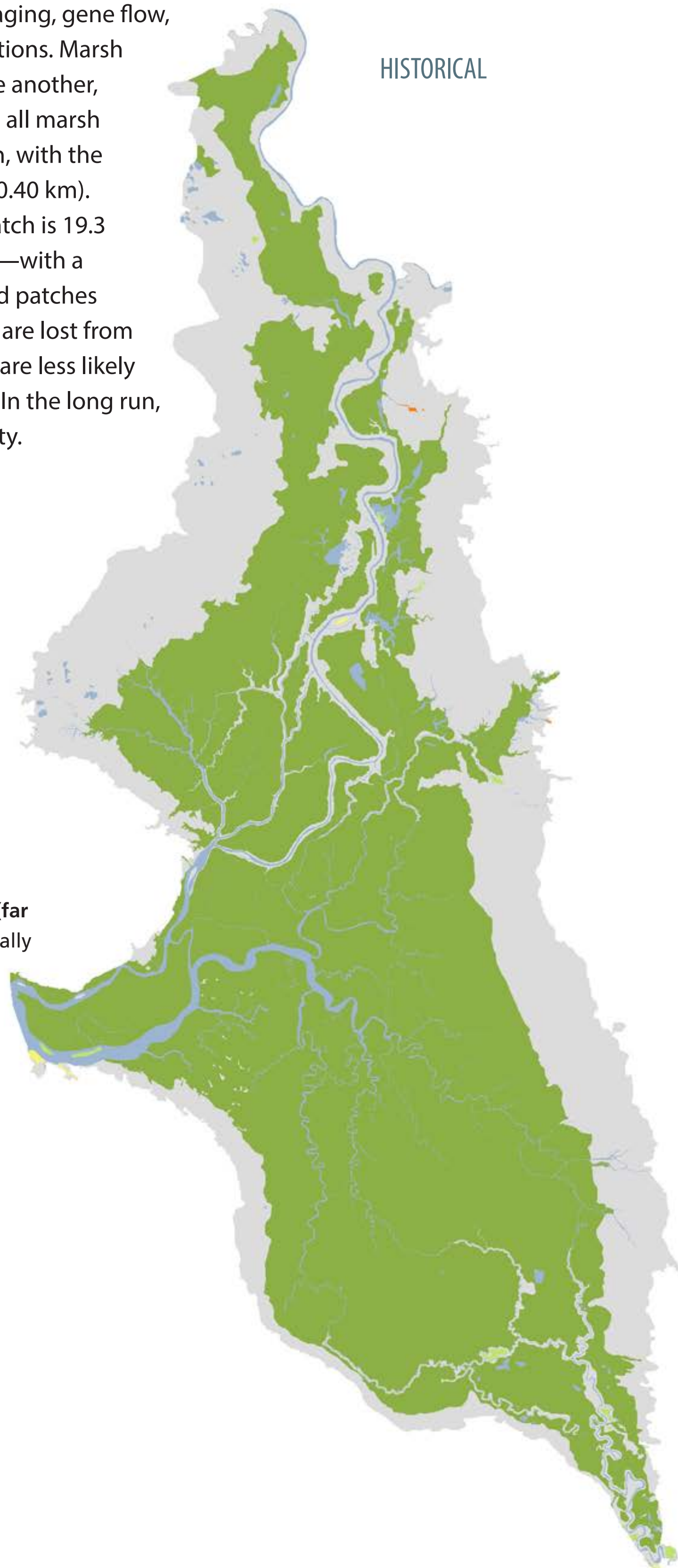


Today there are hundreds of tiny marsh patches scattered throughout the Delta (above), each represented here with a circle indicating the extent of each individual patch. Most of these are fringing marshes along channels or the tips of former large marsh islands. These scattered small remnants were cut off by the excavation of levees and widening of channels over a century ago. For example, the area outlined in grey above shows what was once a continuous historical marsh island that is now fragmented into small pieces.

Existing marshes are isolated

Average distance from a marsh patch to the nearest large marsh has increased more than 50-fold

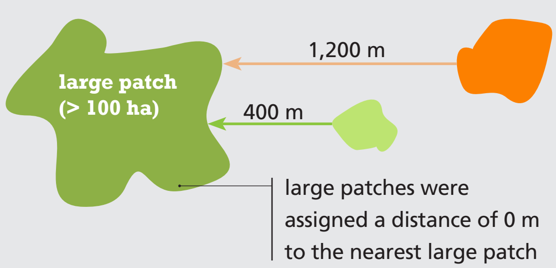
Continuous marsh habitat is essential for dispersal, foraging, gene flow, and resilience to disturbance for marsh wildlife populations. Marsh patches in the modern Delta are now isolated from one another, fragmenting populations of marsh wildlife. Historically, all marsh patches were within 1.62 km of a large (>100 ha) marsh, with the average distance to a large patch being 0.29 km (SD = 0.40 km). In the modern Delta, the average distance to a large patch is 19.3 km (SD = 11.08 km)—two orders of magnitude farther—with a maximum distance of 61.4 km. Wildlife in small, isolated patches are less likely to disperse successfully. Populations that are lost from these patches due to catastrophic or stochastic events are less likely to be re-established due to low re-colonization rates.[18] In the long run, isolated and small populations can lose genetic diversity.

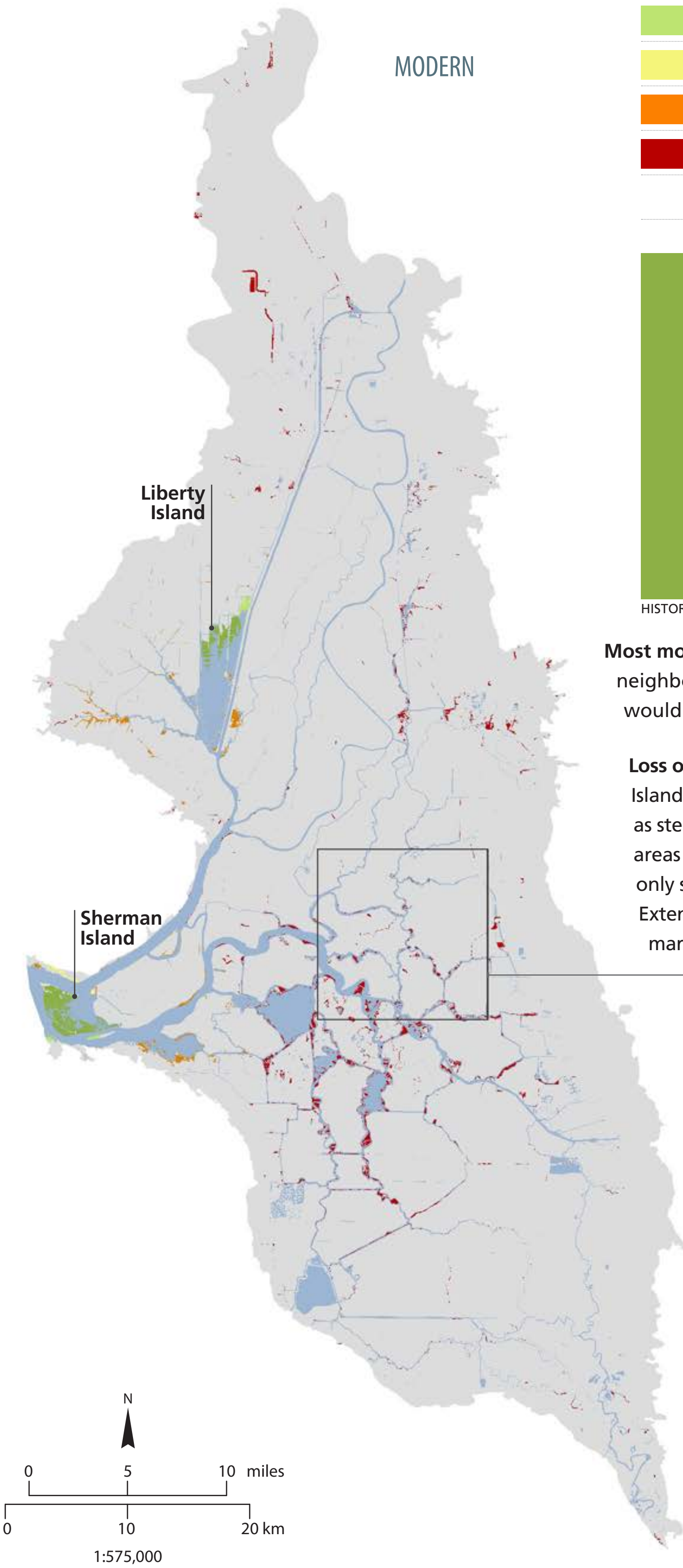


Patterns within the historical (right) and modern landscape (far right). Historically, marsh patches were close together (generally within 1 km). This landscape configuration allowed wildlife movement to maintain diversity within these small patches. Large marsh patches were separated from one another by wide stretches of river or associated riparian forest. In the modern Delta, marsh patches are significantly smaller, and more isolated.

Methods: Nearest large neighbor distance

Measuring each patch's distance to another patch of at least 100 ha

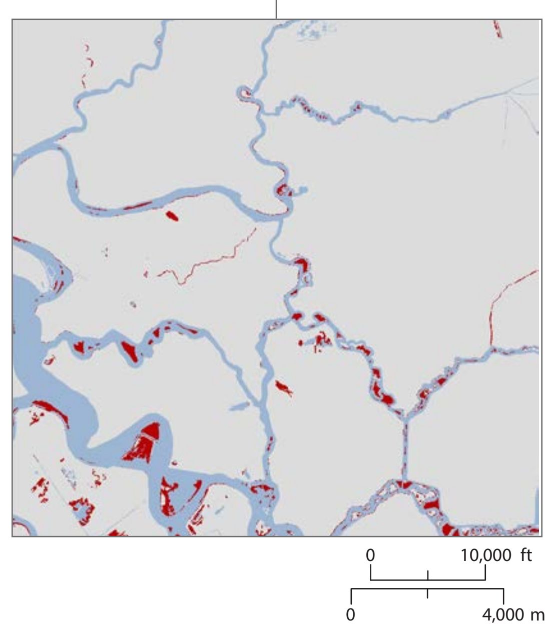




Distance from nearest large neighbor (m)		Total area (ha) Historical	Modern
	<= 100 m	192,523	1,161
	100 - 500	500	143
	500 - 1,000	169	87
	1,000 - 10,000	32	630
	>10,000	0	2,317
	TOTAL	**193,224**	**4,338**

Most modern marsh patches are isolated from significantly sized neighbors **(above)**. Creation of larger marsh patches in the Delta would increase habitat value for the surrounding marshes.

Loss of connectivity. There are few marsh patches between Liberty Island and Sherman Island (today's largest patches) that might serve as stepping stones for movement of wildlife between these two areas **(left)**. In the Central Delta, the patches that do exist are not only small, but are also isolated from the large patches **(below)**. Extensive areas of the south and north Delta are largely devoid of marsh.

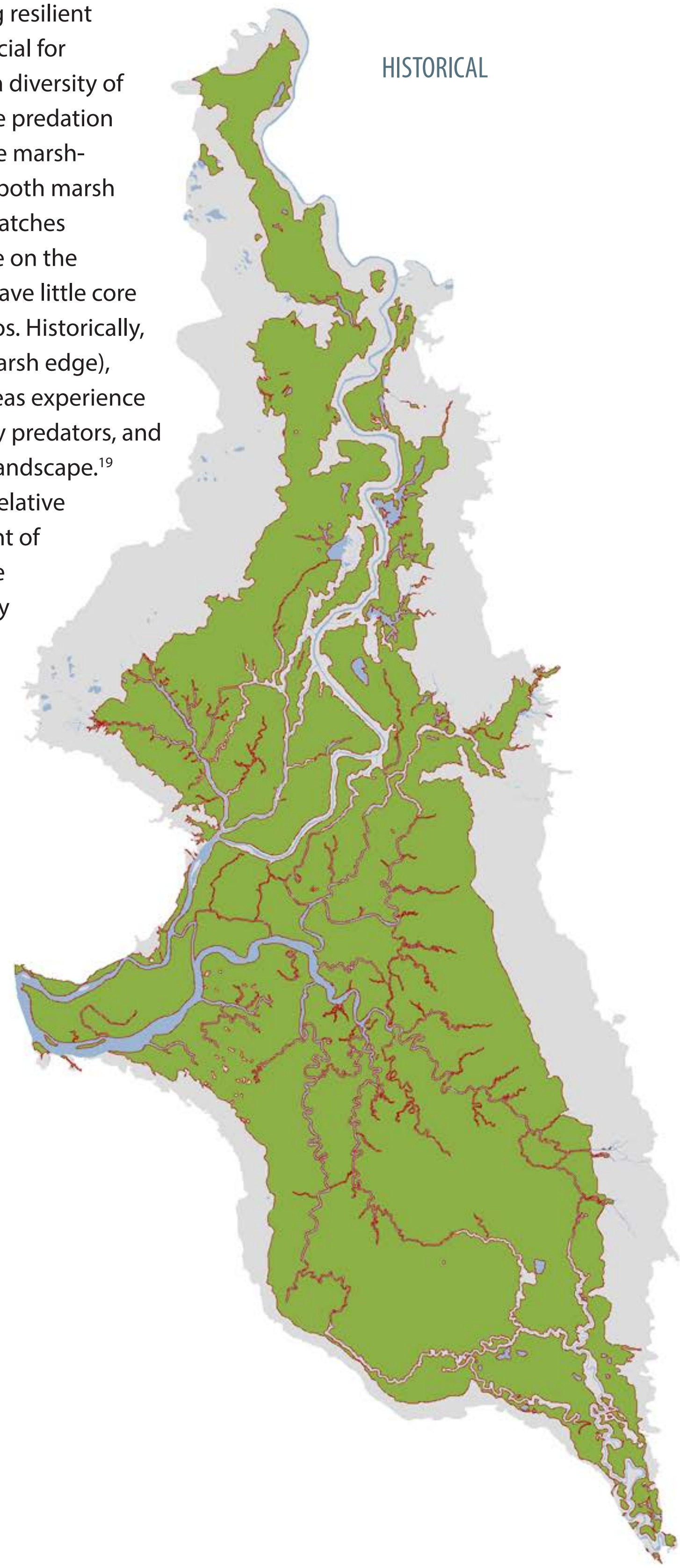


Core area

Existing marshes have little core habitat

This configuration leaves marsh wildlife vulnerable to edge effects

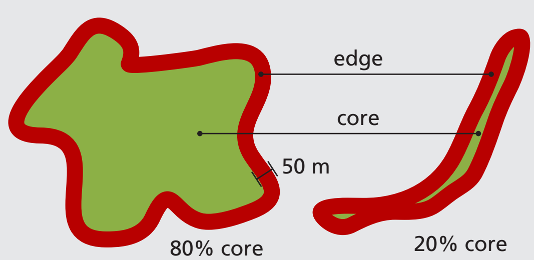
Large areas of core habitat are necessary for sustaining resilient marsh wildlife populations. While edges can be beneficial for wildlife populations—providing transition zones and a diversity of habitats—an increased edge-to-area ratio can increase predation and limit the value of core marsh areas. Historically, the marsh-channel edge was an important zone of exchange for both marsh and aquatic wildlife. Today, the small, isolated marsh patches with vastly altered hydrology have much less influence on the surrounding aquatic habitat. Modern marsh patches have little core area due to their small size and high edge-to-area ratios. Historically, 93% of the marsh was core habitat (>50 m from the marsh edge), while only 19% of marsh is core habitat today. Core areas experience different abiotic conditions, are less accessible to many predators, and are buffered from human disturbance in the modern landscape.[19] Fragmentation and development have increased the relative amount of edge habitat, although the absolute amount of marsh edge habitat in the Delta has been reduced. The character of the marsh edge has also been dramatically altered at both the upland and aquatic interfaces.

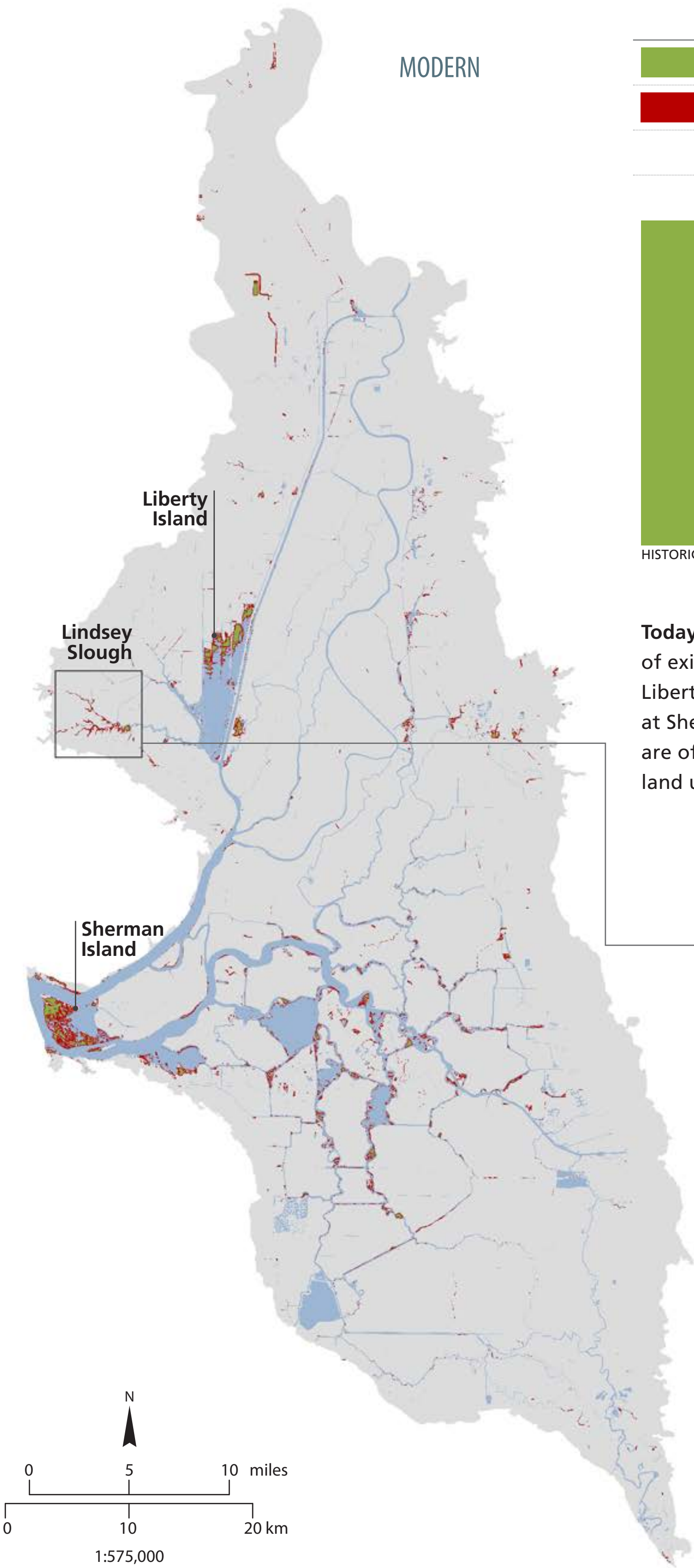


Historical (right) and modern (far right) extents of core marsh area. Historically, marsh edges transitioned to a tidal channel, riparian forest, seasonal wetland, or upland patch. In the modern Delta, edges are often steep levees, and account for proportionally more area than they did in historical marsh patches.

Methods: Marsh Core vs. Edge Area

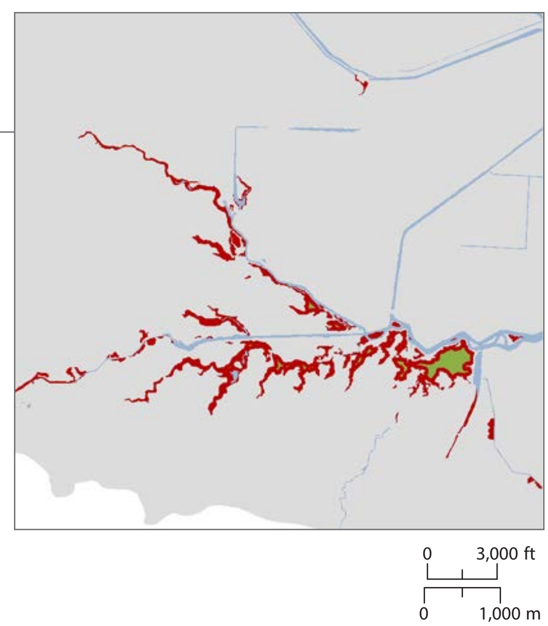
Core area was defined as at least 50 m from the outside edge of the marsh.





		Total area (ha)	
		Historical	*Modern*
	Core	179,504	815
	Edge	13,720	3,522
	TOTAL	**193,224**	**4,338**

Today's marsh habitat is mostly edge (left and above). Over 80% of existing marsh is edge area. The two large marsh patches at Liberty Island are 38% and 56% core area. The large marsh patch at Sherman Island is 34% core area. In the modern Delta, edges are often hard structures such as levees, roads, or agricultural land uses. There has been a 99.5% decline in core marsh area.



Lindsey Slough (above) is one of the largest remaining patches in the Delta (second only to Liberty and Sherman islands), but its long linear shape (14% core area) makes this marsh vulnerable to edge effects.

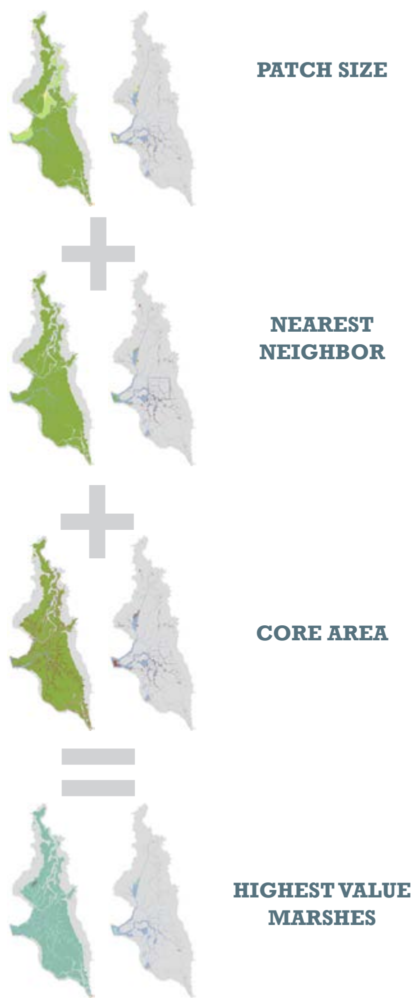
There are no modern analogues to the historical large, complex marshes

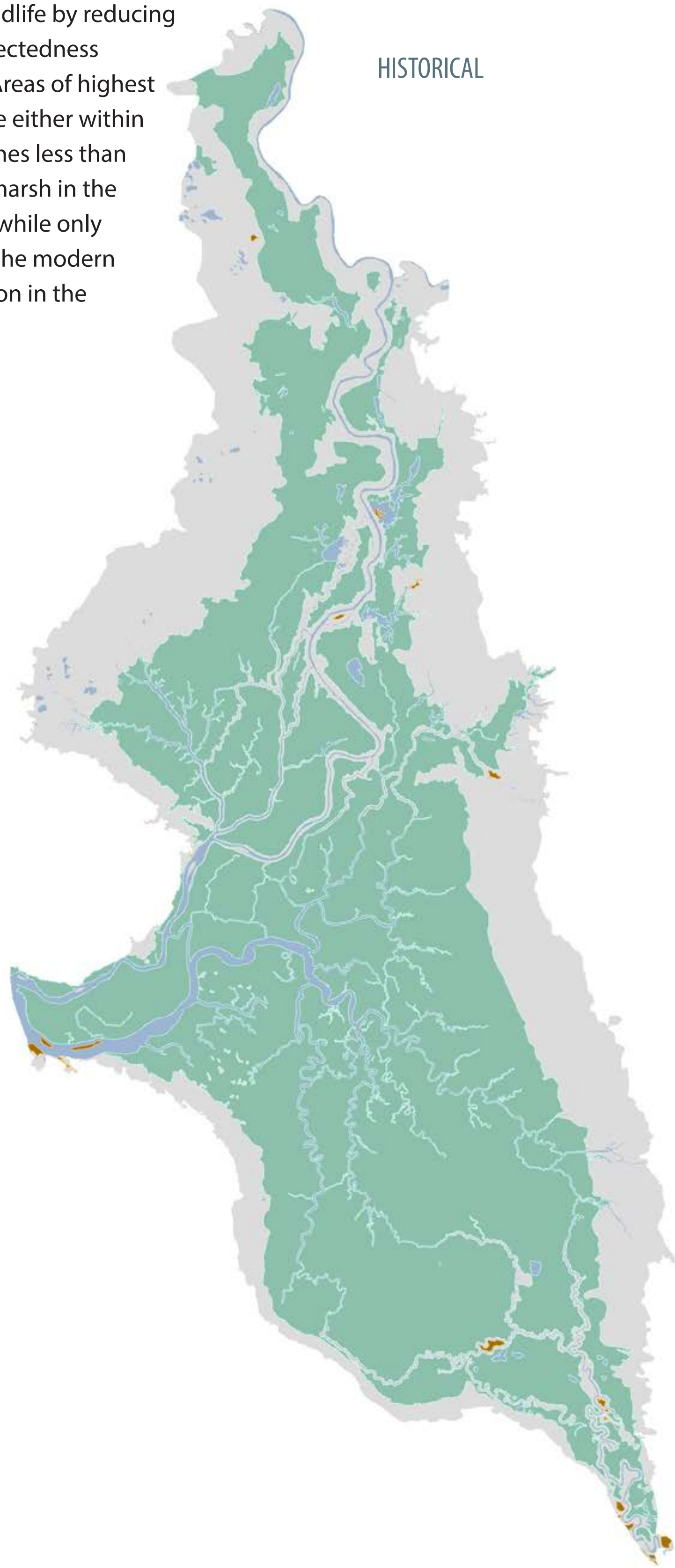
Even the highest quality remaining marsh patches are highly modified

Fragmentation has decreased the value of marsh to wildlife by reducing the size of marsh patches available, reducing the connectedness between marsh patches, and increasing edge effects. Areas of highest value to marsh wildlife are areas of core habitat that are either within large marsh patches (>100 ha) or are within small patches less than 1 km from a large marsh patch. Nearly all of historical marsh in the Delta met this criteria historically (179,495 ha or 93%), while only 491 ha (0.25% of the historical marsh area and 11% of the modern marsh area) meets this criteria today—a 99.7% reduction in the extent of high quality habitat.

Methods: High value marshes

Combining the previous metrics, we can define areas of highest value to marsh wildlife as areas of core habitat that are either within large marsh patches (>100 ha) or are within smaller patches that are near (<1 km) large marsh patches.

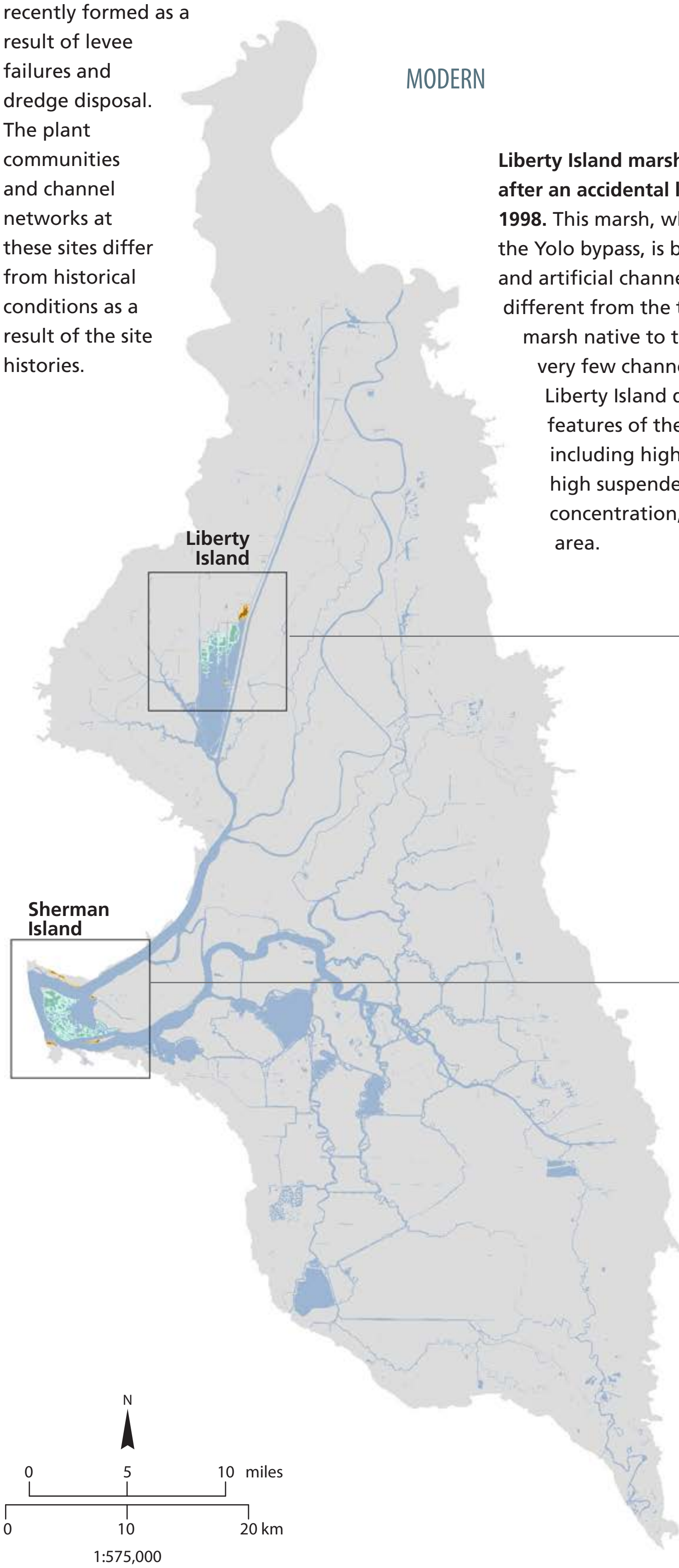




The largest current marsh patches are at Sherman and Liberty islands **(below)**. Marshes in both areas were recently formed as a result of levee failures and dredge disposal. The plant communities and channel networks at these sites differ from historical conditions as a result of the site histories.

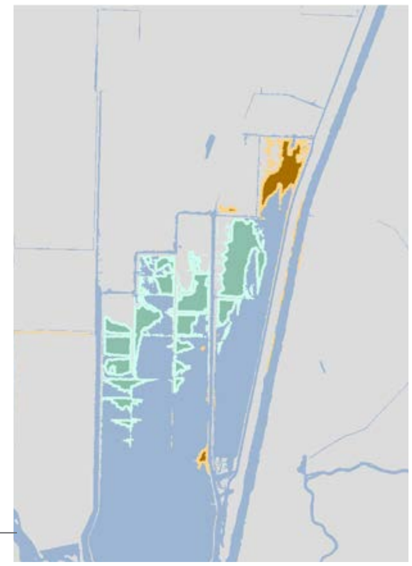
CORE HABITAT	EDGE HABITAT	**Fragmentation index for historical and modern maps**
		Large (>100 ha) marsh patches (more likely to sustain persistent populations)
		Marsh near (<1 km) to large marsh patches (areas more likely to be recolonized and maintain gene flow)

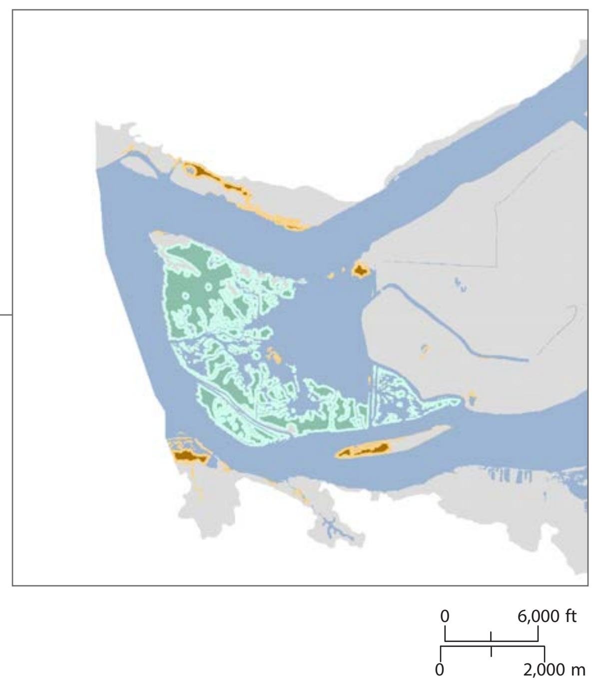
MODERN



Liberty Island marsh (right) formed after an accidental levee failure in 1998. This marsh, which is adjacent to the Yolo bypass, is bisected by levees and artificial channels, making it very different from the tule-dominated marsh native to this area that had very few channels. However, Liberty Island displays important features of the historical Delta, including high residence time, high suspended sediment concentration, and large marsh area.

0 6,000 ft
0 2,000 m





Sherman Island (above) was flooded when its levees failed in the early 1900s. This marsh sits at the brackish (saltier) extreme of the salinity gradient within the Delta. The site was used for the deposition of dredge spoils until the 1960s.[20] Although it is large compared to other patches, it has lots of aquatic edge surrounded by invasive aquatic plants, has few distinct marsh channels, and sits at a low elevation in the tidal frame.

6. Life-History Support for Waterbirds

The historical Delta was important to many species of waterbirds, and supported both wintering and breeding birds. Waterbirds in the Delta included ducks, geese, swans, shorebirds, grebes, cormorants, bitterns, egrets, herons, ibises, rails, and terns.[1] The wetlands of the Central Valley, including the Delta, were associated with extraordinarily high concentrations of wintering waterfowl (ducks, geese, and swans). These wetlands also supported smaller but significant populations of breeding waterfowl, particularly dabbling ducks. The Delta provided year-round support to herons, egrets, and cormorants that nested and roosted in riparian trees and foraged in the extensive adjacent marshes. Coots, moorhens, and grebes likely inhabited the marshes and open waters of the Delta year-round, and Forster's Terns and Black Terns likely nested within the marsh. Waterbird species, such as cranes and shorebirds, which now rely on managed wetlands and flooded agricultural fields, likely took advantage of suitable habitats in the historical Delta, although their exact historical habitat associations are unclear.[2]

Large numbers of waterfowl—an estimated 35-50 million birds—overwintered in the Central Valley historically.[3] This area was a key stopover along the Pacific Flyway, a north-south migration route of global importance for waterfowl and other birds. While the relative value of the Delta among these Central Valley wetlands is unclear, reports from early explorers attest to the abundance of waterfowl within the Delta.[4] Migratory waterbirds adapt to changes in the landscape at a large scale, so the relative importance of Suisun, the Delta, and the Central Valley may have varied over time in response to changes in weather, water conditions, and food availability.[5] Modern waterfowl management focuses on the importance of seasonal wetlands because of the relative abundance of moist-soil seeds in these habitats compared to permanently flooded and tidal wetlands.[6] However, historically the low seed density in tidal wetlands may have been offset by the extensive acreage, leading to high total seed abundance.[7] Other food resources, including rhizomes, may also have been more important to wintering waterfowl using the historical Delta.

Different species of wintering waterfowl likely keyed in on different food resources and habitats within the Delta. Wintering waterfowl common in the Delta historically included Tundra Swans, Snow Geese, Ross' Geese, Greater White-fronted Geese, Canada Geese, Northern Pintails, Mallards, American Wigeons, Green-winged Teals, Northern Shovelers, Gadwalls, and Canvasbacks.[8] Emergent aquatic plants, submerged aquatic vegetation, moist-soil seeds, and invertebrates were all important food sources to these waterfowl.[9] Water depth in channels, lakes, and ponds determined which species could forage most efficiently, with dabbling ducks such as Northern Pintail preferring shallower water and diving ducks such as Canvasback preferring deeper channels and ponds. Swans foraged primarily on submerged aquatic vegetation, while geese grazed in seasonal wetlands and adjacent uplands and also fed on tuberous plants in wetter areas.[10] Waterfowl were unlikely to have foraged in areas of dense tules.[11] However seasonal and perennial lakes within the Delta, along with smaller ponds embedded within the marsh, were known to have supported high densities of waterfowl historically.[12] Regular disturbance via flooding, wildlife

Waterbirds (below). Left to right: Northern Pintail, Sandhill Cranes at Merced NWR, geese migration, Mallards.

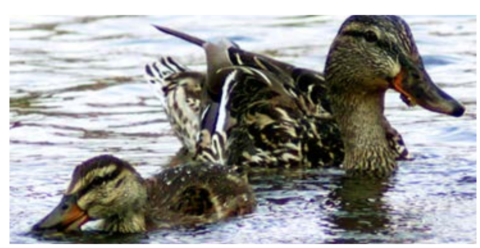
Photo Credits: Unknown, USFWS; Lee Eastman, USFWS; Unknown, USFWS; Scott Flaherty, USFWS

wallows, and burning helped maintain these open water habitats. Geese themselves helped to maintain these ponds by clearing large areas of aquatic vegetation.[13]

Migrating shorebirds using the Pacific Flyway also undoubtedly took advantage of wetland habitats within the Delta, although records of particular species are lacking. Some shorebirds may also have bred in the Delta. Habitats frequently used by shorebirds in the modern Delta (e.g., wastewater treatment facilities, agricultural fields) are without historical equivalents. The sparse extent of mudflats in the central Delta historically, in contrast to the neighboring San Francisco Bay, would have limited shorebird use there. Shorebirds likely took advantage of what mudflat was available in the Cache Slough area and the short-statured vegetation in wet meadows, seasonal wetlands, and grasslands along the periphery of the Delta.[14] Available shorebird habitat historically would have shifted in time and space as water levels changed. Curlews and ibises likely foraged in grasslands and vernal pools.[15] Sandhill Cranes typically forage in low vegetation lacking shrubs and trees that might block their view of predators, and may have also used these habitats.[16] Avocets and stilts may have nested in the Delta, particularly in areas of marsh dominated by low rushes and grasses in the south Delta.[17]

The Central Valley was an important area for breeding waterbirds historically. Duck species that bred in the Delta included Mallards, Gadwalls, Cinnamon Teals, Northern Pintails, and possibly Redheads and Canvasback.[18] Upland areas adjacent to the marsh, or higher areas (like beaver and sand mounds within the marsh), offered nesting opportunities above flood waters.[19] Areas of open water within or adjacent to freshwater emergent marsh were used as brooding habitat for young birds. Waterfowl may have moved a considerable distance between nesting and brooding sites, particularly when nesting occurred in brackish areas, such as Suisun Marsh.[20] Freshwater marshes were also important post-breeding sites for molting birds. Many species of waterfowl molt all their primary flight feathers simultaneously, rendering them temporarily flightless, and the tall, dense vegetation in these wetlands provided critical cover to these vulnerable birds.[21] Riparian forests provided nesting opportunities for cavity-nesting Wood Ducks and supported large rookeries of herons, egrets, and cormorants.[22]

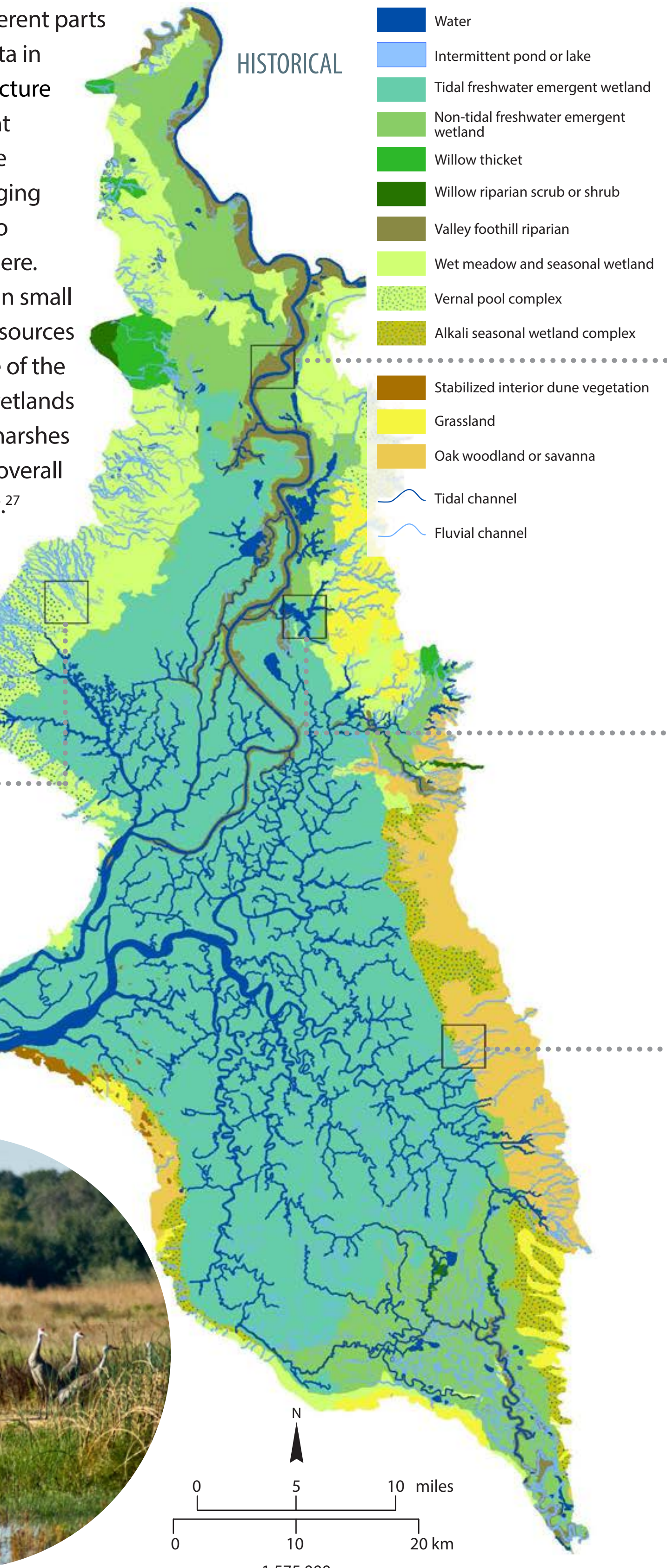
The modern Delta provides less support for waterbirds due to the extensive loss of wetland habitat. Managed wetlands and agricultural fields are key components of the modern landscape for both wintering and breeding waterbirds, as natural wetlands no longer provide adequate space or food resources for wintering waterfowl.[23] Although these managed habitats are now crucial for waterbirds they differ from historical wetland habitats in several important ways. Grain crops provide food resources that are carbohydrate-rich but sometimes nutrient-poor, and these areas lack the invertebrate communities important for particular species at certain times of year.[24] Management is often focused on supporting particular threatened and endangered species, such as Sandhill Cranes, or supporting economic interests, such as duck clubs, and may provide less support for non-target species. Water quality within flooded agricultural fields can be affected by fertilizers and pesticides. In addition, some modern waterfowl habitat may be increasingly threatened by levee failure or water shortages.[25] Restoring wetlands has the potential to shift waterbird support back to natural areas. This support is likely dependent on the size of restored areas.



Delta wetlands supported large numbers of waterbirds historically

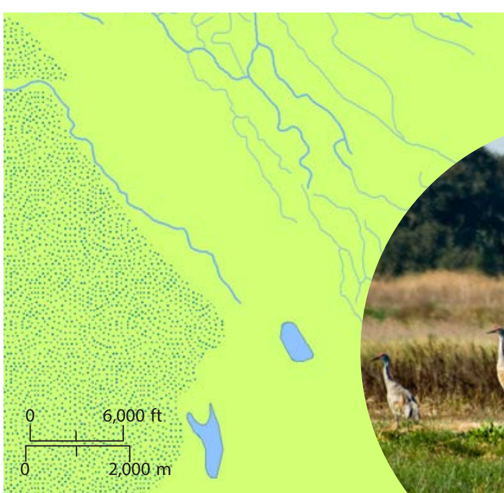
Variable conditions in the Delta provided support for different waterbirds in different seasons

Different waterbirds species were able to take advantage of different parts of the Delta throughout the year. Waterfowl wintered in the Delta in particularly high numbers.[26] The combination of vegetative structure and flooding patterns determined habitat suitability for different waterbird species. There was a high degree of variability in these habitats, with the amount and location of suitable habitat changing significantly from one year to the next. Waterbirds responded to landscape heterogeneity on a finer scale than can be mapped here. For example, wintering waterfowl were found in high densities in small ponded areas within freshwater marshes. The abundant food resources and protection from predators were due in part to the large size of the Delta wetlands. Although waterfowl food density in the Delta wetlands may have been lower than in intensively managed freshwater marshes today, the large historical extent of marshland likely resulted in overall food supplies that rivaled or exceeded the modern-day support.[27] The remaining natural marshes and seasonal wetlands are too small to support abundant waterbirds, and thus in the modern Delta managed wetlands and agricultural fields provide most of the habitat value for waterbirds.



SANDHILL CRANES

The Delta was an important wintering location for Sandhill Cranes. Areas of shallow water and short vegetation likely provided good roosting areas with easy detection of predators. Seasonal wetlands around the edge of the Delta offered this type of habitat historically.[28]

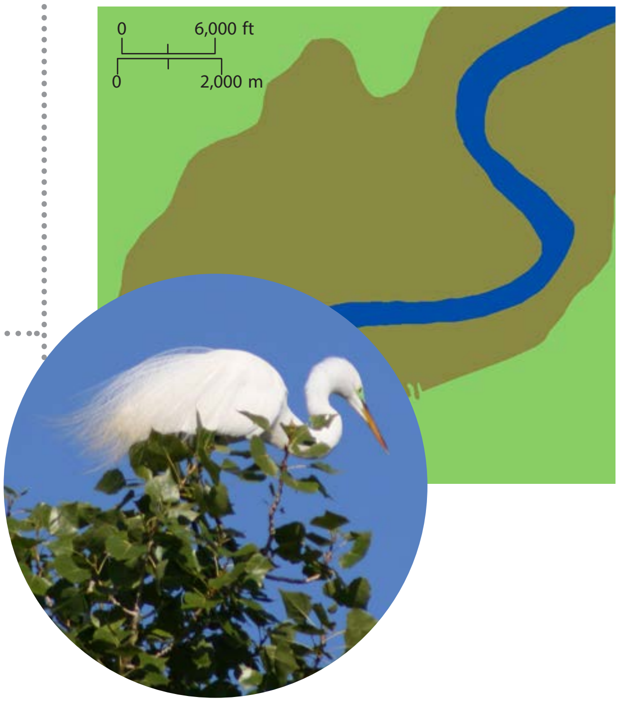


Sandhill Cranes

Photo Credits (left to right): Justine Belson, USFWS; Linda Wanczyk, SFEI; Charles Sharp, Wikipedia Commons; Dan Cox, USFWS

COLONIAL ROOSTING BIRDS

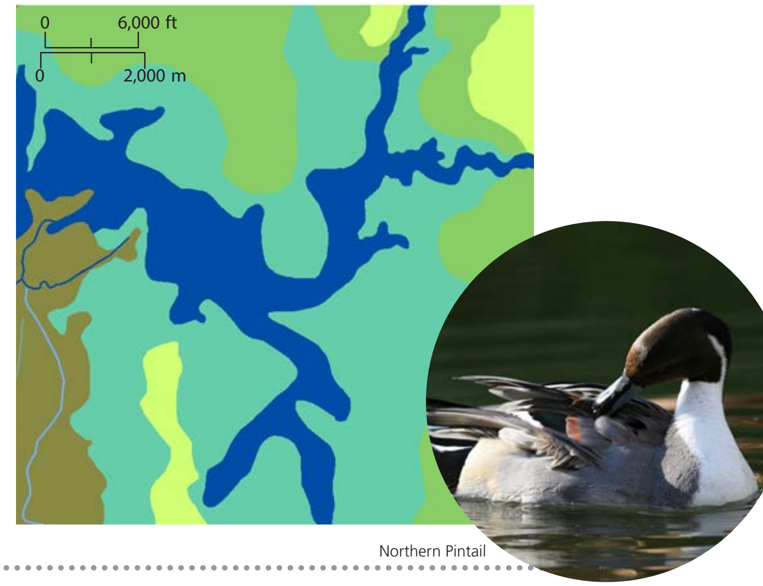
Colonies of herons, egrets, and cormorants used large trees in the riparian forests of the north Delta for roosting and nesting.[29]



Roosting heron

WINTERING WATERFOWL

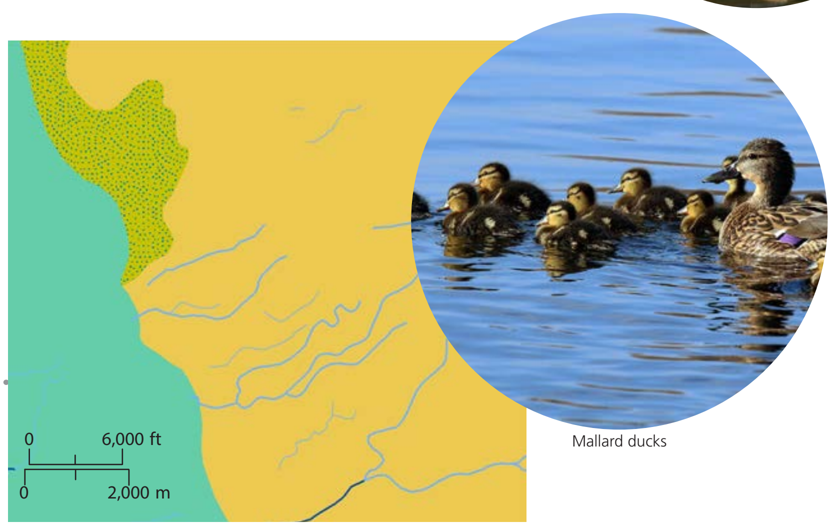
Wintering waterfowl congregated in large numbers in areas of open water within freshwater marsh. Common species included Northern Pintails, Snow Geese, Ross' Geese, and Tundra Swans. Seeds and tubers of marsh plants were particularly important food resources for these species.[30]



Northern Pintail

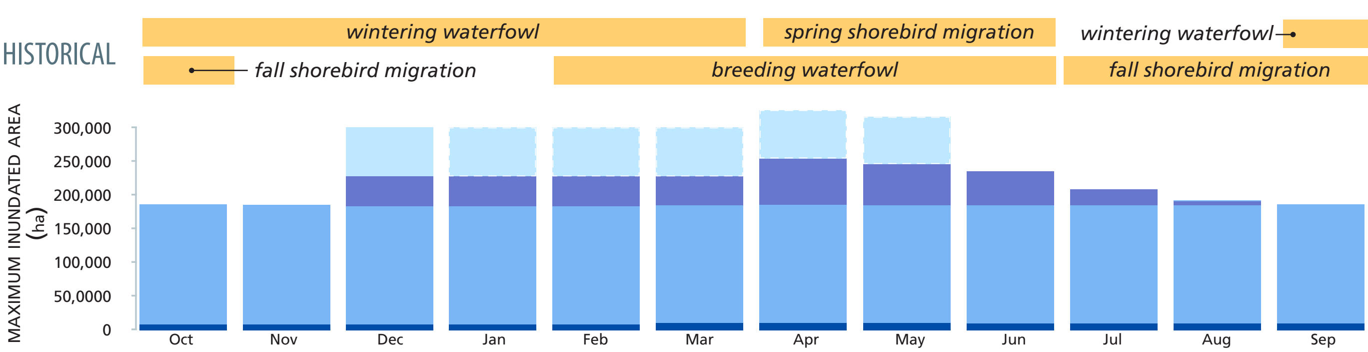
BREEDING DUCKS

Several species of dabbling ducks, including Mallards and Gadwalls, bred in the Delta in significant numbers. Areas of higher elevation, above flood waters, were critical for nesting. Areas of open water with nearby vegetative cover were needed for brooding birds.[31]



Mallard ducks

Flooding in the historical Delta (below). The diagram below relates flooding in the historical Delta (see details and legend on page 40) with patterns of waterfowl and shorebird use.[32]

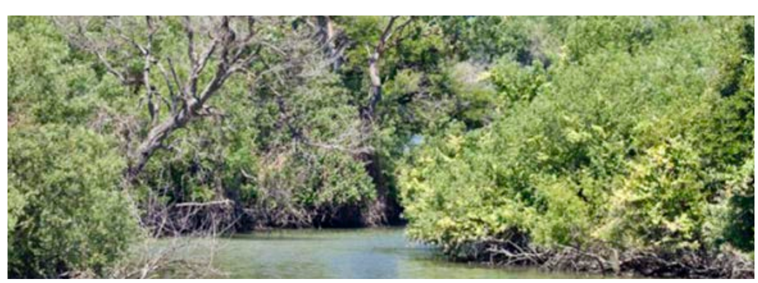


7. Life-History Support for Riparian Wildlife

Woody riparian habitats form the interface between aquatic environments and adjacent areas, providing structurally complex environments that support diverse species. Historically, broad riparian forests and willow shrubs, elevated on natural levees, lined the Sacramento and San Joaquin rivers and their major tributaries. These habitat types were shaped by hydrologic and geomorphic disturbance: floods built up natural levees and stimulated successional processes of riparian forests. These natural levees extended far into the marsh, providing dryland access deep into the Delta's marshes for terrestrial species.[1] The vertical structure and plant diversity of riparian forests provided abundant food resources and sites for numerous resident and migratory birds to forage, nest, and roost.[2] The woody vegetation also provided shade and contributed allochthonous inputs to the river that supported aquatic species, including anadromous fish.[3]

There was considerable heterogeneity within woody riparian habitats, particularly between riparian forests in the north and south Delta. Riparian forests historically were largely confined to the north and south Delta because of the Sacramento and San Joaquin rivers' loss of stream power and ability to build large natural levees as they entered the central Delta. In the north Delta, riparian vegetation consisted of broad riparian forests dominated by oaks and sycamores, often a half mile wide, with a multilayered and diverse understory composed of willow, alder, buttonbush, dogwood, box elder, buckeye, grape, wild rose, and numerous herbaceous species. Riparian areas along the San Joaquin River were narrower and dominated by willows and other shrubs. There was considerable lateral and upstream/downstream heterogeneity within these habitats. Vegetation varied with the elevation of natural levees, with the highest areas supporting large trees, while the wetland and channel edges supported willows and grasses. Compared with areas farther upstream, the downstream reaches of woody riparian habitats were narrower and increasingly dominated by willows and marsh vegetation. Vegetative structure was influenced by channel size, with larger channels often supporting more extensive woody riparian habitat, due to the larger size of their natural levees. Willow-fern complexes in the central Delta may have also provided some support to riparian species, though they differed in habitat structure and continuity from other riparian habitat types.[4]

Despite comprising only a small proportion of the total area of the historical Delta (7%), riparian forests provided important habitat for a diverse suite of species. Woody riparian habitats likely served as movement corridors for far-ranging terrestrial mammals such as coyotes and mule deer as well as smaller mammals including gray fox, long-tailed weasels, and ringtails.[5] The south Delta forests provided important habitat for several endemic species, including the riparian brush rabbit, riparian woodrat, and valley elderberry longhorn beetle.[6] Riparian forests in the Central Valley were particularly important to both resident and migratory birds, supporting a diverse and abundant assemblage of species.[7] These forests contained high densities of breeding birds compared to other habitats, and provided nesting habitat for Red-shouldered Hawks, Swainson's Hawk, Western Yellow-billed Cuckoos, Willow Flycatchers, Least Bell's Vireos, Yellow Warblers, Yellow-breasted Chats, and Blue Grosbeaks.[8]



Riparian forests offered many nesting niches—on the ground, in shrubs and trees, on branches, and in tree cavities. Forests dominated by large oaks and sycamores were particularly important to cavity nesters, including Wood Ducks, Downy Woodpeckers, Oak Titmouse, and Ash-throated Flycatchers. Large riparian trees supported breeding and roosting colonies of herons, egrets, and cormorants. Oak-dominated riparian habitat supported high densities of wintering birds, especially Sharp-shinned Hawks, Hermit Thrushes, Yellow-rumped Warblers, and Golden-crowned Sparrows.[9] These habitats were also used by passing migrants, and may have been especially important to fall migrants that glean insects (e.g., Wilson's Warblers, Western Tanagers) because other green, insect-rich vegetation was sparse at that time of year.[10]

Existing woody riparian habitat occupies 40% of its historical extent, but these areas are now severely fragmented, with virtually no wide corridors of riparian forest remaining. Today's narrow patches are structurally simpler and more homogeneous than historical woody riparian habitats, often lacking the complex microtopography, moisture gradients, vegetative structure, and diversity which provided essential ecosystem services, such as erosion control and riparian forest regeneration.[11] As mapped, 90% of historical Delta woody riparian habitat was riparian forest; today only 58% is forest, and the rest is willow shrub habitat.

Riparian species once common in the Delta are in decline. The endangered Western Yellow-billed Cuckoo, Least Bell's Vireo, and other species no longer breed in the Delta.[12] The decline in nesting Cooper's Hawks and Western Yellow-billed Cuckoos is thought to be a direct result of the loss and fragmentation of available habitat, as both species require large territories to breed.[13] Riparian species have been impacted by degraded habitat quality, that is often hydrologically disconnected from adjoining rivers. Agricultural development adjacent to woody riparian habitats has facilitated movement of non-native Brown-headed Cowbirds and European Starlings into these habitats, negatively impacting native birds through nesting cavity competition and reduced nest success.[14] Levees (with hardened edges and lack of regeneration from flooding) adjacent to woody riparian habitats have allowed non-native predators (feral dogs, cats, and rats) increased access to these habitats, to the detriment of riparian brush rabbits, riparian woodrats, and other species.[15] Riparian brush rabbits have also been impacted by the lack of suitable habitat above regular flood levels that previously provided protection from weather and predators.[16]

The position of woody riparian habitats within the modern Delta landscape has become less coherent. Whereas woody riparian habitat historically lined large rivers and tributaries in continuous bands, today small disconnected riparian patches exist scattershot across the entire Delta, including the central Delta where these habitats were historically absent. In many instances "riparian habitats" are separated from the rivers that created them by artificial levees and upland areas, and are thus disconnected from the physical processes sustain them. Restoration of continuous, self-sustaining woody riparian habitats in the Delta may be particularly important in the face of climate change, because these habitats provide linear habitat connectivity, link aquatic and terrestrial ecosystems, and create thermal refugia for wildlife.[17]

Riparian wildlife (below). Left to right: riparian brush rabbit, riparian vegetation, long-tailed weasel, male valley elderberry longhorn beetle, coyote.

Photo Credits: Brian Hansen, USFWS; William Miller; Rick Kimble, USFWS; Jon Katz and Joe Silveira, USFWS; Steve Thompson, USFWS

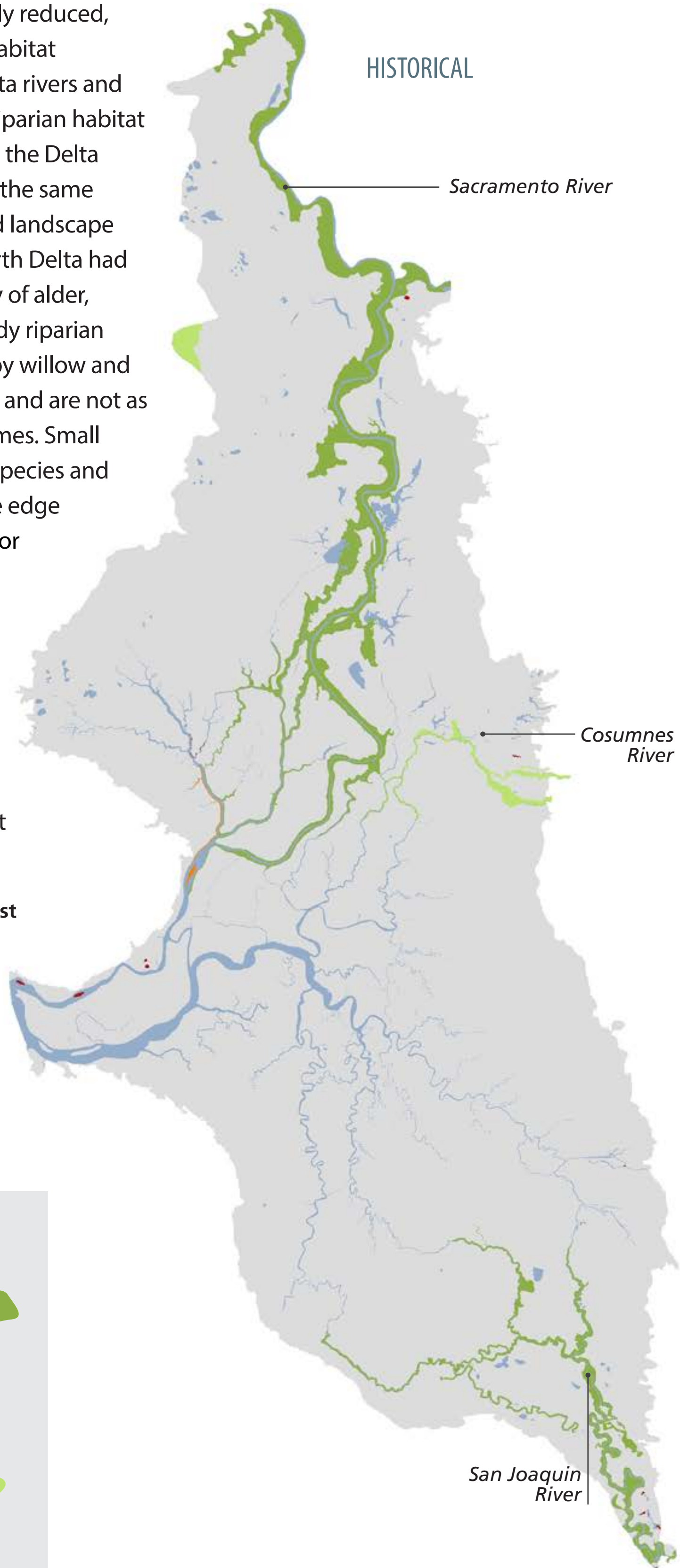
Modern woody riparian habitat is highly fragmented

Large, continuous riparian forest is gone, except along the Cosumnes River

The woody riparian habitats in the Delta today are severely reduced, fragmented, and degraded. Historically, woody riparian habitat existed as large continuous corridors along the major Delta rivers and tributaries in the north and south Delta. Modern woody riparian habitat is a scattering of small discontinuous patches throughout the Delta that no longer support resident and migratory species to the same degree, due to differences in habitat quantity, quality, and landscape configuration. Historical gallery riparian forests in the north Delta had canopies of oak and sycamore with a complex understory of alder, willow, blackberry, and many other species. Modern woody riparian habitats are smaller, simpler systems, largely dominated by willow and invasive understory plants associated with narrow levees, and are not as exposed to regenerative disturbance regimes. Small habitat fragments support fewer species and smaller populations with more edge effects. Researchers found, for example, that Western Yellow-billed Cuckoos in northern and southern California are six times more likely to be found in habitat patches 40-80 ha than patches 20-40 ha (they were detected in all habitat patches larger than 80 ha).[18]

Western Yellow-billed Cuckoo

Historical riparian habitat was predominately continuous forest (right), while today woody riparian habitat is scattered throughout the Delta in small isolated patches (far right). The longest stretch of contiguous riparian forest[19] historically spanned more than 55 km (from the Feather River confluence to Miner Slough), providing a migration corridor across much of the Delta. The longest current stretch of woody riparian habitat extends 16 km (along Elk/ Sutter Slough).



Methods: Riparian patch size

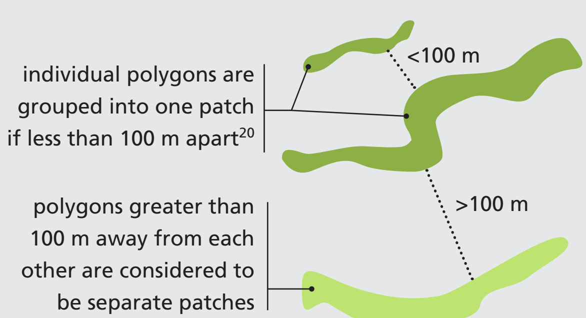
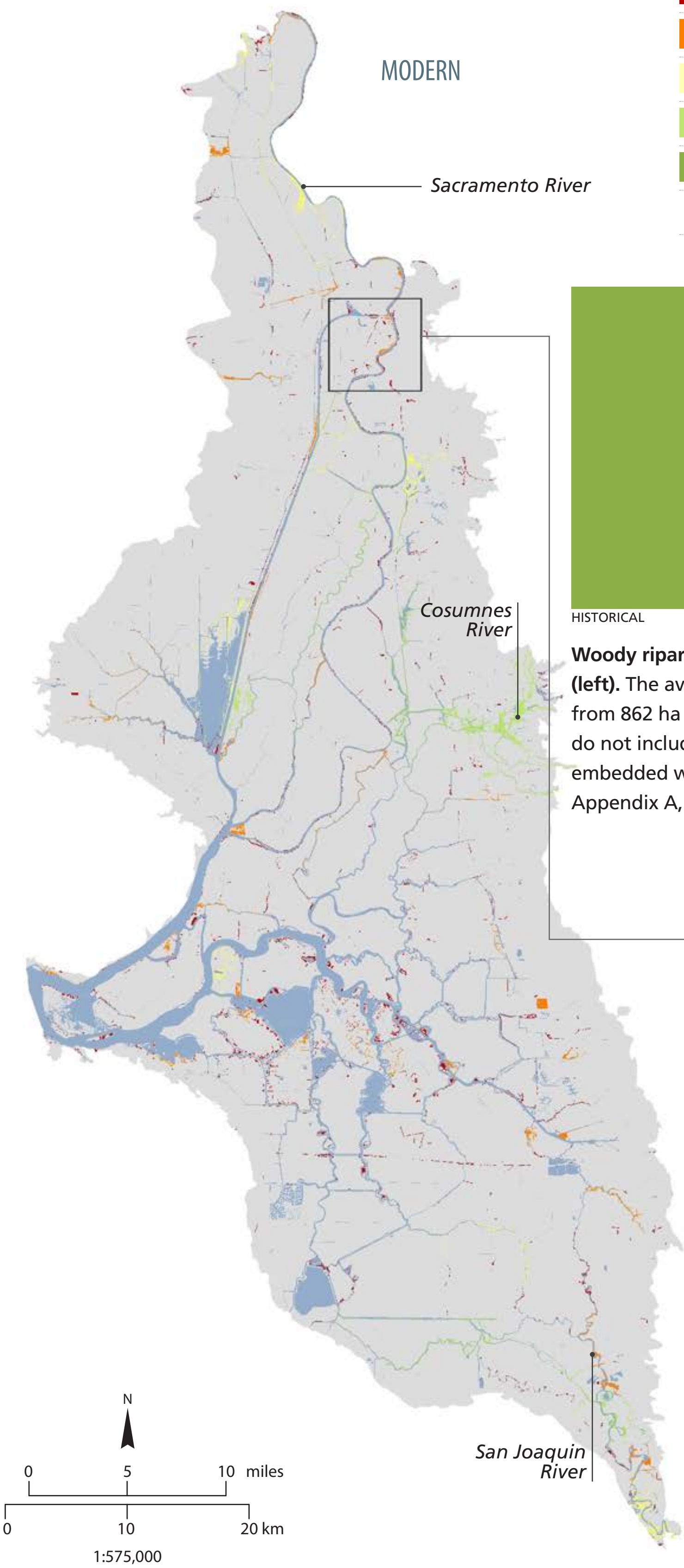
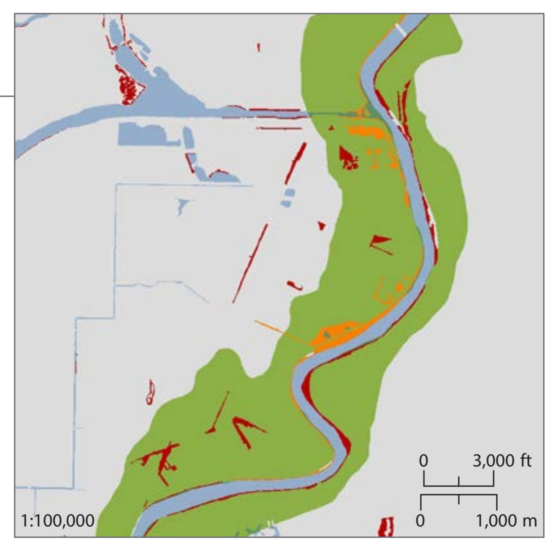


Photo Credit: Factumquintus, Wikipedia Commons



	Woody riparian patch size class (ha)	Total area (ha) Historical	Modern
(red)	<= 20 ha	88	1,991
(orange)	20 - 80	113	1,364
(pale yellow)	80 - 320	0	1,470
(light green)	320 - 1,280	1,594	2,066
(green)	>1,280	15,449	0
	TOTAL	**17,244**	**6,890**

Woody riparian habitat extent in the Delta has been reduced by 60% (left). The average woody riparian patch size in the Delta has decreased from 862 ha (SD = 2,785 ha) to 6 ha (SD = 45 ha). These maps and figures do not include an estimated 3,500 ha of unmapped willow patches embedded within the tule marshes of the historical central Delta (see Appendix A, page 91).



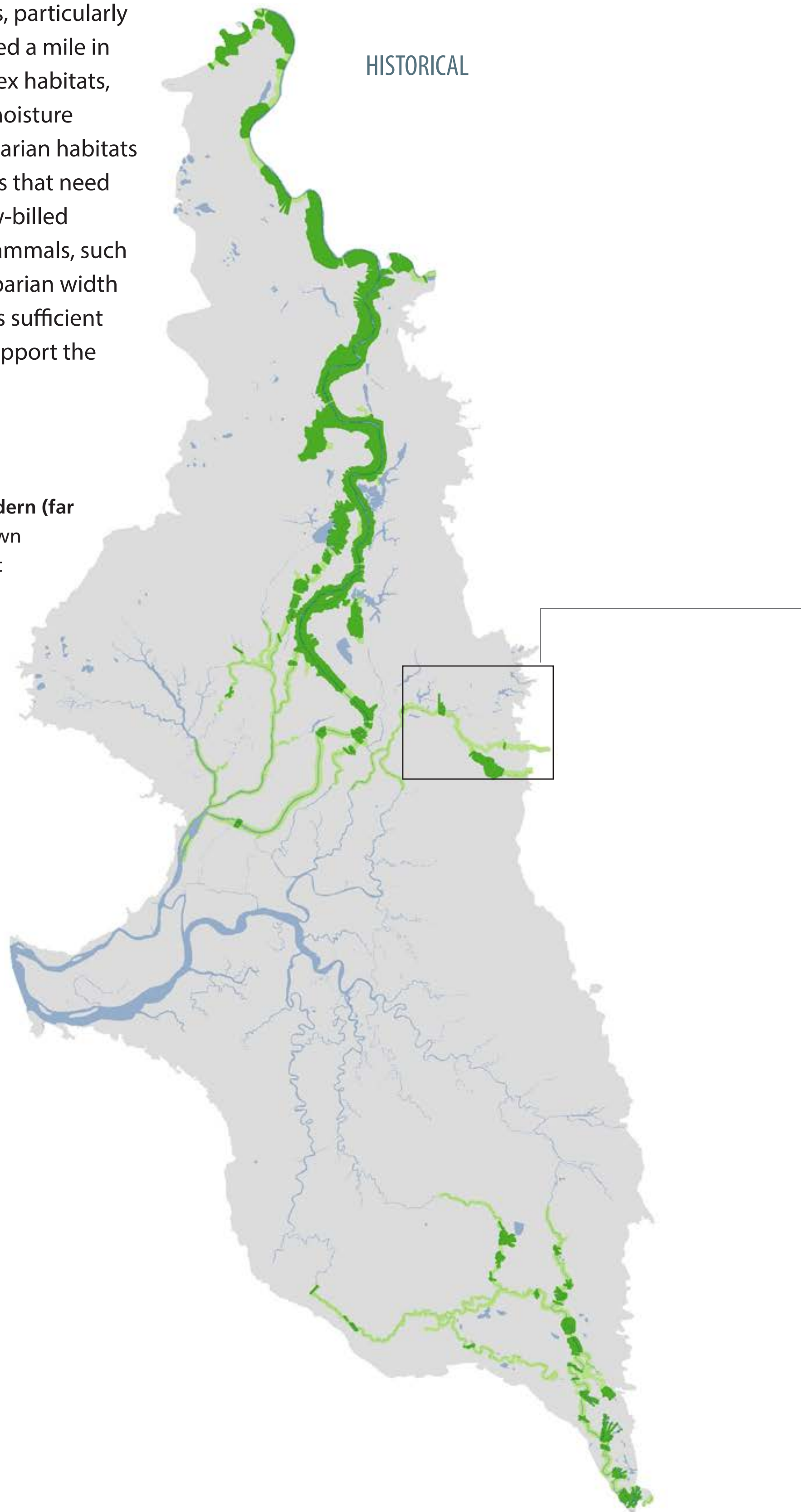
Historically, woody riparian habitat along the Sacramento River formed a wide continuous band of forest—the woody riparian habitat that exists today is made up of many small habitat fragments (above). Historical woody riparian habitat is shown in green with modern woody riparian habitat overlaid in red and orange (depending on their patch size).

Riparian width

Wide woody riparian habitat has declined by 72%

Wide riparian corridors provided habitat complexity and supported species with large home ranges

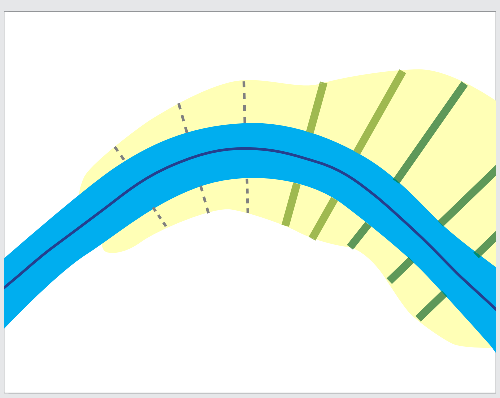
Historically, the Delta contained wide riparian corridors, particularly in the north Delta where the riparian forest could exceed a mile in width. These wide riparian corridors supported complex habitats, with many vegetative zones influenced by elevation, moisture gradients, and disturbance patterns. Interior woody riparian habitats were buffered from edge effects and supported species that need large riparian areas, particularly nesting Western Yellow-billed Cuckoos and Cooper's Hawks, as well as far-ranging mammals, such as coyotes. A review of the literature on the effect of riparian width on birds found that while a riparian width of 100 m was sufficient for many species, a width of 500 m was necessary to support the complete avian community.[21]

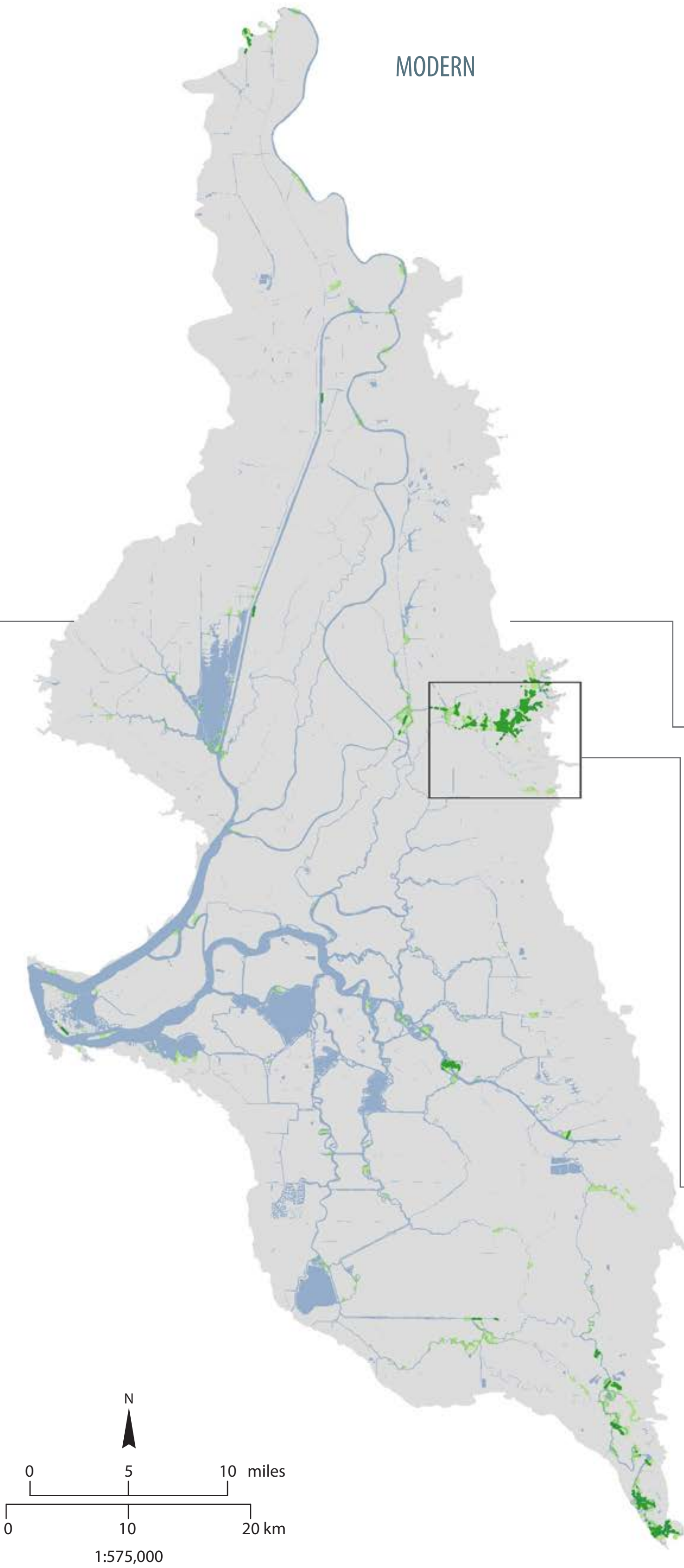


Wide woody riparian habitat in the historical (right) and modern (far right) Delta. Woody riparian habitat wider than 500 m is shown in dark green, and habitat wider than 100 m is shown in light green. The width of the riparian habitat was determined by the river's ability to build natural levees above the marsh of the interior Delta, creating well-drained soils that supported trees. In general, the width and height of riparian habitat declined as the large river systems spread into the central Delta.

Methods: Calculating riparian widths

Transects were cast perpendicular to channels at 100 m intervals. The width of each transect was summed (excluding channels) where it overlapped riparian habitat (shown in yellow below). On the map and in the diagram below, transects wider than 100 m are in light green, and transects wider than 500 m are in dark green. Transects less than 100 m wide (dotted lines below) are not shown on the map. See Appendix A for details.

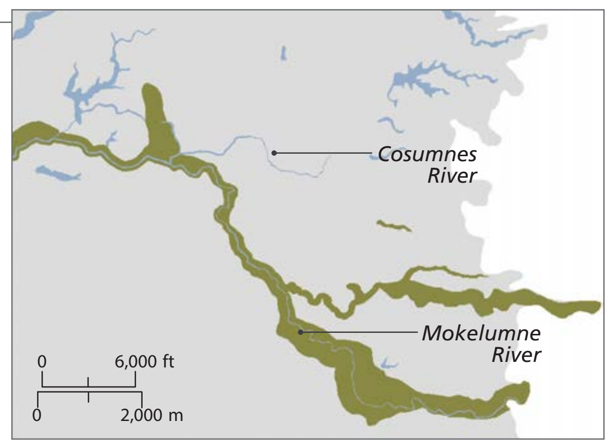




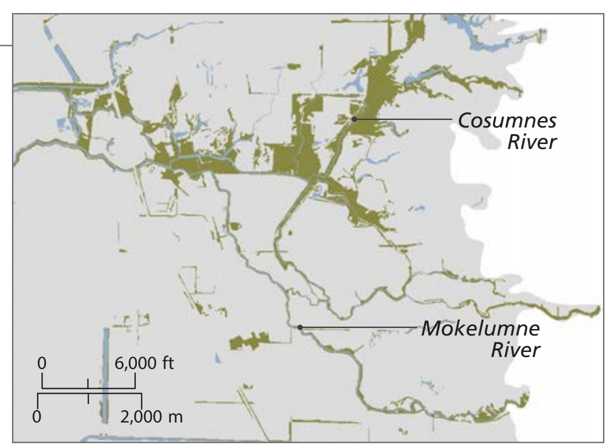
	Woody riparian habitat width (m)	Woody riparian habitat length (km)	
		Historical	*Modern*
NOT SHOWN ON MAP	0 - 100 m	37	626
	100 - 500	239	87
	> 500	116	11
	TOTAL	**393**	**723**

The length of wide riparian habitat has declined. Nearly all (87%) of the woody riparian habitat in the modern Delta is less than 100 m wide, and less than 2% of the habitat is greater than 500 m wide.

The largest cluster of woody riparian habitat >500 m wide is the restored habitat along the Cosumnes River (below). Historically, the Mokelumne River supported wide riparian forest on natural levees. Due to changes in groundwater levels, land use, and channel incision, the majority of woody riparian habitat is now located along the Cosumnes River in an area that historically supported freshwater emergent marsh and wet meadow.[22] However, this wide and complex riparian habitat provides many of the ecological functions that riparian habitat provided historically in other places in the Delta.



HISTORICAL



MODERN

8. Life-History Support for Marsh-Terrestrial Transition Zone Wildlife

The edge (or transition zone) of the Delta marsh provided ecological functions critical for many wildlife groups. The ecological functions of this transition zone varied depending on its position within the Delta. The extensive freshwater emergent marsh was bounded by elevation, with the upslope side transitioning into terrestrial habitats across a broad zone. Seasonal wetlands, including alkali wetlands and vernal pools, were found along the gently sloping upland transition in the northwest and southwest Delta,[1] while grasslands, oak savannas, and woodlands were found along the steeper, well-drained alluvial fans bordering the Delta to the east. The transition zone occurred primarily along the periphery of the Delta, with the exceptions of long corridors of riparian forest extending into the marsh and scattered sand dunes that punctuated the marsh in the southwest Delta. The relatively continuous transition zone along the periphery of the Delta would have supported dispersal and other movement of amphibians and reptiles dependent on both wetland and upland habitats (e.g., giant garter snake, California red-legged frog, and Western pond turtle).[2] Riparian corridors provided predators like bats, weasels, and coyotes with access to abundant prey from the productive marsh.[3] Riparian habitat also provided North American river otters with denning sites near the marsh but above frequently flooded elevations. Sand dunes (isolated upland patches within the Delta) provided important flooding refuge and predator protection.[4] The central Delta consisted of tidal marsh channels that lacked the stream power to build large natural levees, leaving this part of the Delta farther from any terrestrial transition zone.

Habitats occurring next to the marsh varied across the Delta, based on gradients in hydrology, topography, and soil. Along the northwest Delta where slopes were gradual and characterized by heavy clay soils, the marsh transitioned to seasonal wetlands interspersed with vernal pools. These seasonal wetlands were variable and complex, with inundation and vegetation patterns sensitive to small-scale changes in hydrology and topography. Seasonal wetlands in the northwest Delta were inundated by intermittent streams that lost channel definition before reaching the marsh and sometimes by the large floods of the Sacramento River. Along the eastern edge of the Delta the marsh transitioned to alkali wetland and oak savanna. Alkali wetlands, characterized by evaporative salt residues, were found in areas inundated only by extreme flooding. The oak savanna occurred on the well-drained soils of the alluvial fans that bordered the eastern side of the Delta, built by the Calaveras and Mokelumne rivers. To the south where soils were shallower, alkali wetlands were interspersed with grassland habitats. The interior dune scrub found along the southwestern edge of the Delta was a relic of Pleistocene dunes. The width and complexity of the transition zone was greater in areas with more gradual slopes, particularly areas supporting seasonal wetland.[5] These gradual transitions allowed movement and adaptation for particular species along moisture and elevation gradients.

The habitats adjacent to the marsh were key for wildlife in their own right, in addition to the transition zone species they supported. While none of these habitat types were unique to the Delta periphery, their proximity to Delta wetlands benefited the species they supported (e.g., by providing access to freshwater in the summer). The number of different habitat types adjacent to Delta marshes augmented the overall biodiversity of the region. Many of the species once associated with habitats adjacent to marsh are species of concern or otherwise important to land managers within the Delta today. Riparian forests supported migratory songbirds and several protected species of small mammals (e.g., riparian woodrat, riparian brush rabbit).[6] Seasonal wetlands provided habitat for many species of migratory waterbirds and amphibians.[7] Alkali wetlands and vernal pools supported many endemic plants and invertebrates.[8] Grasslands were important to many species now extirpated or uncommon in the Delta, including large mammals, such as grizzly bears, pronghorn, and tule elk.[9] Vernal pools, alkali wetlands, grasslands, and sand dunes are discussed in more detail below because of the number of endemic species they supported and their importance to overall Delta biodiversity.

The terrestrial transition zone was comprised primarily of seasonal wetlands which expanded the availability of wetland and aquatic habitat at certain times of the year. The majority of seasonal wetlands were found bordering the north Delta and encompassed a diverse range of plant communities, perhaps owing to variable inundation frequencies, dry-season dessication, topographic complexity, soil types, and freshwater inputs or "sinks" from tributaries. Vernal pools and alkali complexes were often intergraded with the seasonal wetlands, particularly in the southern parts of the Delta margin where drier conditions promoted the accumulation of salts in soils. When flooded, seasonal wetlands provided connectivity for terrestrial species such the giant garter snake between the nutrient-rich Delta and the surrounding valley, as well as short-term foraging habitat for certain aquatic species.

Vernal pools and alkali seasonal wetlands in particular supported many unique species. Vernal pools tend to support endemic species uniquely adapted to their hydrology. These are ephemeral wetlands characterized by shallow depressions that are inundated for too long to support upland species, but not long enough to support aquatic species.[10] Many vernal pool plants are specially adapted annuals that grow quickly as the ponds dry. Several invertebrates and amphibians use these pools to breed, taking advantage of the lack of predatory fish. Special status species supported by vernal pools included California linderiella, conservancy fairy shrimp, longhorn fairy shrimp, midvalley fairy shrimp, vernal pool fairy shrimp, and vernal pool tadpole shrimp.[11] The alkali seasonal wetlands that characterized much of the periphery of the Delta were complex habitats made up of small brackish ponds, perennially wet alkali marsh, alkali sink scrub, and seasonally inundated alkali meadow.[12] These habitats supported many unique plant species adapted to alkaline conditions, including saltgrass, swamp grass, Delta button celery, popcorn flower, iodinebush, San Joaquin spearscale, and the now potentially extinct caper-fruited tropidocarpum.[13]

The Delta edge (below). Left to right: Suisun Marsh, San Joaquin kit fox, Guadalcanal Mitigation Site, tule elk.

Photo Credits: Daniel Burmester, CDFW; Carley Sweet, USFWS; Gena Lasko, CDFW; Steve Martarano, USFWS

Grasslands were important to a diverse suite of wildlife, many of which are now locally threatened or endangered. Prior to non-native annual grasses establishing dominance, these habitats were believed to be dominated by forbs, with some annual and perennial grasses intermixed.[14] Grassland and savanna habitats were important to far-ranging large mammals that occasionally ventured into the marsh, including grizzly bears, mule deer, and tule elk. These grasslands supported many species of burrowing animals, such as California ground squirrels, California voles, and San Joaquin kangaroo rats, which created topography and structure important to Western Burrowing Owls, giant garter snakes, spadefoot toads, and California tiger salamanders. Swainson's Hawks foraged in grasslands historically.[15] The Meadowlark, Short-eared Owl, Horned Lark, Savannah Sparrow, and San Joaquin kit fox were also associated with these grasslands.[16]

Scattered sand mounds—high points of glacial-age eolian dunes—rose above the marsh plain, adding supra-tidal topographic variation and habitat complexity to the flat terrain of the western Delta. The mounds supported numerous species of plants and animals that would have otherwise been unable to persist within the Delta's tidal environment, such as lupine, the special status Antioch Dunes evening primrose, the western wallflower (Contra Costa wallflower), the endangered Lange's metalmark butterfly, and even live oaks on certain dunes with a developed soil profile. Tule elk were observed to have used these sites as protected breeding and foraging habitat, since the mounds offered some protection from larger predators less likely to venture far into the marsh. These areas of high elevation were also used and sometimes augmented by the indigenous communities who lived in and around the Delta. Sand dunes, as well as large man-made mounds, or middens, were often occupied by village sites, as they were in close proximity to the rich abundance of food and resources provided by the Delta but were protected from daily tidal flooding.[17]

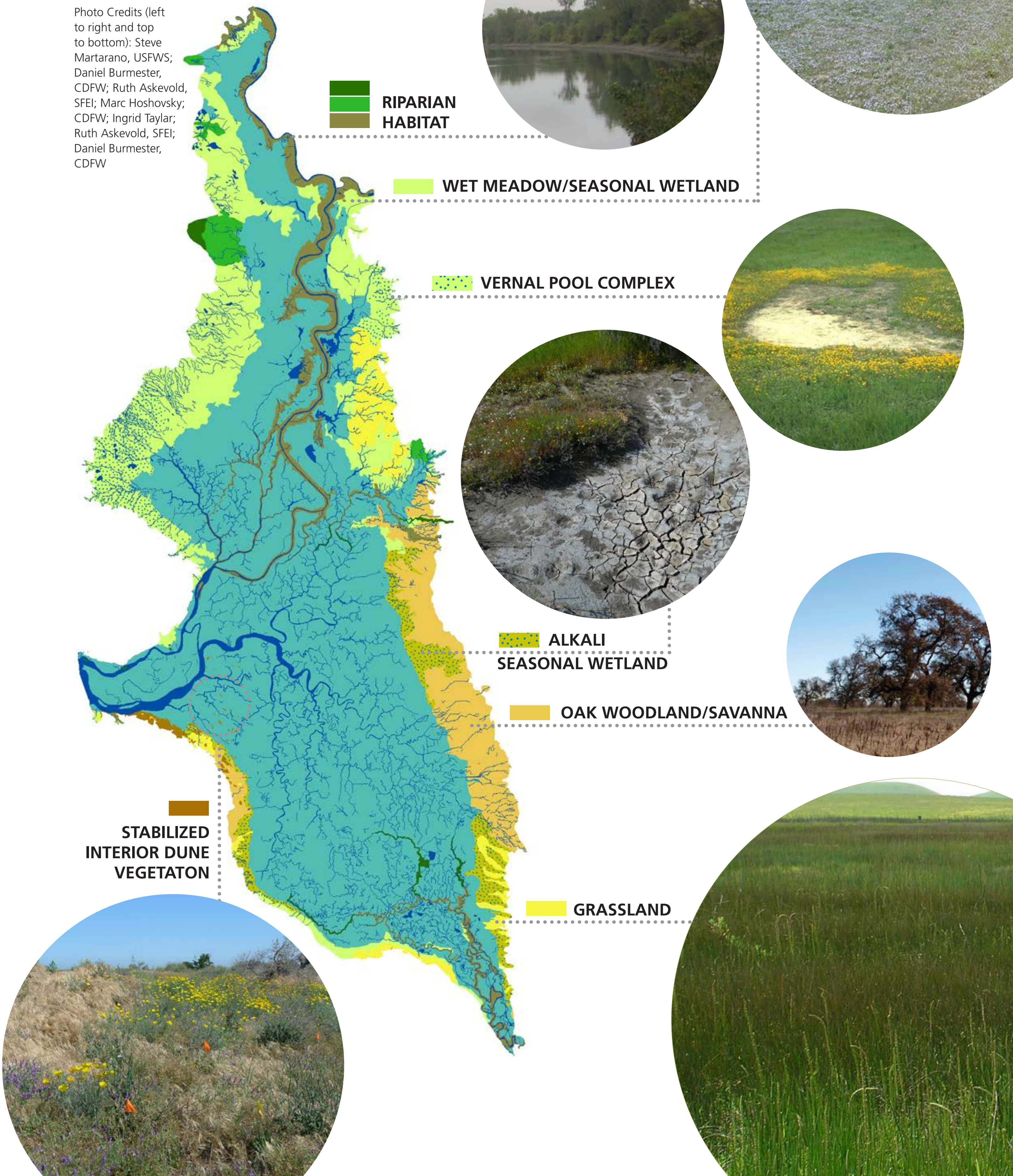
The marsh-terrestrial transition zone in the Delta has been dramatically reduced, fragmented, and degraded. This loss is largely due to the 97% reduction in marsh and the conversion of adjacent habitats to agriculture and development. Much of the remaining marsh occurs as islands in the central and west Delta, in places where the marsh-terrestrial transition zone was never present historically. The terrestrial boundary of modern marshes, where it does exist, is often characterized by an abrupt transition to upland or man-made structures, such as a steep, sparsely-vegetated rock levees and other inflexible edges that offer little in the way of cover, gradients, or habitat value. In addition, remaining marsh patches may no longer provide the same food subsidy to terrestrial species because of their greatly reduced size. The marsh-terrestrial transition zone once formed a complex but continuous band, predictable along hydrological and elevation gradients. That transition zone is now fragmented and disorganized, making it difficult for wildlife to anticipate resources available from the edge.

The terrestrial habitats that occur in the Delta today are largely disconnected from the marsh and from the processes that established and maintained these habitats historically. The dominant habitats in the modern Delta are grasslands and seasonal wetlands that occur in the center of the Delta as often as the periphery. The location of many of these habitats makes them particularly vulnerable to sea level rise. The hydrology of seasonal wetlands is heavily managed and disconnected from seasonal flooding patterns, and seasonal wetlands are now found where perennial wetlands once existed. Agricultural fields and ditches provide a limited portion of the natural functions provided by seasonal wetlands, do not support the same hydrologic regime, and experience stress from human disturbances and contaminants.

The transition zone is critical for a future Delta that can support terrestrial wildlife. Restoring gentle habitat transitions along a natural elevation gradient now will facilitate marsh transgression in the future as sea level rises.[18] The greatest marsh restoration opportunities are located along the periphery of the Delta because these areas are less subsided.

Contemporary photographs of terrestrial habitat types along the Delta's edge. These habitat types also formed marsh-terrestrial transition zones where they graded into emergent wetlands.

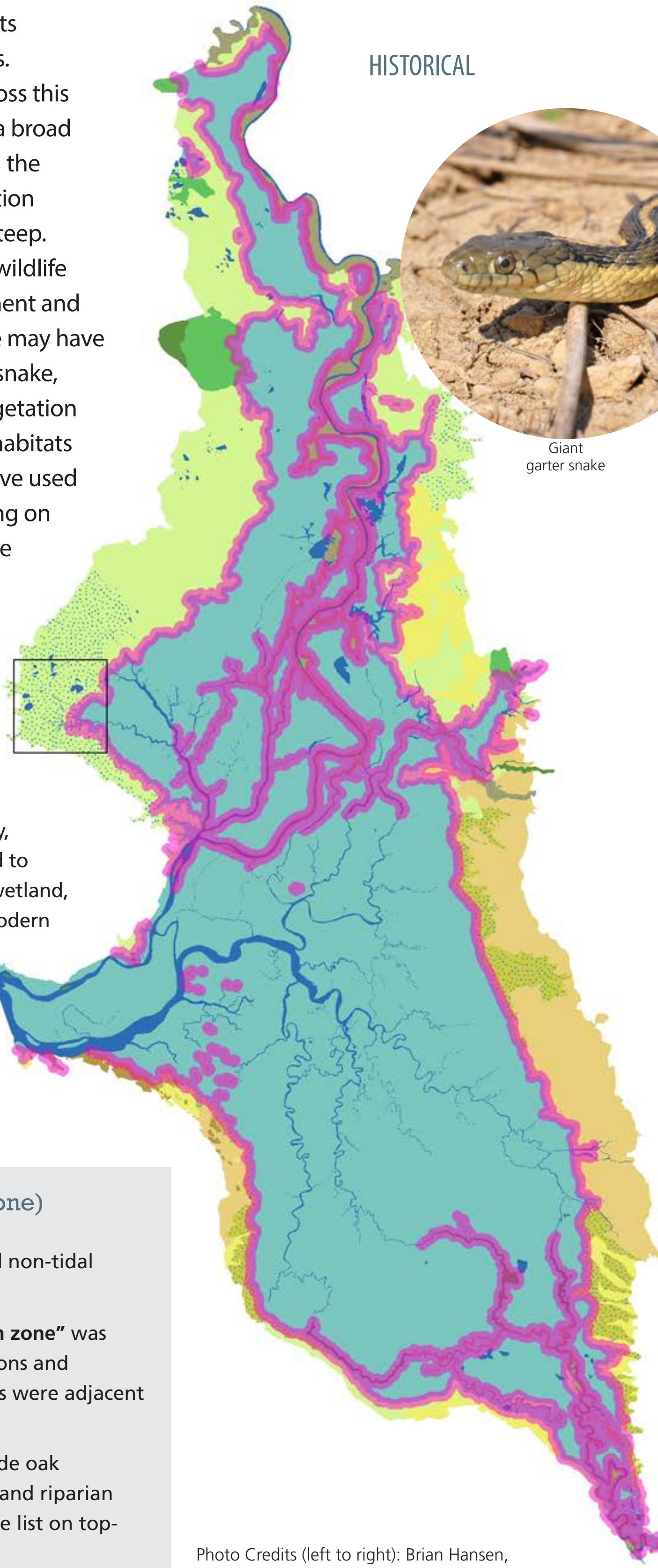
Photo Credits (left to right and top to bottom): Steve Martarano, USFWS; Daniel Burmester, CDFW; Ruth Askevold, SFEI; Marc Hoshovsky; CDFW; Ingrid Taylar; Ruth Askevold, SFEI; Daniel Burmester, CDFW



The historical marsh-terrestrial transition zone was continuous and gradual

Today's marsh-terrestrial transition zones are fragmented

The transition zone between marsh and terrestrial habitats supported many wildlife species and ecological functions. Animals, organic matter, sediment, and water moved across this wide, complex, and heterogeneous area that supported a broad moisture gradient. Continuous transition zones bordered the Delta periphery and major riparian corridors. Most transition zones were wide and gradual, yet some were short and steep. This continuity and variability allowed diverse terrestrial wildlife to access wetland habitat, and was critical for the movement and dispersal of transition-zone obligates. The transition zone may have been particularly important to the endemic giant garter snake, which used aquatic habitats dominated by emergent vegetation from early spring to mid-fall, and drier, higher-elevation habitats during winter dormancy. Foraging birds and bats may have used seasonal wetlands at different times of the year depending on inundation and food production. In the modern Delta, the terrestrial edge is fragmented and narrow, providing less foraging access, cover, and movement corridors.

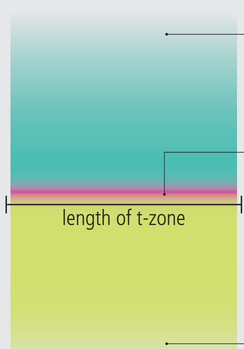


Giant garter snake

Marsh-terrestrial transition zones in the historical (right) and modern (far right) Delta, represented by pink lines. Historically, much of the marsh gradually transitioned to seasonal wetland, vernal pool, alkali wetland, or riparian forest. In contrast, the modern transition zone is discontinuous and rapidly shifts to mostly grassland. Modern grasslands are heavily altered habitats, and modern transition zones are often steep levees.

Marsh-terrestrial transition zone

Methods: Marsh-terrestrial transition zone (T-zone)

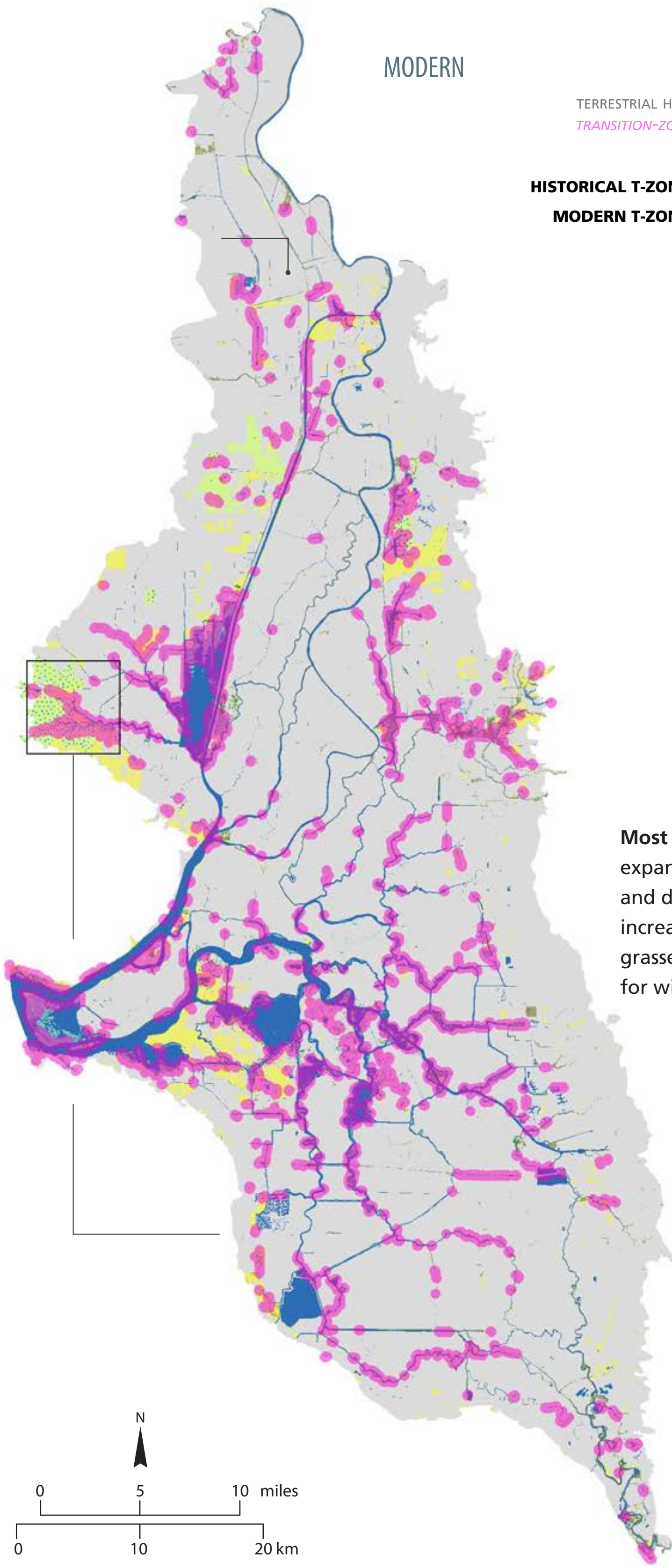


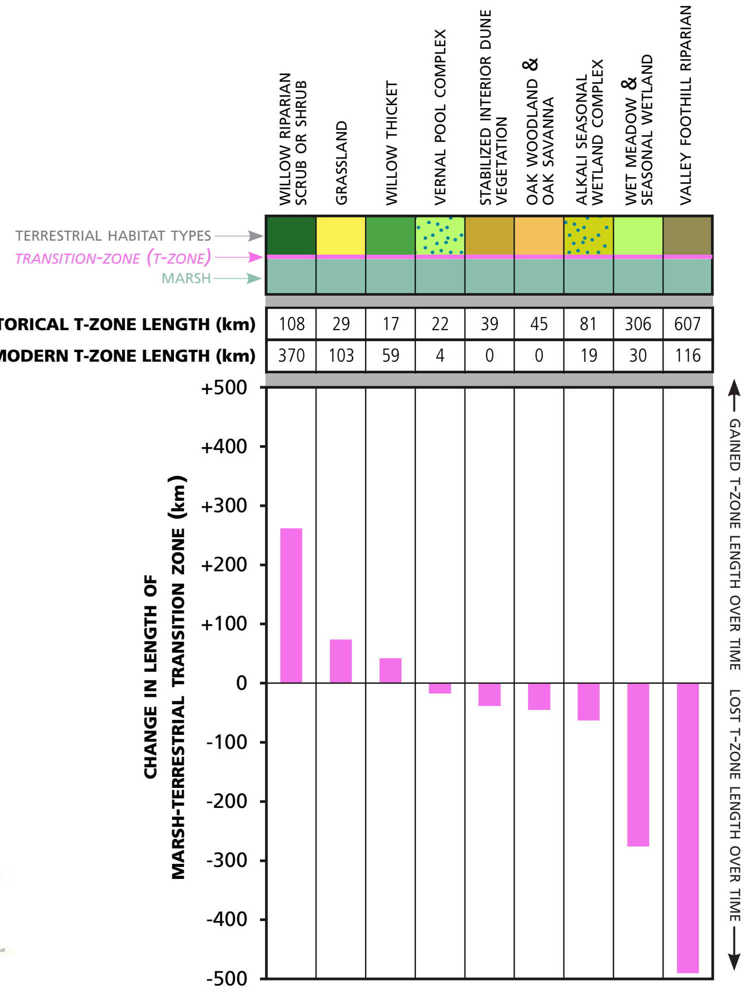
"marsh" includes both tidal and non-tidal freshwater emergent wetland

the **"marsh-terrestrial transition zone"** was mapped wherever marsh polygons and terrestrial habitat type polygons were adjacent to one another

"terrestrial habitat types" include oak woodlands, seasonal wetlands, and riparian habitat types, among others (see list on top-right of facing page)

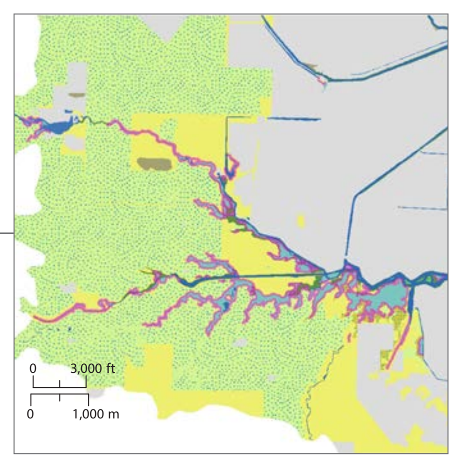
Photo Credits (left to right): Brian Hansen, USFWS; Daniel Burmester, CDFW





	WILLOW RIPARIAN SCRUB OR SHRUB	GRASSLAND	WILLOW THICKET	VERNAL POOL COMPLEX	STABILIZED INTERIOR DUNE VEGETATION	OAK WOODLAND & OAK SAVANNA	ALKALI SEASONAL WETLAND COMPLEX	WET MEADOW & SEASONAL WETLAND	VALLEY FOOTHILL RIPARIAN
HISTORICAL T-ZONE LENGTH (km)	108	29	17	22	39	45	81	306	607
MODERN T-ZONE LENGTH (km)	370	103	59	4	0	0	19	30	116

Most transition zone types are greatly reduced. A few types have expanded in quantity, but these tend to be relatively fragmented and disturbed. For example, although the extent of grassland has increased, modern grasslands are dominated by non-native annual grasses, which has changed the timing and availability of resources for wildlife.



The longest continuous unleveed marsh-terrestrial transition zone left in the Delta is along Lindsey Slough (above). This area offers restoration opportunities to improve support for species using the transition zone.

Conclusion

The Delta has undergone a massive physical and biological transformation during the past two centuries. The native plant and animal species that lived and evolved in the Delta now reside in a completely different environment. With the benefit of historical research and contemporary ecological knowledge, we can infer how the pre-development Delta supported native wildlife, and identify the missing functions in today's landscape.

Most fundamentally, the historical Delta was a vast wetland complex composed of an array of habitat types, primarily freshwater marsh, defined by varying cycles of inundation. Differential patterns of flooding, from both rivers and tides, created and maintained tule marshes, lakes, seasonal wetlands, willow thickets, and riparian forests. The disconnection of natural flooding processes due to the construction of levees has profoundly altered the Delta landscape, reducing the natural resilience of the Delta's landforms and wildlife populations. The excavation of channels and building of levees created a dichotomous landscape of dry land and open water where once existed much more variable and dynamic wetlands.

Severe declines in Delta wildlife and likely future impacts from climate change and other drivers motivate a desire to restore a resilient landscape with improved wildlife support functions. Yet the major physical changes to the system, as well as the impacts from invasive species, water diversions, and other stressors, make it difficult to envision how Delta ecosystems could work successfully in the future. The native ecosystems of the Delta are altered and reduced, with few functional examples to learn from. Today's novel Delta ecosystems illustrate stressors but provide few attributes to emulate. The way forward is to design functional landscapes that can take advantage of native geomorphic templates and restorable physical and biological processes to shift the current novel Delta ecosystems toward greater wildlife support functions.

The landscape metrics presented here offer a new set of tools to analyze, design, and evaluate Delta restoration scenarios and outcomes. In the next steps of the Delta Landscapes project, the metrics and other information about past, present, and projected future conditions will be used to develop conceptual restoration visions for the Delta.

For more information, please visit: www.sfei.org/projects/delta-landscapes-project.

Appendix A: Methods

1. STUDY EXTENT

Our study extent is defined by the area mapped in the SFEI-ASC *Sacramento-San Joaquin Delta Historical Ecology Investigation*.[1] As detailed in that report, this area was selected to include the full extent of the Delta's historical tidal wetlands, adjacent non-tidal freshwater wetlands, and upland transitional areas. The study area was generally defined as "the contiguous lands lying below 25 feet (7.6 m) in elevation." This differs from the extent of the legal Delta and "encompasses an area of about 800,000 acres, including parts of Sacramento, Yolo, Solano, Contra Costa, and San Joaquin counties. The boundary was defined using the National Elevation Dataset (NED) 10m-Resolution (⅓-Arc-Second) Digital Elevation Model (DEM)." The report authors "used GIS tools to generalize the boundary and removed upland (fluvial) channels less than 650 feet (200 m) wide." To avoid holes in the study area, the authors included small hillocks within the outer boundary and also included areas within the sinks of Putah and Cache creeks that were above the 25 foot (7.6 m) contour.

As in the *Sacramento-San Joaquin Delta Historical Ecology Investigation*, the western boundary of this study "was established at the west end of Sherman Island in order to match the historical ecology mapping previously completed for the Bay Area EcoAtlas and Baylands Ecosystem Habitat Goals Project (Goals Project 1999)." Upstream, "the study area falls at hydrogeomorphically logical locations. On the west side of the Sacramento River, the study area extends northward in the Yolo Basin to Knights Landing Ridge, also near where the Feather River enters the Sacramento River." Not included in this or the *Delta Historical Ecology* study was "the American Basin on the east side of the Sacramento River between the American and Feather rivers as it was completely non-tidal and extended well above the 25 foot (7.6 m) contour." The southern extent of the study area was defined as the confluence of the San Joaquin and Stanislaus rivers.[2]

2. HABITAT TYPE DATASETS

2.1 Sources for the historical Delta

GIS data depicting historical Delta habitat types were obtained from SFEI-ASC's *Sacramento-San Joaquin Delta Historical Ecology Investigation* (Table 1).[3] The dataset classifies the historical Delta into 17 habitat types, the majority of which are based on modern clas-

Table 1. Sources for historical and modern habitat type datasets.

Title	Citation	Minimum mapping unit	Minimum width	Incorporated area (ha)	Study extent coverage
Historical					
Sacramento-San Joaquin Delta Historical Ecology Investigation ***('SFEI 2012 Delta HE')***	Whipple et al. 2012	5 ha	15 m (channels only—narrower channels digitized as lines)	316,426	100%
Modern					
Vegetation and land use classification and map of the Sacramento-San Joaquin River Delta ***('CDFG 2007 Delta Vegetation')***	Hickson & Keeler-Wolf 2007	0.4 ha (water) 0.8 ha (vegetation)	10 m	253,457	80%
Central Valley Riparian Mapping Project ***('CDWR 2012 CVRMP')***	GIC 2012	0.4 hectares	≥10 m	60,761	19%
Natural Communities Mapping of the Cache Slough Complex vicinity from combined data sources ***('WWR 2013 CSCCA Natural Communities')***	WWR 2013	varies	varies	725	<1%
Bay Delta Conservation Plan Natural Communities Mapping ***('CDWR 2013 BDCP Natural Communities')***	DWR 2013	varies	varies	65	<1%
San Francisco Estuary Institute supplemental mapping ***('SFEI 2013 supplemental mapping')***	n/a	varies	varies	1,381	<1%

sification systems (Table 2, at end of Appendix A). Readers should refer to that report for detailed methods on defining and mapping each habitat type.

2.2 Sources for the modern Delta

Since no recent effort to map modern natural communities in the Delta covers the entire study extent, modern habitat data were compiled from multiple sources (Table 1) and then crosswalked, when possible, to the historical habitat types used by Whipple et al. (2012) (Table 3, at end of Appendix A; see Section 2.3 for information on the crosswalk utilized in this study). Additional habitat types were incorporated into the modern classification system when analogues to historical classifications were unavailable (e.g., 'Managed wetland,' 'Agriculture/Non-native/Ruderal,' and 'Urban/Barren').

The Vegetation Classification and Mapping Program's (VegCAMP) 2007 Sacramento-San Joaquin River Delta dataset ('CDFG 2007 Delta Vegetation')[4] served as the primary component of our modern habitat type layer. This mapping effort utilized true color 1-foot resolution aerial photography from the spring of 2002 (and from the summer of 2005 in some marginal areas) to classify 129 fine-scale to mid-scale vegetation mapping units within the extent of the legal Delta. Although the dataset is derived from imagery that is now more than a decade old, it is still the most comprehensive (with respect to extent and resolution of vegetation mapping units) available for the Delta. Eighty percent of our Modern Habitat Type layer was derived from this source.

Since our dataset extended beyond the boundaries of the legal Delta, the 'CDFG 2007 Delta Vegetation' dataset was supplemented with VegCAMP's 2012 Central Valley Riparian Mapping Project Group Level dataset ('CDWR 2012 CVRMP').[5] This mapping effort utilized 2009 National Agricultural Inventory Program (NAIP) aerial imagery, from which polygons were hand-digitized. Nineteen percent of our Modern Habitat Type layer was derived from this source.

When combined, the 'CDFG 2007 Delta Vegetation' and 'CDWR 2012 CVRMP' datasets provided coverage for more than 99% of our study extent. Remaining data gaps were filled with a combination of sources, including an unpublished natural communities dataset developed for the Cache Slough Complex Conservation Assessment (itself a combination of sources compiled by Wetlands and Water Resources, Inc.; '2013 CSCCA Natural Communities')[6] and a natural communities dataset developed for the Bay Delta Conservation Plan ('CDWR 2013 BDCP Natural Communities').[7] Polygons for the remaining areas without coverage were hand-digitized and classified by SFEI staff using Bing aerial photographs accessed in 2013 ('SFEI 2013 supplemental mapping').

A map displaying where each dataset was used to develop the modern habitat type layer can be found on page 15.

2.3 Historical-modern crosswalk

To compare the historical and contemporary landscape, we were required to crosswalk the detailed modern classifications (from each of the modern datasets listed above and in Table 1) to the habitat types utilized in the historical habitat types layer. The crosswalk from 'CDFG 2007 Delta Vegetation' mapping units to the historical habitat types was developed for the S*acramento-San Joaquin Delta Historical Ecology Investigation*[8] with the help of local experts (Table 3, at end of Appendix A).[9] Since the historical habitat types were based on modern classification systems, the crosswalking process was generally straightforward. However, several map units classified in the 2007 mapping were challenging to associate with a historical classification. It was determined that "Distichlis spicata- Annual Grasses," for example, should be placed in the "Wet meadow or seasonal wetland" category instead of the "Alkali seasonal wetland complex" category, as the area where it was extensively mapped (in the Yolo Bypass) is characterized by conditions more similar to the wet meadow or seasonal wetland type used for mapping the historical Delta.[10] Willow-dominated communities also posed challenges. The crosswalk attempted to group the modern alliances based on the historical habitat classification of whether the willows were part of a backwater swamp community (willow thicket), the dominant species along channel banks (willow riparian forest, scrub, or shrub), or were part of a forest with oaks (valley foothill riparian forest).

Since the fine-scale (mostly Alliance level) classifications of 'CDWR 2012 CVRMP' were derived from the 'CDFG 2007 Delta Veg' map, our crosswalk developed for the 2007 Delta layer was also applicable to the 2012 Central Valley layer. The medium-scale (mostly Group level) classifications of 'CDWR 2012 CVRMP,' however, had no existing crosswalk. The crosswalk for this dataset (presented in Table 3, at end of Appendix A) was developed by SFEI staff from group characteristic vegetation descriptions[11] and with input from local experts.[12]

'CDWR 2013 BDCP Natural Communities' and '2013 CSCCA Natural Communities' layers utilized the Multi-Species Conservation Strategy NCCP Habitat Types classifications,[13] which had already been related to the historical classification types (Table 2, at end of Appendix A) and were therefore simple to crosswalk (Table 3, at end of Appendix A).

For some purposes, the classifications established by the crosswalks were modified based on additional data and criteria (see Section 2.4).

2.4 Deviations from established crosswalk

2.4.1 Willow-marsh complex

Many polygons in the modern dataset classified as 'Freshwater emergent wetland' are ringed by a strip of vegetation classified as 'Willow thicket.' Conversations with California Department of Fish and Wildlife scientists and further examination of the underlying vegetation types crosswalked to 'Willow thicket' indicated that a significant percentage of polygons contained some freshwater emergent wetland species and thus might be considered part of a larger willow-marsh complex.[14] To capture this unique landscape feature also reported historically in the Central Delta,[15] we reclassified 'Willow thicket' polygons that contained freshwater emergent wetland species (and thus indicated a lower, wetter environment) as 'Willow-marsh complex.' We also selected contiguous 'Freshwater emergent wetland' polygons that intersected the new 'Willow-marsh complex' polygons and reclassified these as 'Willow-marsh complex.' Most of the modern Delta's in-channel marsh islands are classified as 'Willow-marsh complex.' For many metrics, 'Freshwater emergent wetland' and 'Willow-marsh complex' are lumped during analysis. This reclassification was particularly important for metrics addressing the marsh-water edge (since freshwater emergent wetlands ringed by a thin strip of willow thicket would not have any such edge). A list of the map units that composed the original 'Willow thicket' habitat type and an account of which units were reclassified as 'Willow-marsh complex' can be found in Table 4.

2.4.2 Managed wetlands

For the modern habitat type layer we sought to distinguish managed wetlands (characterized by novel forms and managed hydrographs, often separated from direct tidal action by tide gates and weirs, and commonly constructed to support waterfowl) from other wetland areas. Managed wetlands were identified with BDCP's Natural Communities dataset (2009-2013). Polygons with the 'SAIC_Type' of 'Managed wetland' were extracted from the BDCP layer and incorporated into our modern habitat map with ArcGIS's 'Union' tool. Since both datasets were compiled, in large part, from CDFW's Delta Vegetation dataset,[16] alignment between the two datasets was quite high. Additional managed wetlands were identified by SFEI staff from modern aerial images.

2.4.3 Riparian connectivity

Not all polygons in the modern dataset classified as riparian vegetation types ('Valley foothill riparian' and 'Willow riparian scrub/shrub') are hydrologically connected to an adjoining channel. To distinguish between functionally riparian vegetation and hydrologically disconnected riparian-type vegetation, we created two new habitat subtypes. The 'Valley foothill alliance' and 'Willow scrub/shrub alliance' classifications represent hydrologically disconnected polygons originally classified as 'Valley foothill riparian' or 'Willow riparian scrub/shrub,' respectively. A polygon was considered hydrologically connected if it shared an edge with a polygon classified as 'Water.' Riparian polygons that were connected to water through other riparian polygons (of either type), polygons classified as 'Freshwater emergent wetland,' and/or polygons classified as 'Willow-marsh complex' were also considered hydrologically connected. This analysis was meant only to approximate hydrologic connectivity at a coarse level—it does not, for example, distinguish between standing water and creeks, nor does it consider topography or flood frequency. Not all analyses use the split classifications—for some (where vegetation type and structure is more important than hydrology), the original, more general classifications are used. See Section 16.2 for a map of hydrologically connected and disconnected riparian habitat.

2.4.4 Vernal pool complex

It became apparent that much of the 'CDFG 2007 Delta Veg' map units initially crosswalked to 'Grassland' were likely better represented as 'Vernal pool complex.' The same issue was addressed by the BDCP Natural Community Mapping effort (CDWR 2013, Appendix 2.B), which assembled a Vernal Pool Review Team to classify and map vernal pool complexes within the BDCP Plan Area. The BDCP classifications were informed by a number of datasets, including the Soil Survey Geographic Database (SSURGO), the BDCP composite vegetation GIS layer, Google Earth aerial imagery, 2007

Table 4. Reclassifying *Willow thicket* for modern habitat type layer.

Map units originally classified as Willow thicket	Reclassification
Buttonbush (*Cephalanthus occidentalis*)	Willow thicket
California Dogwood (*Cornus sericea*)	Willow thicket
California Hair-grass (*Deschampsia caespitosa*)	Willow thicket
Cornus sericea - *Salix exigua*	Willow thicket
Cornus sericea - *Salix lasiolepis* / (*Phragmites australis*)	Willow-marsh complex
Salix lasiolepis - (*Cornus sericea*) / *Scirpus* spp.- (*Phragmites australis - Typha* spp.) complex unit	Willow-marsh complex
Shining Willow (*Salix lucida*)	Willow thicket

LiDAR elevation data, California Natural Diversity Database (CNDDB) records, existing management and habitat conservation plans, and vernal pool expert knowledge.[17]

In light of this focused effort, we replaced polygons crosswalked as 'Grassland' in our preliminary modern habitat types layer with polygons identified as 'Vernal pool complex' by the BDCP mapping effort whenever the two overlapped. Specifically, we used the 'Union' tool in ArcGIS to replace polygons from 'CDFG 2007 Delta Vegetation' and 'CDWR 2012 CVRMP' crosswalked to 'Grassland' with those polygons from '2013 CSCCA Natural Communities' that had an "SAIC_Type" of 'Vernal pool complex' (a classification derived from the 'CDWR 2013 BDCP Natural Communities' layer). Where polygons from the two datasets overlapped, the habitat type was changed to 'Vernal pool complex' (otherwise the habitat type remained 'Grassland').

2.4.5 Swale form

'CDWR 2012 CVRMP' polygons with an "NVCS_NAME" of "California annual forb/grass vegetation" were initially crosswalked to 'Grassland.' However, when these polygons exhibited the natural swale form common to the edge of alluvial fans between ridges on the eastern and western edges of the Delta, the 'Grassland' classification was changed to 'Wet meadow/Seasonal wetland.' This reclassification better captures the hydrology and landscape position of these features, which are natural, seasonally wetted low spots on the landscape that generally offer potential for upland transgression of marshes with sea level rise. Additionally, the reclassification provides greater alignment with the habitat type assigned to these landforms by the finer-resolution 'CDFG 2007 Delta Vegetation' mapping and crosswalk.

2.5 Non-native and invasive species

We sought to map areas in the modern Delta where invasive or non-native plant species are dominant or co-dominant with native vegetation and to quantify the percent area dominated by non-native/invasive vegetation by habitat type. Individual habitat type polygons were marked as dominated by non-native/invasive vegetation if their vegetation mapping unit (generally associated with alliance- and association-level classifications) featured a non-native species (as defined by CalFlora) or invasive species (as defined by Cal-IPC). Where alliance/association-level classifications were unavailable, the non-native/invasive designation was determined based on Group-level classifications and best professional judgement. Table 5 (at end of Appendix A) lists the mapping units of the modern habitat type layer and whether or not each was classified as dominated by non-native/invasive vegetation. For the purposes of the map, we also classified areas with a habitat type of either "Agriculture/Non-native/Ruderal" or "Urban/Barren" as non-native, regardless of the more specific mapping unit classification.

3. CHANNEL VECTOR DATASETS

GIS layers of Delta hydrography were required to develop the project's suite of channel-related metrics. Since both forms of data were needed for our analyses, we obtained or generated polygon and polyline datasets of channel hydrography in the historical and modern Delta (unlike polygons, polylines are one-dimensional features with no width or area in the GIS). From these geodatasets, we developed metrics of channel length, width, adjacency, density, and sinuosity (the latter two are not presented in this report). We also classified channel reaches as either "dendritic" or "looped" (see Section 9 for definitions of these terms). Maps of these datasets can be found on page 15.

3.1 Sources for the historical Delta

Historical Delta channel polygons were obtained from the SFEI-ASC *Sacramento-San Joaquin Delta Historical Ecology Investigation*'s historical habitats layer.[18] The SFEI-ASC study generated polygons for channels at least 15 m in width and 50 m in length and incorporated these features into the map of historical Delta habitat types. For use in developing channel-related metrics, polygons classified as 'fluvial low order channel,' 'fluvial mainstem channel,' 'tidal low order channel,' or 'tidal mainstem channel' were extracted from the habitat type layer and clipped to the study extent.

Historical Delta channel polylines were obtained from the SFEI-ASC *Sacramento-San Joaquin Delta Historical Ecology Investigation*'s historical creeks layer.[19] This line layer contained all channel features longer than 50 m, regardless of their width. For channels also digitized as polygons, the polyline layer represents an approximate channel centerline. The layer was edited to ensure that channel polylines associated with polygons fell completely within the polygon boundaries.

3.2 Sources for the modern Delta

Modern Delta channel polygons were obtained from a 2013 version of the National Hydrography Dataset (NHD),[20] clipped to the project study extent, and selected by feature type to isolate features classified as 'StreamRiver' or 'CanalDitch.'

Modern Delta channel polylines were generated from the NHD polygons (described above) with a custom centerline generation tool. To best match the historical dataset, channel polylines were only generated around islands greater than 25 ha in size. If an island did not meet this size requirement, it was considered an "in-channel" island (an island located within a single channel as opposed to an island bounded by multiple, separate channels), and dissolved with the channel polygon for the purposes of centerline generation. To generate the channel polyline layer from the NHD polygons, the centerline tool converted NHD polygons to outlines, added additional vertices to these lines every 10 meters, created points from the vertices, and calculated Theissan polygons from the points. These Theissan polygons were converted to outlines, which were then clipped to the NHD polygons and split at vertices. The tool then removed segments less than 100 m with dangling ends, merged and exploded all lines, and then deleted all lines that were not connected on both ends and consisted of only 2 vertices (leaving only the polygon centerlines). To eliminate channels associated with small man-made harbors, we manually removed resulting reaches that were both less than 500 m in length and deemed unnatural. After evaluating the resulting layer, we digitized additional channel polygons and polylines that were not in the original NHD dataset, including the tidal channel networks of Sherman Island, Mandeville Tip, the Liberty Island Conservation Bank, the Cosumnes Floodplain Mitigation Bank, and along the Yolo Bypass Toe Drain. Like with the historical dataset, there was no minimum width employed for digitizing a channel line.

4. CHANNEL RASTER DATASETS (BATHYMETRY)

To develop metrics involving channel depth, we obtained or generated rasters of channel bathymetry for both the historical and modern time periods. Using this elevation data, we developed approximations of water depth at specific tidal datums (see Section 10). As described below, the historical Delta DEM was developed for a separate project and was constructed at a 2 m resolution (to capture the smallest channels). The modern Delta DEM, a California Department of Water Resources product, is an integrated 2 m and 10 m resolution raster. Both DEMs were clipped to include only the mutually mapped areas.

4.1 Sources for the historical Delta bathymetry

It is the goal of a separate, ongoing project to characterize the hydrodynamics of the San Francisco Bay-Delta Estuary under more natural conditions (those prior to major modification of Bay-Delta geometry and hydrology beginning in the mid-19th century) through the development and use of a 3D hydrodynamic model. One critical task of this larger project is the creation of a bathymetric-topographic digital elevation model (DEM) of the early 1800s historical Delta. The development of this raster is a collaborative effort between researchers and technicians at the San Francisco Estuary Institute (SFEI), the Center for Watershed Sciences (CWS) at the University of California, Davis, and Resource Management Associates, Inc. (RMA), funded by CWS and the Metropolitan Water District. Please see Table 6 for a list of individuals who have contributed to the development of the historical Delta DEM used in this report.

A manuscript with the methods used to develop the historical Delta DEM is currently in preparation for publication.[21] Here, we provide a simplified overview of the methods used to develop the historical bathymetry raster utilized in this report. Greater details on the development of the dataset (including the topographic component, which is not used or discussed in this report) will be available in the near future. Since the project is ongoing, the historical DEM used in this report constitutes an interim product and is subject to future modification.

This report utilizes version 3.1 of the Historical Delta Topographic-Bathymetric DEM, an interim product released internally in July 2014. To create this DEM, the project team integrated 2D historical Delta channel planform and land cover data from previous mapping efforts (Whipple et al. 2012) with elevation data from numerous historical sources. Raw historical bathymetric data were obtained primarily from mid-19th century sources, including U.S. Coast Survey (USCS) hydrographic sheets and early river surveys. Different areas and components of the Delta had to be addressed separately, given data availability. Three general sets of methods were used and combined to develop the DEM bathymetry (Figure 1).

Table 6. Individuals who have contributed to the development of the historical Delta digital elevation model (DEM) used in this report (alphabetical by institution). This work is being conducted as part of a separate, ongoing project (funded by CWS and the Metropolitan Water District).

Contributors
Center for Watershed Sciences (CWS)- University of California, Davis
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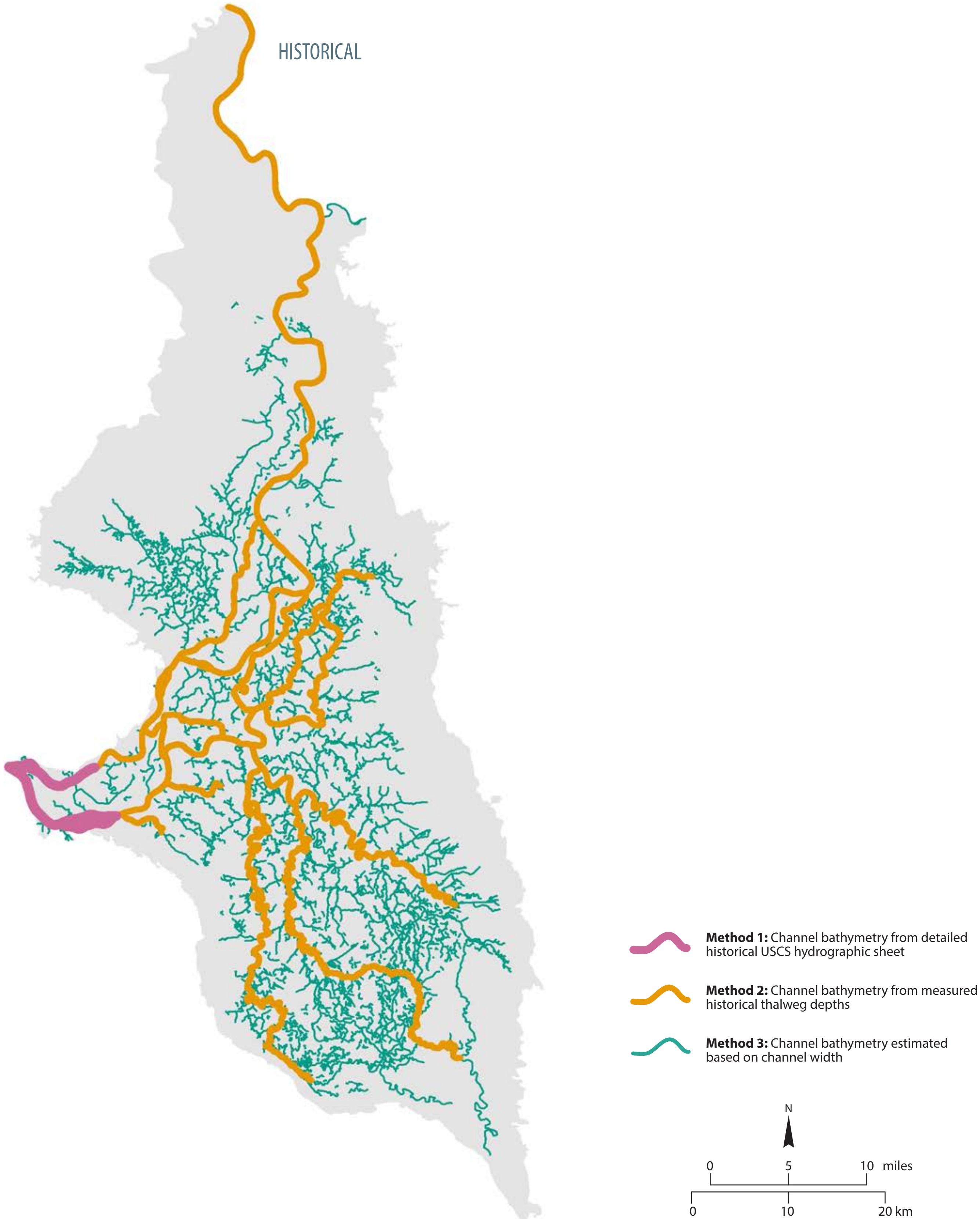


Figure 1. Three methods used to develop historical Delta bathymetry. Methodology varied based on data availability. See section 4.1 of this chapter for a more detailed description of each method.

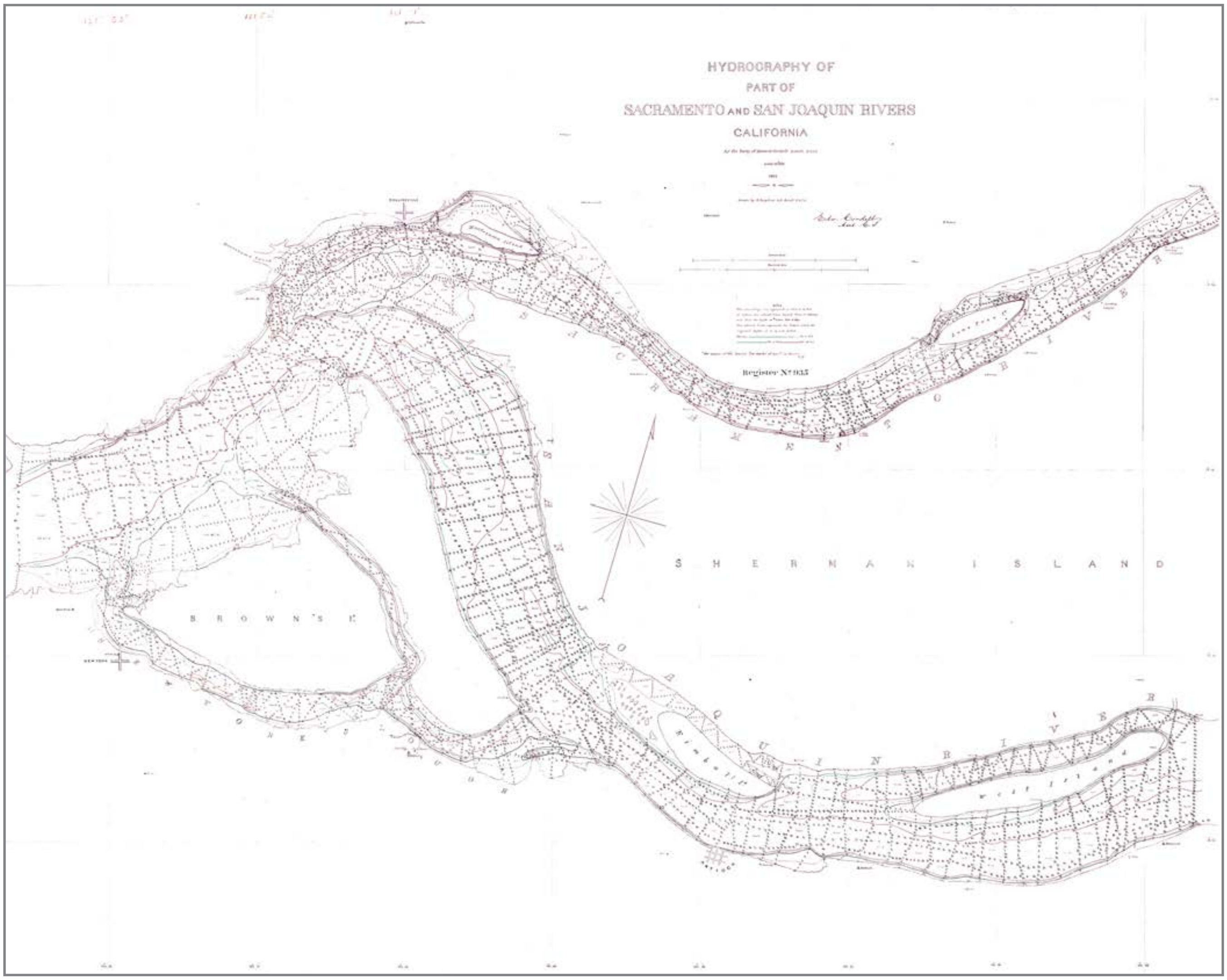


Figure 2. Cordell 1867 (United States Coast Survey), "Hydrography of part of Sacramento and San Joaquin Rivers California." This map is a hydrographic sheet ("H-Sheet") with historical bathymetry of the Delta mouth. The bathymetry seen here was digitized directly from a georeferenced version of the map.

4.1.1 Method 1: Bathymetry of the Delta mouth

A detailed 1867 U.S. Coast Survey hydrographic sheet with historical bathymetry was available downstream of Sherman Island (Figure 2).[22] The project team digitized 4,809 soundings and three bathymetric contour lines (6, 12, and 18 ft) directly from a georeferenced version of this map (which indicated depth at mean lower low water [MLLW]). After converting the digitized soundings to a modern fixed datum (NAVD88, see Section 4.1.4), the points were used directly as TIN inputs to generate continuous DEM bathymetry.

4.1.2 Method 2: Bathymetry of channels with measured historical data

The U.S. Coast Survey produced detailed 19th century bathymetric maps for the San Francisco Bay Estuary only as far upstream as Sherman Island. Bathymetry upstream of this location was derived from three historical river surveys (Ringgold 1850a, Ringgold 1850b, and Gibbes 1850), each conducted before the extensive mid- to late 19th century hydraulic mining in the Sierra Nevada foothills that altered bed elevations in the Delta. Critical locations were substituted with soundings from maps created by the California Debris Commission between 1908 and 1913.[23] Unlike the USCS (1867) hydrographic sheet, the historical river surveys generally only indicated the depth of the deepest part of the channel (the channel "thalweg"). Soundings were generally taken or adjusted by the surveyors to low water conditions. In total, the project team georeferenced 1,484 historical soundings indicating mean lower low water thalweg depth.[24] We snapped georeferenced points to a historical thalweg polyline and interpolated thalweg depths between these points using a spline function. We assumed a parabolic channel shape to generate bathymetry on either side of the thalweg.[25] Channels with bathymetry derived from this method are shown in Figure 1.

4.1.3 Method 3: Bathymetry of channels without measured historical data

Measured historical soundings were not available for much of the study extent. Because of this, we sought to determine historical channel depths by generating a regression relating channel depth to channel width. The relationship between these two variables was determined with available measured historical thalweg depths (described above). Historical channel widths (see Section 6) were spatially joined to historical soundings to create a dataset of historical channel widths with associated MLLW thalweg depths. Measured historical widths and depths were plotted against one another and fitted with a power function (Figure 3). A power function was selected because of known power relationships between width and depth in fluvial systems and because it avoided generating negative depths at smaller channel widths. While not perfect, this method was selected after extensive conversations with experts on tidal marsh morphology, and appears to provide reasonable estimates of channel depth given the available information. The function took the following form and was used to extrapolate depths for all channels:

Let y = channel depth at MLLW
Let x = channel width
$y = 0.8516x^{0.4111}$
$R^2 = 0.34$

Small historical channels (with widths <15 m) were originally digitized as polylines and thus did not have a precisely known width for use in the regression. We assigned these channels a width of 7 m (approximately half the minimum mapping unit for digitizing channels polygons) when extrapolating depths using the width-depth regression.

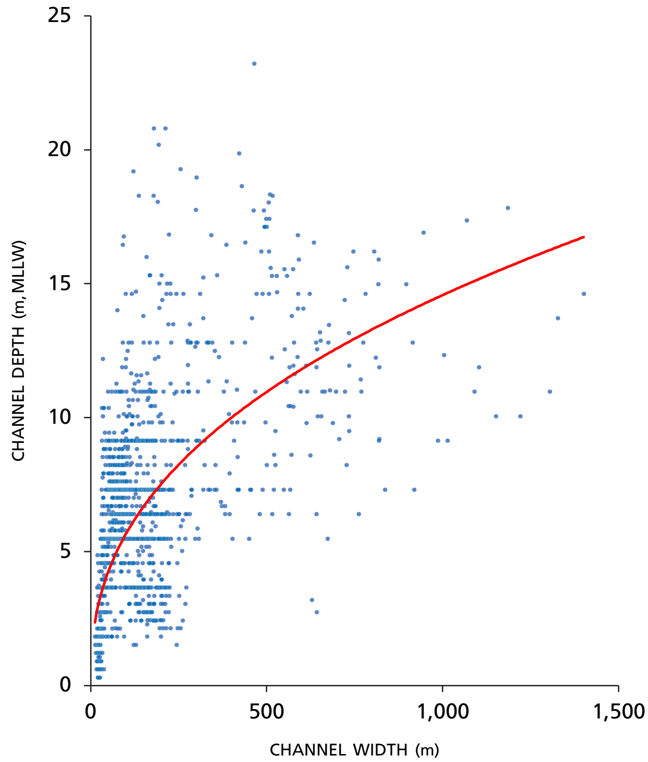


Figure 3. Scatter plot of historical channel depth vs. historical channel width. Each data point represents one historical sounding (adjusted to MLLW and representative of the thalweg depth) plotted against the width of the historical channel at the sounding's location (as derived from the historical channel polygon layer; N = 1,484). Data points have been fitted with a power function (red line) with the above equation.

4.1.4 Converting a historical tidal datum (MLLW) to modern fixed datum (NAVD88)

Historical sources for bathymetry were created well before the development of a standardized vertical datum (such as the Sea Level Datum of 1929) and were simply referenced to a low water surface. To use the historical Delta DEM in hydrodynamic models, the project team converted the historical MLLW data to a modern fixed datum (NAVD88). The method utilized in version 3.1 of the historical Delta DEM entailed two primary steps: (1) converting historical mean lower low water (MLLW) depths to historical local mean sea level (MSL) depth by adding tidal amplitude (or one-half the tidal range) to MLLW depth and (2) obtaining historical bed elevations (in NAVD88) by subtracting MSL depth from MSL elevation (in NAVD88). To implement these steps, the project team was required to determine two variables: (1) historical Delta tidal range and (2) historical Delta mean sea level elevation, both of which vary spatially. Rasters quantifying these variables across space were developed to convert historical depths to NAVD88.

The historical tidal range surface utilized in version 3.1 of the historical Delta DEM was developed by interpolating between georeferenced historical textual data using a natural neighbors method and the 'Create TIN' tool in ArcGIS. Additional points with a tidal range of 0 were created at the boundary between tidal and nontidal channel reaches as mapped by Whipple et al. (2012). Where records were too far apart for the TIN to successfully/realistically interpolate between them, best professional judgment was used to add values between known points. In total, 75 georeferenced points of historical tidal range were used to generate the historical tidal range surface.

The historical MSL surface utilized in version 3.1 of the historical Delta DEM was modeled using the RMA-2V model of the contemporary Delta, minus Delta exports and the most significant channel cuts, gates, and barriers. This simulation also subtracted estimated sea level rise (SLR) since the historical period, assuming an average rate of 0.1-0.2 cm/yr.[26]

Adjusted bathymetry was exported as a 2 m DEM and clipped to the tidal open water portions of the historical Delta, as mapped in the Delta Historical Ecology Investigation.[27]

4.2 Sources for the modern Delta bathymetry

Modern bathymetry was extracted from a continuous topographic-bathymetric DEM of the San Francisco Bay-Delta Estuary developed by California Department of Water Resources staff.[28] To facilitate comparison with the historical bathymetry raster (which was clipped to tidal open water features), we clipped the modern raster to include only cells with subtidal elevations. Subsided islands surrounded by levees posed a problem, since these areas have elevations well below sea level but are not actually aquatic habitat. Because the modern DEM features numerical orthogonal reinforcement of levees around islands,[29] we were able to exclude subtidal elevations associated with subsided islands by using the 'Magic Erase' tool in ArcGis 10.1 (ArcScan extension). We reclassified raster cells into supratidal and inter/subtidal elevations (above and below a mean higher high water elevation of 195 cm NAVD88)[30] and then used the tool to select subtidal cells directly connected to the Sacramento-San Joaquin river confluence/tidal source. Inter/subtidal areas ringed by supratidal levees were not connected and thus not selected. This process identified two subsided islands with underresolved/unenforced artificial levees in the modern DEM. We manually modified the suspect cells to enforce these levees and exclude the subsided areas within them.

5. UNMAPPED CHANNELS

It is likely that at least one class of low-order tidal channels existed in the Delta that was not represented by historical sources and was thus under-represented in the historical mapping of the Delta.[31] To match the detail and minimum mapping unit of the modern channel dataset, we sought to estimate the length of these "unmapped" historical channels in the study extent and to account for them in our analyses.

No remnant marshes with intact channel networks exist in the modern Delta from which to estimate historical channel density. General agreement exists that the channel density observed now at Sherman Island (~70 m/ha) is higher than it was historically due to the relatively young age of the system (until recently, Sherman Island was a depository for dredge spoils and the channel network observed today is likely overly-interconnected and under-developed as a result).[32] Length of unmapped channels was therefore estimated based on observed historical tidal channel densities in regional freshwater tidal marshes. Grossinger (1995) used USCS T-Sheets to calculate historical tidal marsh channel densities in the upper reaches of the Napa River, where freshwater influence is dominant—the upper-two systems in Napa were found to have historical densities of 19 and 51 m/ha.[33] Collins and Grossinger (2004) also calculated a historical channel density of approximately 30 m/ha in the freshest Bay Area systems.[34] These values agree with the highest local mapped densities in the historical Delta of 30 m/ha.[35] Weighing this evidence, we established low- and high-end estimates of Delta channel density of 20 m/ha and 40 m/ha, respectively. Since these estimates are for regularly inundated tidal marshes with developed channel networks, they were only applied to areas classified as tidal freshwater emergent wetland within the area thought to experience daily tidal inundation (see Section 10).

Mapped channel density in the study extent (14.76 m/ha) was determined by dividing the length of mapped tidal channels within regularly inundated tidal freshwater emergent wetland (1,129,158 m) by the area of the regularly inundated tidal freshwater emergent wetland itself (76,506 ha). Given the mapped density, the additional unmapped channel length needed to reach our low (20 m/ha) and high (40 m/ha) density estimates was calculated to be 400,960 m and 1,931,080 m, respectively.

6. CHANNEL WIDTH

Channel width was determined by casting perpendicular transects from the channel polyline layer, trimming these transects with the channel polygon layer, and then attributing the lengths of the trimmed transects back to the channel polyline. Prior to this analysis, versions of the historical and modern polyline layers were smoothed with a maximum offset of 0.2 meters to eliminate small sharp angles in the polyline (legacies of the original digitization process). Transects were cast at 100 m intervals perpendicular to the smoothed polyline and then trimmed with the channel polygon layer. Trimmed transects were then used to segment the original channel polyline layer. Channel width was calculated for each of the resulting segments by averaging the length of transects intersecting the segment (generally one transect at each end of the segment).

Prior to trimming transects with the channel polygon layer, the channel polygons were first dissolved and then split manually at confluences to eliminate overestimations of channel width where channels converge. The overall channel width analysis was also complicated by the existence of numerous islands located within channels. For islands greater than 25 ha in size, separate channels were drawn on either side of the island and each assigned their own widths. If an island was less than 25 ha, however, it was considered an island within a single channel. When calculating channel width, we only measured the width of the water, excluding width associated with in-channel islands. For the historical channel width analysis, channels digitized only as polylines were assigned a width of 7 m (approximately half the minimum mapping unit used for digitizing channels as polygons).

7. WATER DEPTH

In Section 4 above, we described the process of developing rasters of channel bed elevations (channel bathymetry) in the historical and modern Delta. This section describes the process of using these rasters to develop approximations of water depth at a specific tidal datum.

Water depths were derived from the raster datasets of historical and modern bathymetry, which were clipped to exclude supratidal habitat (described in Section 4). Since these rasters quantify bed-elevations, we were required to establish water surface elevations to determine water depth. In the absence of comprehensive spatial datasets indicating the elevations of tidal datums to relate geodetic data to tide heights (for both the historical and modern Delta), we opted to measure depth from a single water surface elevation across the Delta. In the modern Delta, the water surface was set to 0.64 m NAVD88, a mean lower low water (MLLW) elevation calculated from various monitoring data in the Cache Slough Complex.[36] For the historical Delta, we made the simplifying assumption that the only changes to the elevation of MLLW since the historical period are from sea level rise (SLR). This assumption discounts any changes in Delta water surface elevations caused by large-scale changes like channel geometry modification, channel armoring, subsidence, or water exports). Assuming a SLR rate in the Delta of 2 mm/year during the historical period, we estimated that 0.33 m of SLR occurred between 1850 and 2013. This factor was subtracted from the contemporary elevation of MLLW at the Cache Slough Complex (used as the water surface elevation in the modern analysis) to yield a historical water surface elevation of 0.31 m. The values used to bin bed-elevations (m, NAVD88) into water-depth classes (m, MLLW) based on these water surface elevations can be found in Table 7. Water-depth classes were chosen based on input from the Landscape Interpretation Team (Chapter 2, page 6) and meaningful photic zones.[37]

Table 7. The values used to bin bed-elevations (m, NAVD88) into water-depth classes (m, MLLW). The process for setting the historical and modern water surface elevations is described in Section 7.

	Bed elevation (m, NAVD88)	
Water depth (m, MLLW)	**Historical**	**Modern**
0 m (reference plane/water surface elevation)	0.31	0.64
1	-0.69	-0.36
2	-1.69	-1.36
5	-4.69	-4.36
10	-9.69	-9.36

7.1 Depth by area

Using the values listed in Table 7, we calculated the area of habitat in each depth-class using the 'Build Raster Attribute Table' tool in ArcGIS 10.1 and multiplying the cell count in each bed-elevation/water-depth range by cell area.

Historical perennial tidal lakes were not accounted for in the version of the historical Delta DEM utilized in this report (version 3.1). To account for these features in our analysis of historical depth, we extracted historical habitat type polygons classified as 'Tidal perennial pond/lake' and then assigned these polygons with depths obtained or derived from the available historical data. Some lakes (such as Secret Lake and Beaver Lake in the north Delta) have specific historical accounts describing their depths. When available, we used this information to assign the lakes a maximum depth, and then used buffers to generate concentric rings at each of the shallower depth classes (we assumed depth increased linearly from 0 m at the edge of the lake to the maximum depth at the center). The majority of mapped historical lakes, however, did not have lake-specific data on historical depths. For these features, we assigned inferred depths based on more general regional accounts. Historical sources, as reported by Whipple et al. (2012) suggest that many lakes in the north Delta (even large ones) were "only a few feet below the general elevations of the basins. Early travelers . . . could wade across." Considering this, we assigned most of the North Delta lakes a depth of 0–1 m. The centers of larger lakes (where more than 1,000 ft from the lake's edge) were placed in the 1-2 m depth class. This distance was relatively arbitrary, but was chosen to give the larger lakes a three-dimensional shape. In the south Delta, Whipple et al. (2012) note that historical descriptions of "knee-deep" water suggest relatively shallow features and that a map from 1850 "includes soundings of six to nine feet (1.8-2.7 m) of water in a lake." Weighing this evidence, we used a 300 m buffer to assign the centers of the larger south Delta lakes to the 1-2 m depth class. Small lakes and the outer edges of larger lakes were placed to the 0-1 m depth class. The area of lakes in each of these depth classes was tallied and added to the totals derived from the historical Delta DEM.

7.2 Depth by length

Methods used to calculate the linear extent of channels based on their thalweg depths differed for the historical and modern analyses. Historical thalweg depths were generated by segmenting the historical thalweg polyline (developed with/for the historical Delta DEM) at intervals of approximately 100 m and then intersecting the segments with the historical Delta DEM. Each 100 m segment was attributed with the average bed-elevation associated with the raster cells it crossed. These thalweg bed-elevations were converted to water depths using the methods/table described in Section 7.

Modern thalweg depths were generated by intersecting the trimmed modern channel width transects (see Section 6) with the clipped modern bathymetry raster (see Section 4.2) and attributing each transect with the minimum encountered cell value (i.e., the lowest bed-elevation). This is akin to taking the minimum value from a channel cross-section. Minimum bed-elevations were then attributed to the modern channel polyline segments and converted to water-depths using the methods/table described in Section 7.

8. CHANNEL ADJACENCY

Channel adjacency was determined from the habitat type layers by extracting habitat types associated with open water or aquatic habitat (for historical: 'Fluvial low order channel,' 'Fluvial mainstem channel,' 'Tidal low order channel,' 'Tidal mainstem channel,' 'Non-tidal intermittent pond/lake,' 'Non-tidal perennial pond/lake,' and 'Tidal intermittent pond/lake,'; for modern: 'Water') and intersecting the resulting layer with all other habitat types. The output of this operation is a polyline that traces the locations where open water touches other habitat types (the "shoreline"), and includes all of the attributes of the adjacent habitat type polygons.

Also included as open water when generating the historical shoreline layer were the historical channel polylines (which, due to their size, were not represented a polygons in the habitat types layer). A buffer of 5 m was applied to each side of the polylines to give the features an area. Before shorelines were generated, the new open water polygons were incorporated into the habitat layer with ArcGIS's 'Erase' and 'Merge' tools. Shorelines were not generated for possibly exhumed channels (as marked in the channel polylines "Notes" field).

The shoreline layer was used to determine marsh-open water edge length (page 44-45). For this analysis, we selected reaches where the shoreline habitat type was either 'Tidal freshwater emergent wetland' or 'Non-tidal freshwater emergent wetland' (for the historical analysis) or 'Freshwater emergent wetland' or 'Willow-marsh complex' (for the modern analysis). These selections were symbolized by the size of the contiguous marsh polygon they were associated with. Contiguous marsh polygons (which differ from marsh "patches"; see Section 10) were generated by dissolving polygons with the marsh habitat types listed above using the 'Dissolve' tool in ArcGIS 10.1. The sizes of these polygons were attributed to the shorelines with a spatial join.

To assign shoreline data to the channel polylines, channel polylines were segmented at 100 m intervals and given the attributes (via a spatial join) of the nearest shoreline feature. Channels bordered on each side by different habitat types only received attributes from the nearest shoreline feature. We used these methods to determine which dendritic channels were adjacent to marsh (see page 46-47). For this analysis, we considered marsh to be polygons with the habitat types 'Tidal freshwater emergent wetland' or 'Non-tidal freshwater emergent wetland' (for the historical analysis) or 'Freshwater emergent wetland' or 'Willow-marsh complex' (for the modern analysis).

9. LOOPED AND DENDRITIC CHANNELS

We classified tidal channel reaches as either "looped" or "dendritic." Looped channels are interconnected, generally large distributary reaches that delineate the Delta islands and can be thought of as forming circular networks connecting back to the tidal source. They are sometimes referred to as "mainstem and subsidiary channels"[38] or "through-flow channels."[39] Dendritic channels, alternatively, are terminal sloughs that eventually dead-end and do not connect on both ends to the larger network. The term "dendritic" is derived from the typical form of historical terminal sloughs—branching, tree-like networks that terminated in wetlands and resembled dendrites. These sloughs generally drained (and were formed by) tidally introduced water, rather than runoff from associated wetlands and uplands.[40] Although terminal, dead-end sloughs do not always have the branched form today, we still refer to them as "dendritic." These channels have also been referred to as "branching dead-end channel networks,"[41] "backwater tidal sloughs,"[42] "tidal creeks,"[43] and "blind channels."[44]

Ultimately, a channel reach was considered "looped" if it was (1) tidal and (2) connected to the tidal source (the Delta mouth) via two independent and non-overlapping paths (Figure 4). Tidal channel reaches accessible from the tidal source by only one non-overlapping path were considered "dendritic." Classification was carried out manually within ArcGIS. For the historical channel polyline network, tidal channels were selected using the layer's "tidal_status" field, which classified channels as either "tidal" or "fluvial." Since most channels within the study area were at least somewhat influenced by both tidal and fluvial processes, Whipple et al. (2012) classified historical channel reaches by their probable hydrology (instead of by the dominant physical process). Specifically, a channel reach was classified as "tidal" if it likely experienced bidirectional (tidal) flow during spring tides in times of low river stages (even though the primary processes that formed and maintained the channel could be fluvial). "Fluvial" reaches—those upstream of the limit of

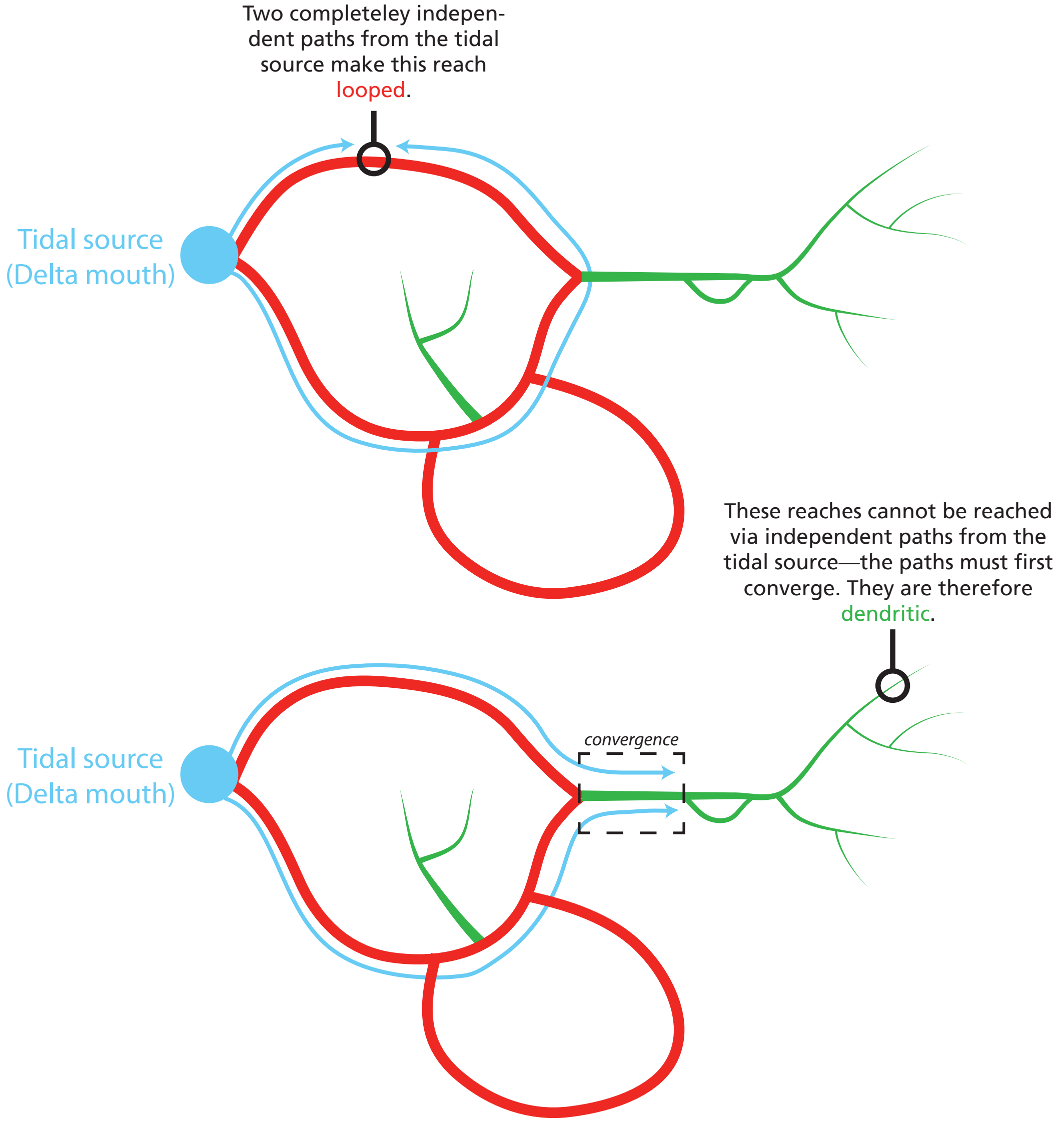


Figure 4. Classifying dendritic and looped channels.

bidirectional flow—were not classified as either dendritic or looped. To identify tidal reaches in the modern network using this definition, we drew from the work of Cavallo et al. (2012) who identified the locations along the Sacramento, San Joaquin, and Mokelumne river systems where bidirectional flows rapidly give way to unidirectional flows under multiple flow regimes.[45] Channel reaches upstream of these transition points under the authors' low-flow scenarios were considered fluvial and not classified as either dendritic or looped.

For both the historical and modern analyses, channel reaches were excluded from the looped/dendritic channel analysis if they lacked a direct, perennial connection (through the larger network) to the Delta mouth (and therefore to the tidal source). This was determined in ArcGIS with a recursive spatial selection that identified intersecting reaches extending outwards/upstream from the downstream-most channel reach at the Delta mouth. This rule excluded most upland intermittent streams, many of the possibly exhumed and disconnected channels mapped in the historical south Delta,[46] and channels in the modern Delta separated from the tides by levees, weirs, and other barriers (often identified with supplemental information).

Tidal reaches that ultimately connect upstream to perennial fluvial systems were not classified as either dendritic or looped between the perennial fluvial reaches upstream and where they first become looped channels downstream. This rule prevented major rivers like the Sacramento, San Joaquin, and Mokelumne (which are mostly tidal within the study extent) from being lumped with the true dendritic channels that terminate within the study extent.

One final exception to the classification rules described above was made for the large channels bordering Liberty Island in the modern network. Although only one independent path from the tidal source exists for these reaches (paths into the area must converge at the single access point west of the base of the Sacramento Deepwater Ship Channel), they were deemed functionally looped due to their form (a circular path around the former extent of Liberty Island via the "Stair Step" channel) and high local wind wave energy.

10. INUNDATION

10.1 Historical inundation

For the historical Delta, areas regularly subject to inundation were derived from the map of historical habitat types, which were defined, at least in part, by their typical hydrology (Whipple et al. 2012). Areas mapped as 'Tidal freshwater emergent wetland' were classified for the inundation analysis as areas of "tidal inundation"; 'Non-tidal freshwater emergent wetlands' and 'Willow thickets' were classified as areas of "seasonal long-duration flooding"; and 'Vernal pool complex,' 'Wet meadow/seasonal wetland,' and 'Alkali seasonal wetland complex' were classified as areas of "seasonal short-term flooding." Areas mapped as 'Tidal mainstem channel,' 'Fluvial mainstem channel, 'Tidal low order channel,' 'Fluvial low order channel,' 'Freshwater pond or lake,' and 'Freshwater intermittent pond or lake' were classified as "ponds, lakes, channels, & flooded islands."

The methods described above were further developed in the following ways.

(1) The area mapped by Whipple et al. (2012) as 'Tidal freshwater emergent wetland' (and thus classified as an area of "tidal inundation") represented the area "wetted or inundated by spring tides at low river stages."[47] To distinguish the smaller portion of this area that experienced daily tidal inundation, we relied on the available historical data and best professional judgment.[48] Ultimately, the mapped extent of daily tidal inundation (~76,500 ha) corresponds well with estimates of this area identified in historical records. Most early accounts state that approximately 200,000 acres (80,940 ha) or less were regularly overflowed by "ordinary" tides (i.e., daily high tides).[49] A more specific calculation from an early engineering report states that roughly 160,000 acres (64,750 ha) were "subject to inundation at each high tide, twice in twenty-four hours."[50]

(2) The tidal portion of the lower Yolo Basin, which was only inundated during spring tides (north of the area determined to be inundated daily) was classified both as an area of "tidal inundation" and as area of "seasonal long-duration flooding." This area is displayed on the maps as "seasonal long-duration flooding" during winter and spring and as "tidal inundation" during fall and summer. In the charts on pages 40-41 and 61, the area is included in both categories.

Information on the depth, timing, and duration of each inundation type was derived from Whipple et al. (2012) and other supplemental sources.[51]

10.2 Modern inundation

Since the modern habitat type dataset does not distinguish between tidal and non-tidal freshwater emergent wetland, a proxy was used to define modern areas of tidal inundation. Specifically, areas were assigned the "tidal inundation" classification if they were mapped as either 'Freshwater emergent wetland' or 'Willow-marsh complex,' were adjacent to open water, and fell within the historical extent of tidal marsh. Additional areas of modern inundation were identified, mapped, and classified after conducting a literature search and consulting with regional experts. The extent of the "seasonal short-term flooding" in the Yolo Bypass, for example, was digitized by Sommer et al. (2004) from aerial photographs of the flooding that took place in January 1998. The extent of the Cosumnes River floodplain (also classified as "seasonal short-term flooding") was digitized by SFEI staff from a map of the upper and lower floodplain.[52] We recognize that other areas of the modern Delta may experience inundation, but we only digitized areas identified by the LIT.

11. IDENTIFYING MARSH PATCHES

Historical marsh patches were created from historical habitat type polygons classified as either 'Tidal freshwater emergent wetland' or 'Nontidal emergent wetland'; modern marsh patches were created from modern habitat type polygons classified as either 'Freshwater emergent wetland' or 'Willow-marsh complex.' In the GIS, discrete marsh polygons were aggregated and considered part of a single patch if they were located within 60 m of one another. Groups of polygons separated by less than this distance were identified and aggregated using ArcGIS's 'Aggregate Polygons' tool and assigned unique patch IDs. Multipart feature layers delineating marsh patches (for both the historical and modern Delta) were generated for further analysis (the "patch layers").

The 60 m threshold for grouping marsh polygons was taken from a rule set for defining resident intertidal rail patches developed by Collins and Grossinger (2004), which was based on the best available data on rail habitat affinities and dispersal distances.[11] In the absence of more specific data, we made the assumption that the rules developed for defining intertidal rail patches in the South Bay (primarily for California Clapper Rails, which are not generally found in the Delta) are broadly applicable to the Delta's freshwater (and often non-tidal) marshes/species. Unlike Grossinger and Collins (2004), however, our analysis only considered roads and levees as dispersal barriers if the width of these features (as mapped in the habitat type layers) exceeded the 60 m threshold. It is worth noting that this model of a binary landscape (marsh and non-marsh) simplifies the complexities of how species interact with their surroundings. It necessarily assumes that all patches of marsh are equally suitable for rails, that the routes of travel between patches are linear, and that the only barrier to rail movement is distance.[53]

12. MARSH PATCH SIZE

The size of individual marsh patches was determined with ArcGIS. In addition to determining the size of each patch, we also identified the number and distribution of "large" marsh patches, where "large" was defined based on functionality for marsh bird support. For the purposes of this analysis, a marsh patch was considered "large" if it had an area greater than or equal to 100 ha. This threshold is based on (1) regression models indicating a significant negative correlation between California Black Rail presence and distance to the nearest marsh greater than or equal to 100 ha[54] and (2) research that found that California Clapper Rail densities decrease in patches <100 ha.[55]

13. MARSH CORE VS. EDGE

For the purpose of this analysis, core area index is defined as the percent of a marsh patch's total area that is greater than 50 m from the patch's edge. The core area of each marsh patch was identified in ArcGIS using the 'Buffer' tool with an internal linear buffer distance of 50 m. This distance is based on research indicating a significant positive relationship between California Black Rail presence and marsh core area (defined as >50 m from marsh edge).[56]

14. MARSH NEAREST LARGE NEIGHBOR DISTANCE

Nearest large neighbor distance (NLND) was determined with ArcGIS's 'Generate Near Table' tool, which calculated the linear distance of each marsh patch to the nearest "large" neighboring marsh patch (>100 ha, see Section 12). Large patches themselves were assigned a NLND of 0 m. This metric is supported by research indicating a significant negative relationship between California Black Rail presence and distance to nearest 100 ha marsh.[57]

15. IDENTIFYING RIPARIAN HABITAT PATCHES

Historical riparian patches (here meaning woody riparian habitat patches) were created from historical habitat type polygons classified as either 'Valley foothill riparian' or 'Willow riparian scrub or shrub.' Modern riparian patches were created from modern habitat type polygons classified as either 'Valley foothill riparian' or 'Willow riparian scrub or shrub,' but also from some polygons ultimately classified as 'Managed wetland' (where the original classification was either 'Valley foothill riparian' or 'Willow riparian scrub or shrub'—see Section 2.4.2). Since, for this analysis, vegetation type and structure were deemed to be more important characteristics than hydrology, riparian habitat type polygons were included whether or not they were deemed hydrologically connected (see Section 2.4.3 for further explanation—this stands in contrast to the riparian width analyses, which exclude hydrologically disconnected riparian habitat polygons).

In the GIS, discrete woody riparian polygons were aggregated and considered part of a single patch if they were located within 100 m of one another. The 100 m threshold for grouping riparian polygons is based on the typical maximum gap crossing distance of dispersing songbirds, as determined by the best professional judgment of regional experts.[58] Groups of polygons separated by less than this distance were identified and aggregated using ArcGIS's 'Aggregate Polygons' tool and assigned unique patch IDs. Multipart feature layers delineating woody riparian habitat patches (for both the historical and modern Delta) were generated for further analysis (the "patch layers"). The size of individual woody riparian habitat patches (and total patch size distribution) for both the historical and modern Delta was determined using these layers with simple ArcGIS table summaries.

As was the case when defining marsh habitat patches, it is worth noting that this model of a binary landscape (woody riparian habitat and non-woody riparian habitat) simplifies the complexities of how species interact with their surroundings. It makes the assumption that all patches of woody riparian habitat are equally suitable for riparian wildlife, that the routes of travel between patches are linear, and that the only barrier to movement is distance.[59]

The thresholds defining woody riparian patch size bins used to assess patch size distribution use a geometric progression starting at 20 ha and multiplying by a common ratio of four. These bins result in thresholds at 20 ha and 80 ha, both of which have apparent ecological significance for Western Yellow-billed Cuckoos. For nesting cuckoos in California, researchers characterize willow-cottonwood patches >80 ha in size as "optimal" and set 20 ha as the minimum threshold for "marginal" habitat suitability.[60] Below this area (<20 ha for mesquite habitat and <15 ha for willow-cottonwood habitat), patches become "unsuitable." The size thresholds of the larger bins do not have specific ecological justifications.

15.1 Estimating the area of unmapped willow-fern swamps

Scattered "clumps" or "patches" of willows are known to have occurred within the tule marshes of many central Delta islands, adding a dimension of woody vertical structure to the freshwater emergent wetland plain.[61] Although not strictly a "riparian" habitat type (the willow patches were not limited to channel banks and are thought to have occurred across central Delta islands where tidal processes were dominant), we quantified the area of this vegetation community since it offers the taller woody vegetation structure that is an important component of many of the functions provided by riparian habitat (sometimes independent of actual hydrological connection to fluvial systems). While "willow-fern swamp" vegetation community was described in detail by Whipple et al. (2012), it was not mapped as a unique habitat type and was instead considered part of the 'Tidal freshwater emergent wetland' habitat type. We estimated the historical area of willow-fern swamp using a historical map made in 1850 by Charles Gibbes[62] and some of the general conclusions drawn from other historical sources by Whipple et al. (2012). In the *Sacramento-San Joaquin Delta Historical Ecology Investigation*, Whipple et al. (2012) determined that willow-fern swamps were most common within Sherman, Bradford, Webb, Venice, and Mandeville islands, and indicated the extent of 'Tidal freshwater emergent wetland' over which the vegetation community is thought to have occurred (Figure 5).[63] We estimated the number individual willow fern-swamp patches in the central Delta by multiplying this area (31,570 ha) by the willow patch density mapped by Gibbes in 1850 (0.007 patches/ha; sampled from a georeferenced version of the map in ArcGIS). The estimated area of willow-fern swamp habitat was determined by multiplying the estimated number of patches (221) by the average patch size (16 ha, determined by measuring the area of a random sample of 35 patches drawn by Gibbes; SD = 12 ha). With this simple operation (and all of its inherent assumptions), we estimated that there were approximately 3,500 ha of willow-fern swamp habitat in the historical central Delta.

16. RIPARIAN HABITAT WIDTH

For both the historical and modern Delta, we sought to visualize and quantify the length of riparian habitat (defined here as woody riparian habitat) based on the riparian habitat's width. We measured historical and modern riparian habitat widths by casting transects

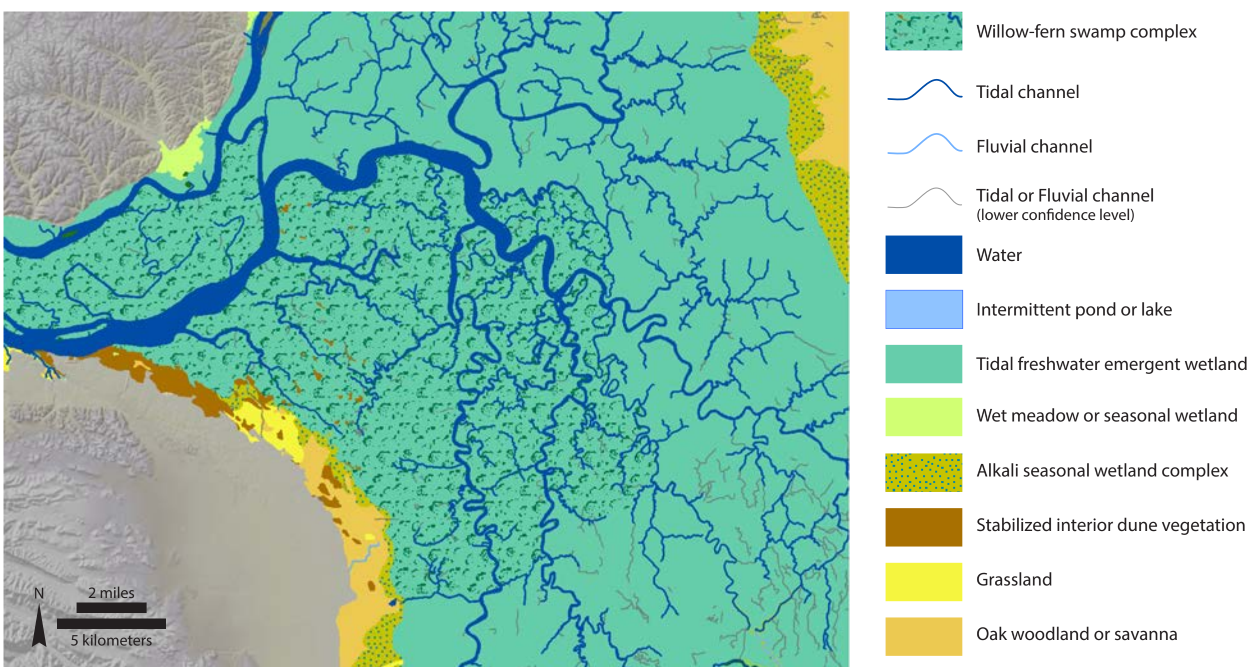


Figure 5. The generalized extent of willow-fern swamp complex (shown by the dark, clumped tree symbol) as mapped by Whipple et al. (2012). The extent was determined from various sources, none of which explicitly described the boundaries of this wetland community. Actual boundaries were likely indiscernible, as the presence of willows within the islands gradually became less prevalent moving away from this mapped area. In this report, we use the approximate extent and data on the density and size of patches sampled from an 1850 map by Charles Gibbes to estimate the total area of willow-fern swamp habitat.

perpendicular to modified channel centerlines and then trimming the transects at the edges of riparian habitat polygons (a method similar to/adapted from our analysis of channel width; see Section 6). The nature of the historical and modern datasets required two different (although generally similar) methods to determine riparian habitat width. These methods are described in detail below.

16.1 Historical riparian habitat width

For the historical layers, riparian areas classified as either 'Valley foothill riparian' or 'Willow riparian scrub or shrub' were extracted from the historical habitat types dataset and merged with adjacent open water polygons. These merged riparian "zones" (including the open water areas) were dissolved, split manually at confluences, and assigned unique identifiers. Next, we generated centerlines for each split riparian habitat zone (from which to cast perpendicular transects that measure the zone's width at regular intervals). To develop the riparian habitat centerlines, we started with the historical channel polylines, which were modified to adhere to the following rules:

- Riparian centerlines were not drawn for side channels within otherwise contiguous zones of riparian habitat (those that effectively form islands of woody riparian habitat)—these smaller side channels were merged with the larger channel and riparian zone (Figure 6, A and B).
- Riparian centerlines were not drawn for small crevasse splays (Figure 6, C).
- Riparian centerlines were straightened through sinuous areas (Figure 6, D).

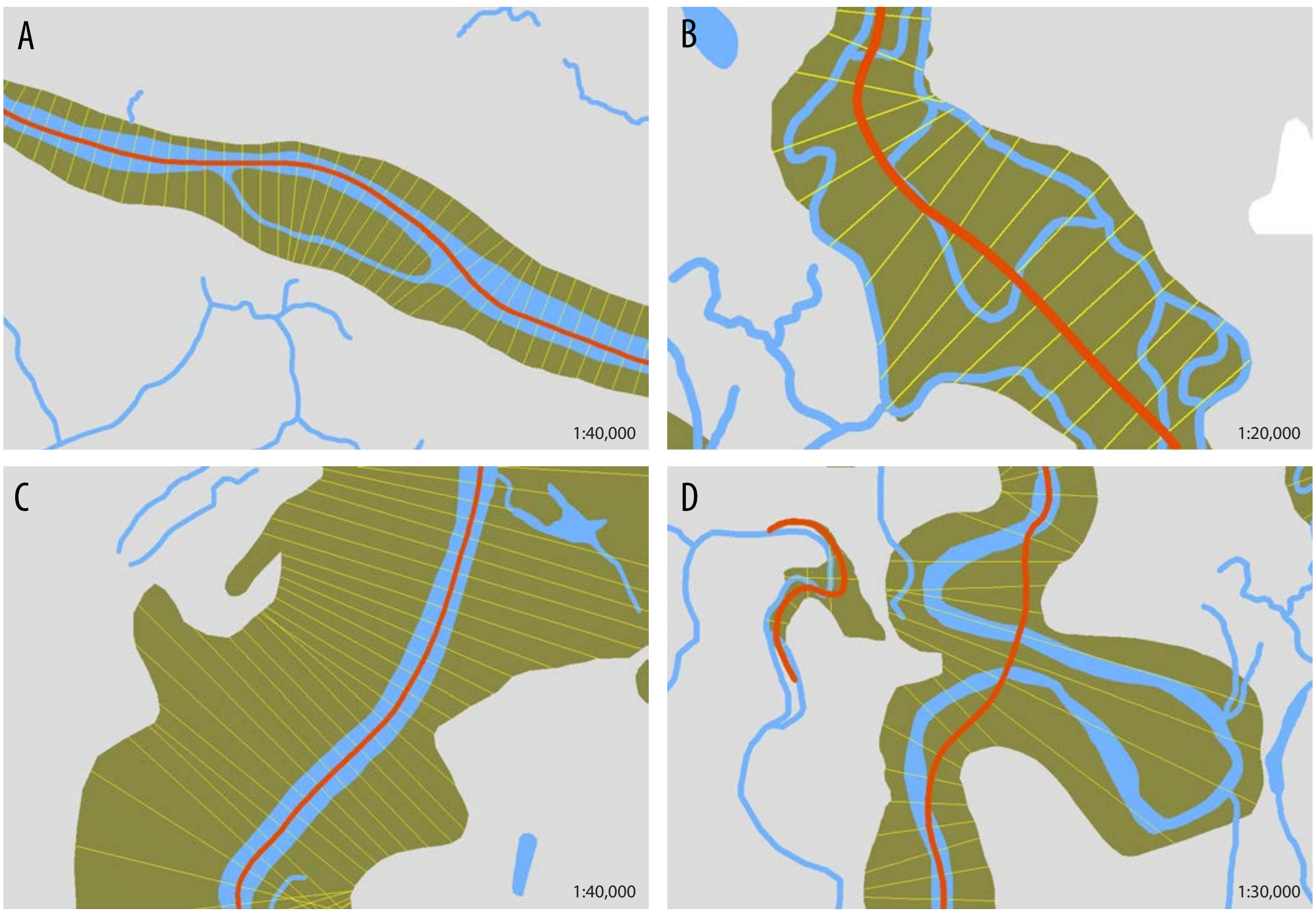
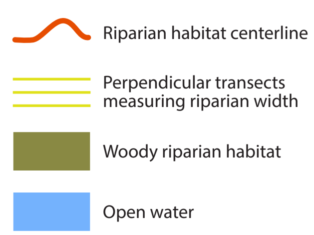


Figure 6. Determining historical riparian width in complicated areas. (A-B) Riparian centerlines were not drawn for side channels within otherwise contiguous zones of riparian habitat. (C) Riparian centerlines were not drawn for small splays (seen here on the left hand side of the woody riparian habitat). (D) Riparian centerlines were straightened through sinuous areas.



- Riparian centerlines were smoothed with a maximum offset of 2 m and generalized by 0.1 to remove sharp angles and to prevent transects from being cast at incorrect angles.

Merged lines were intersected with the riparian habitat zone polygons to associate each line with only one zone. The riparian centerlines were then segmented at 100 m intervals and transects were cast perpendicularly from the centroid of each segment (as determined by the x, y coordinates of its endpoints) 2,000 m in each direction (a distance greater than the maximum width of the woody riparian habitat zone). Transects (containing the unique identifier of the centerline/zone from which they were cast) were then intersected with riparian zone polygons (with the same identifier), thereby trimming the transects to the width of the adjacent woody riparian habitat zone. Since riparian habitat "zones" included both open water and woody riparian habitat, we erased segments of the trimmed transects that intersected open water polygons to determine only the width of the woody riparian habitat. This process was automated with a custom ArcPy script.

16.2 Modern riparian habitat width

Due to the complicated shape and distribution of woody riparian habitat in the modern Delta, we used a second set of methods to determine modern riparian habitat widths. Extensive areas of vegetation in the modern Delta classified as 'Valley foothill riparian' and 'Willow riparian scrub or shrub' are not adjacent to channel features. Since we sought to measure the length/width of riparian habitat along linear zones of open water, we only counted the width of modern woody riparian habitat if it was deemed hydrologically connected (see Section 2.4.3 for how we determined the hydrologic connectivity of woody riparian habitat types; see Figure 7 for a map of the modern woody riparian habitat classified as hydrologically "connected" and "disconnected").

To determine modern riparian habitat widths, we cast transects at 100 m intervals from the modern channel polyline dataset (described in Section 3.2) 1,500 m in each direction. To prevent counting woody riparian vegetation located behind artificial levees (and thus disconnected from the linear channel features), transects were intersected with a polyline layer consisting of artificial levee centerlines.[64] Segments of the transects falling on the far side of the levee centerlines (away from the channel) were discarded. Transects were then intersected with the hydrologically connected woody riparian habitat polygons resulting in trimmed transects with lengths equal to the width of the woody riparian habitat polygons. Trimmed transects were edited manually to remove instances of double counting (where transects cast from one channel intersected riparian habitat associated with another channel). Riparian habitat only contributed to measurements of width if was associated with the channel reach from which the intersecting transect was cast (determined by visual inspection of the riparian habitat polygons, channel centerlines, and transects). Where there were gaps in the riparian habitat, we counted the area on both sides of the gap towards total riparian width (assuming both areas met the above rule), but did not count the width of the gap itself.

Trimmed riparian width transects >100 m and >500 m were selected to display on the historical and modern maps of woody riparian habitat width. The 100 m width threshold is based on the work of Gaines (1974), who found that Western Yellow-billed Cuckoos were only present in riparian habitat patches at least 100 m wide. The 500 m width threshold is based on the work of Kilgo et al. (1998), who found that riparian forest areas at least 500 m wide were necessary to maintain the "complete avian community" in bottomland hardwood forests in South Carolina. These widths largely agree with the findings of Laymon and Halterman (1989), who (based on occupancy and nest predation rates) define riparian habitat <100 m wide as "unsuitable," habitats 100-600 m wide as "marginal" or "suitable," and habitats at least 600 m wide as "optimal" for cuckoo nesting.

17. MARSH-TERRESTRIAL TRANSITION ZONE LENGTH

The marsh-terrestrial transition zone ("t-zone") was identified using the habitat type layers by extracting habitat type polygons considered "marsh" (described below), generating contiguous polygons from these features (without interior borders), and then intersecting these contiguous polygons with all other habitat type polygons. The output of this operation was a polyline that traces the locations where marsh habitats are directly adjacent to other habitat types. We then extracted segments of this polyline associated with terrestrial habitat types (identified below). This new polyline (that traces locations where marsh shares a border with terrestrial habitat types) was deemed the marsh-terrestrial transition zone. The lengths of t-zone polyline segments (for both the historical and modern datasets) were summed by terrestrial habitat type to generate the chart on page 73.

For this analysis, marsh habitat types were 'Tidal freshwater emergent wetland' (historical), 'Non-tidal freshwater emergent wetland' (historical), 'Freshwater emergent wetland' (modern), and 'Willow-marsh complex' (modern). Terrestrial habitat types were 'Valley foothill riparian,' 'Willow riparian scrub or shrub,' 'Willow thicket,' 'Wet meadow and seasonal wetland,' 'Vernal pool complex,' 'Alkali

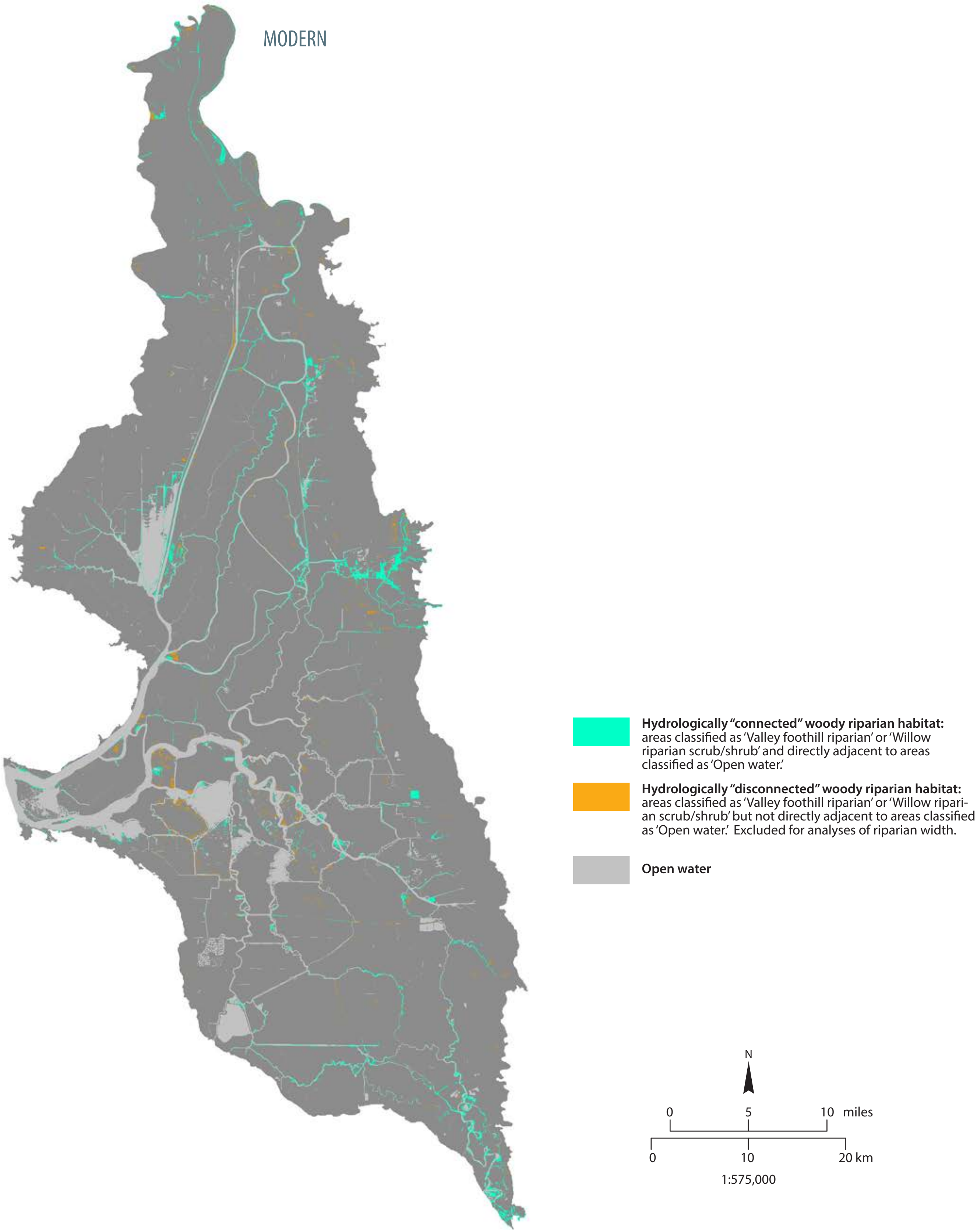


Figure 7. Hydrologically "connected" and "disconnected" woody riparian habitat in the modern Delta. We distinguished contemporary hydrologically connected woody riparian habitat from hydrologically disconnected woody riparian habitat. Only contiguous woody riparian habitat polygons that shared an edge with open water were deemed hydrologically connected. Although both types were considered when determining woody riparian habitat patch size distribution (pages 64-65), disconnected woody riparian habitat was not considered when calculating riparian width. See Section 16.2 of this chapter for more detailed methods.

seasonal wetland complex,' ' Grassland,' ' Oak woodland and savanna,' and 'Stabilized interior dune vegetation.'

18. CERTAINTY AND LIMITATIONS

18.1 Historical data certainty

Each feature in the historical Delta datasets (habitat type polygons and channels) was assessed for certainty during the mapping process. Whipple et al. (2012) describes this process in the Delta Historical Ecology Investigation:

> Our confidence in a feature's habitat type and presence (interpretation), size, and location was assigned based upon the number of kinds and quality of evidence, accuracy of digitizing source, our experience with the particular aspects of each data source, and by factors such as stability of features on a decadal scale (following standards discussed in Grossinger et al. 2007; [Table 8]). Certainty in tidal status was also included for the channel line layer. In cases where features were likely to have shifted positions over relatively short time periods, we assigned lower certainty for location and size. These attributes provide a way to estimate ranges of uncertainty associated with different locations and kinds of feature or habitat type, and allows subsequent users to assess accuracy [Table 8]. (49)

Using these classifications, the authors were able to assess and roughly quantify the uncertainty associated with the historical mapping:

> Overall, confidence in interpretation and location was fairly high, 64% and 77% respectively. The lower certainty in shape (of each mapped feature) reflects the large areas of habitats, primarily around the perimeter of the Delta, where boundaries were challenging to determine. For the channel lines layer (the network along the polygon channels plus the channels narrower than the polygon minimum mapping width), high interpretation certainty accounted for about 64% of the mapped channel length, with high shape certainty at 59% and high location at 85%. Less than 10% of the area was assigned a low interpretation certainty for either mapping layer. The fourth certainty level standard, tidal interpretation, was only included in the lines layer, where 75% of the channel length was assigned a high certainty level for its tidal interpretation. (89-90)

Mapping certainty varied by habitat type:

> Habitat types with less than 50% of the area assigned with high certainty include alkali seasonal wetland complex, grassland, tidal intermittent pond or lake, vernal pool complex, wet meadow or seasonal wetland, willow riparian scrub or shrub, and willow thicket. Habitat types associated with the highest interpretation certainty tended to be the water bodies and freshwater emergent wetland, given the many sources available confirming these habitat types (e.g., descriptions of tule to identify freshwater emergent wetland). Not surprisingly, the similar summary of the channel line layer shows the larger mainstem channels that are well-established in numerous historical sources with nearly 100% interpretation certainty, while the interpretation of lower order channels was more challenging, mostly due to the difficulties associated with distinguishing the early 1800s channels from the many signatures of ancient channels exposed by exhumed peat in the south Delta. (90-91).

For a full discussion of the uncertainties associated with the historical habitat types and channel datasets, please refer to the *Delta Historical Ecology Investigation*.[65]

Table 8. Certainty level standards assigned to each mapped historical feature for the assessment of confidence in interpretation (classification and historical presence), size, location, and tidal status. From Whipple et al. (2012).

Certainty Level	Interpretation	Size	Location	Tidal Status (line features only)
High/ "Definite"	Feature definitely present before Euro-American modification	Mapped feature expected to be 90%-110% of actual feature size	Expected maximum horizontal displacement less than 50 m (150 ft)	Channel bed definitely within or outside tidal range (<3.5 ft elevation)
Medium/ "Probable"	Feature probably present before Euro-American modification	Mapped feature expected to be 50%-200% of actual feature size	Expected maximum horizontal displacement less than 150 m (500 ft)	Channel bed probably within or outside tidal range
Low/ "Possible"	Feature possibly present before Euro-American modification	Mapped feature expected to be 25%-400% of actual feature size	Expected maximum horizontal displacement less than 500 m (1,600 ft)	Channel bed possibly within or outside tidal range (if within, no clear tidal connection)

18.2 Modern data certainty

As a compilation of multiple sources, the modern habitat types layer utilized in this report represents a conglomeration of certainty levels that vary within and between the individual sources. The two primary modern data sources combined in this report each underwent independent assessments of mapping accuracy. For the VegCAMP 2007 Sacramento-San Joaquin River Delta dataset ('CDFG 2007 Delta Vegetation'—the source for 80% of this project's study extent) accuracy was assessed using the fuzzy logic method.[66] The overall accuracy of the map was nearly 89%, while the average accuracy score per vegetation type was 83%. For the Central Valley Riparian Mapping Project Group Level dataset ('CDWR 2012 CVRMP'—the source for 19% of this project's study extent) accuracy was assessed by comparing how photo interpreters (producers) and field surveyors (users) classified the same regions.[67] The overall user's accuracy score averaged 76% and the producer's accuracy averaged 79%.

Some uncertainty was also introduced through the development of the crosswalk used to relate each of the different original classification systems (to each other and to the historical classifications). As noted by Hickson and Keeler-Wolf (2007), "The complexity and uncertainty of such relationships arise not only from independent evolution of classifications, but also from their imprecise definitions, without quantitative rules for proper interpretation. The best crosswalks are those that have been developed with a good understanding of the meaning and definitions of each classification system." By having Todd Keeler-Wolf (an author of the primary modern dataset utilized in this report) assist with the development of this project's crosswalk, we were able to minimize the uncertainty associated with a somewhat subjective process.

Since our modern mapping is from a compilation of sources, it represents a compilation of years. The oldest—the VegCAMP 2007 Sacramento-San Joaquin River Delta dataset—utilized U.S. Geological Survey High Resolution Orthoimagery taken in 2002 and 2005.[68] The most recent source—supplemental polygons digitized by SFEI staff (covering less than 1% of the study extent)—was derived from Bing aerial photos accessed in 2013. The Delta is a continually changing place and there is uncertainty associated with modern classifications that are already outdated at the time of publication; we are aware of at least seven sizeable parcels (including areas mapped as 'Grassland,' 'Wet meadow and seasonal wetland,' and 'Agriculture/Non-native/Ruderal') that have been developed since the modern habitat type datasets were generated.[69]

18.3 Issues of historical and modern data fidelity: comparing apples to apples (or at least to crabapples)

One of the fundamental goals of this report was to ensure that, when making comparisons between the historical and modern landscape, we compared the same things, at the same scale, using the same measurements. Due to the severity of change in the Delta and differences between the historical and modern datasets, this task was far from trivial. In this section we discuss the consequences of differences in historical and modern data resolution. These differences were more or less pronounced depending on the datasets used and the analyses in question. The extent to which we could control for differences in resolution also varied across analyses. While some analyses are affected by differences in data resolution (that increase the uncertainty surrounding specific numbers and the precise magnitude of the measured changes), we do not believe that these differences impact the direction of changes or the overall stories indicated by our analyses.

Generally speaking, the spatial data for the modern Delta has a higher resolution than the spatial data for the historical Delta, but these differences are not always very pronounced and were largely manageable. In our analysis of marsh core area, for example, it was important to make sure that the resolution of non-marsh features within the marsh (which effectively create marsh edge) was similar in the historical and modern datasets. When calculating historical core area ratio, we chose only to include channels mapped as polygons, because their minimum mapping width (15 m; MMW) was comparable to the MMW for water features in the modern dataset (10 m; see Table 1). Although not identical, these MMWs are well within an order of magnitude of one another. While it is true that the slightly lower MMW for water features in the modern dataset increases the amount of modern edge habitat, this difference is insignificant when comparing the core area ratios of the historical and modern marshes: the vast area of largely contiguous historical marsh ensures a higher core area ratio. Similarly, since willow patches in the historical central Delta were not explicitly mapped (due to a lack of data) and instead were lumped into the tidal freshwater emergent wetland classification, we made a concerted effort to do the same for the modern dataset (because the historical lumping effectively decreases marsh edge). This was largely accomplished through the modern data crosswalk (which included areas of marsh and some woody vegetation in the 'Freshwater emergent wetland' category) but also by generating a 'Willow-marsh complex' designation that allowed us to further lump areas of willows with freshwater emergent wetland species into the areas we considered "marsh" when calculating marsh core area ratio (see sections 2.4.1 and 11).

Decisions like this increased fidelity between the historical and modern analyses.

The historical and modern habitat type datasets also utilized different minimum mapping units (MMUs) for areal features—5 ha in the historical dataset and 0.8 ha (for vegetation) in the modern dataset. While these values are within an order of magnitude, their difference is still a concern, because the inclusion of a smaller class of features in the modern dataset that are not included in the historical dataset can increase estimates of patch number and edge length, while decreasing estimates of average patch size. Since outright exclusion of the smallest features in the modern Delta (to match the MMU of the historical Delta) would eliminate a significant proportion of most habitat types and generate unwieldy data gaps, we instead developed methodologies and analyses that minimize/manage the impact of MMU differences and consider here how the differences are likely affecting our results.

One method we used to manage the difference in minimum mapping units was to aggregate individual polygons into patches (see sections 11 and 15; marsh polygons were aggregated if less than 60 m apart, riparian polygons if less than 100 m apart). Small, highly resolved modern features, if proximal to one another, were not counted separately and were effectively lumped to a size above the historical mapping unit. Although small, unmapped areas of marsh certainly existed in the historical Delta, these areas would have had to exist more than 60 m away from a mapped marsh to impact the number of historical patches in our analysis. The same goes for unresolved gaps in the historical marsh—unless these gaps isolated an area of marsh 60 m in all directions, the total number of marsh patches was not affected. Although the process of aggregating polygons into patches minimizes the effects of different patch sizes on our analyses, many modern patches analyzed in Chapter 5 are below the minimum historical mapping unit. To assess the impact of including these patches on our landscape metrics, and the sensitivity of the modern analyses to differences in MMUs, we calculated marsh patch statistics without patches less than 5 ha in size (the historical minimum mapping unit). Doing so yielded a significant decrease in the total number of patches—from 1,211 to 43. Average patch size increased, but perhaps less dramatically—from 4 ha (SD = 24 ha) to 22 ha (SD = 66 ha). It is worth noting that 9 (of 43) historical marsh patches are also below the historical dataset's minimum mapping unit (largely due to study boundary conditions)—enforcing a 5 ha MMU would thus increase historical average patch size from 4,494 ha (SD = 17,956 ha) to 5,682 ha (SD = 20,085 ha). Although removal of the marsh patches less than 5 ha would affect the precise magnitude of change, the direction of change and larger story remain unchanged.

The fidelity of the historical and modern channel polyline datasets is quite high. Both used no minimum mapping width, and channels were digitized wherever evidence of them existed. As described in Section 5, we estimated the length of unmapped historical low-order channels that we expect are comparable in size to the smallest channels visible/digitized in the modern Delta. Although these channels are not explicitly drawn on the map, accounting for their estimated length allowed us to more effectively make comparisons with the modern channel dataset. In both datasets, channels were only digitized around islands larger than 25 ha.

Table 2. Habitat types used to map the historical habitats of the Sacramento-San Joaquin Delta.

Landcover grouping	Habitat type	Description	MSCS NCCP Habitat Types (CALFED 2000c)
Water	**Tidal mainstem channel**	Rivers, major creeks, or major sloughs forming Delta islands where water is understood to have ebbed and flowed in the channel at times of low river flow. These delineated the islands of the Delta.	Tidal Perennial Aquatic
	Fluvial mainstem channel	Rivers or major creeks with no influence of tides.	Valley Riverine Aquatic
	Tidal low order channel	Dendritic tidal channels (i.e., dead-end channels terminating within wetlands) where tides ebbed and flowed within the channel at times of low river flow.	Tidal Perennial Aquatic
	Fluvial low order channel	Distributaries, overflow channels, side channels, swales. No influence of tides. These occupied non-tidal floodplain environments or upland alluvial fans.	Valley Riverine Aquatic
	Freshwater pond or lake	Permanently flooded depressions, largely devoid of emergent Palustrine vegetation. These occupied the lowest-elevation positions within wetlands.	Tidal Perennial Aquatic, Lacustrine
	Freshwater intermittent pond or lake	Seasonally or temporarily flooded depressions, largely devoid of emergent Palustrine vegetation. These were most frequently found in vernal pool complexes at the Delta margins and also in the non-tidal floodplain environments.	N/A
Freshwater emergent wetland	**Tidal freshwater emergent wetland**	Perennially wet, high water table, dominated by emergent vegetation. Woody vegetation (e.g., willows) may be a significant component for some areas, particularly the western-central Delta. Wetted or inundated by spring tides at low river stages (approximating high tide levels).	Tidal Freshwater Emergent
	Non-tidal freshwater emergent wetland	Temporarily to permanently flooded, permanently saturated, freshwater non-tidal wetlands dominated by emergent vegetation. In the Delta, occupying upstream floodplain positions above tidal influence.	Non-tidal Freshwater Permanent Emergent
Willow thicket and riparian forest	**Willow thicket**	Perennially wet, dominated by woody vegetation (e.g., willows), emergent vegetation may be a significant component, generally located at the "sinks" of major creeks or rivers as they exit alluvial fans into the valley floor.	Valley/Foothill Riparian

Wildlife Habitat Relationship (WHR)	Representative types from California Terrestrial Natural Communities (CNDDB 2010)	Cowardin et al. (1979)/ USFWS Riparian Mapping System (USFWS 2009)	Hydrogeomorphic classification (HGM) (Brinson 1993)
Estuarine, Riverine	*Azolla (filiculoides, mexicana)* (Mosquito fern mats) Provisional Alliance (52.106.00), *Stuckenia (pectinata) - Potamogeton* spp. (Pondweed mats) Alliance (52.107.00)	Estuarine subtidal, Estuarine intertidal, Riverine	Riverine wetland, surface flow, unidirectional flow and bidirectional flow
Estuarine, Riverine	*Azolla (filiculoides, mexicana)* (Mosquito fern mats) Provisional Alliance (52.106.00), *Stuckenia (pectinata) - Potamogeton* spp. (Pondweed mats) Alliance (52.107.00)	Estuarine subtidal, Estuarine intertidal, Riverine	Riverine wetland, surface flow, unidirectional flow and bidirectional flow
Estuarine, Riverine	*Azolla (filiculoides, mexicana)* (Mosquito fern mats) Provisional Alliance (52.106.00), *Stuckenia (pectinata) - Potamogeton* spp. (Pondweed mats) Alliance (52.107.00)	Estuarine subtidal, Estuarine intertidal, Riverine	Riverine wetland, surface flow, unidirectional flow and bidirectional flow
Estuarine, Riverine	*Azolla (filiculoides, mexicana)* (Mosquito fern mats) Provisional Alliance (52.106.00), *Stuckenia (pectinata) - Potamogeton* spp. (Pondweed mats) Alliance (52.107.00)	Estuarine subtidal, Estuarine intertidal, Riverine	Riverine wetland, surface flow, unidirectional flow and bidirectional flow
Estuarine, Lacustrine	*Azolla (filiculoides, mexicana)* (Mosquito fern mats) Provisional Alliance (52.106.00), *Stuckenia (pectinata) - Potamogeton* spp. (Pondweed mats) Alliance (52.107.00), *Nuphar polysepala* (Yellow pond-lily mats) Provisional Alliance (52.110.00)	Lacustrine	Depressional wetland, surface flow and groundwater, vertical fluctuations
N/A	N/A	N/A	Depressional wetland, surface flow and groundwater, vertical fluctuations
Fresh Emergent Wetland	*Schoenoplectus acutus* (Hardstem bulrush marsh) Alliance (52.122.00), *Schoenoplectus californicus* (California bulrush marsh) Alliance (52.114.00), *Typha (domingensis, latifolia)* (Cattail marshes) Alliance (52.050.00), American bulrush marsh (52.111.00), California bulrush marsh (52.114.00), *Juncus effusus* (Soft rush marshes) Alliance (45.561.00), *Juncus articus* (Baltic and Mexican rush marshes) Alliance (45.562.00), *Salix lucida* (Shining willow groves) Alliance (61.204.00), *Eleocharis macrostachya* (Pale spike rush marshes) Alliance (45.230.00)	Estuarine intertidal persistent emergent wetland. Temporarily to seasonally flooded, permanently saturated.	Fringe wetland, surface flow including tidal, bidirectional flow
Fresh Emergent Wetland	*Schoenoplectus acutus* (Hardstem bulrush marsh) Alliance (52.122.00), *Schoenoplectus californicus* (California bulrush marsh) Alliance (52.114.00), *Typha (domingensis, latifolia)* (Cattail marshes) Alliance (52.050.00), *Juncus effusus* (Soft rush marshes) Alliance (45.561.00), *Juncus articus* (Baltic and Mexican rush marshes) Alliance (45.562.00), *Eleocharis macrostachya* (Pale spike rush marshes) Alliance (45.230.00)	Palustrine persistent emergent freshwater wetland. Temporarily to permanently flooded, permanently saturated.	Riverine wetland, surface flow, unidirectional flow
Valley foothill riparian	*Salix gooddingii* Alliance (61.211.00), *Salix laevigata* Alliance (61.205.00), *Salix lasiolepis* Alliance (61.201.00), *Salix lucida* Alliance (61.204.00), *Salix exigua* Alliance (61.209.00), *Cornus sericea* (Red osier thickets) Alliance (80.100.00), *Rosa californica* Alliance (63.907.00), *Acer negundo* (Box-elder forest) Alliance (61.440.00), *Sambucus nigra* (Blue elderberry stands) Alliance	Palustrine forested wetland. Temporarily flooded, permanently saturated. / Riparian scrub/shrub deciduous.	Riverine wetland, surface flow, vertical fluctuations

Table 2 (continued). Habitat types used to map the historical habitats of the Sacramento-San Joaquin Delta.

Landcover grouping	Habitat type	Description	MSCS NCCP Habitat Types (CALFED 2000c)
Willow thicket and riparian forest (continued)	Willow riparian scrub or shrub	Riparian vegetation dominated by woody scrub or shrubs with few to no tall trees. This habitat type generally occupies long, relatively narrow corridors of lower natural levees along rivers and streams.	Valley/Foothill Riparian
	Valley foothill riparian	Mature riparian forest usually associated with a dense understory and mixed canopy, including sycamore, oaks, willows, and other trees. Occupied the supratidal natural levees of larger rivers that were occasionally flooded.	Valley/Foothill Riparian
Seasonal wetland	Wet meadow or seasonal wetland	Temporarily or seasonally flooded, herbaceous communities characterized by poorly-drained, clay-rich soils. These often comprised the upland edge of perennial wetlands.	Natural Seasonal Wetland
	Vernal pool complex	Area of seasonally flooded depressions, characterized by a relatively impermeable subsurface soil layer and distinctive vernal pool flora. These often comprised the upland edge of perennial wetlands.	Natural Seasonal Wetland
	Alkali seasonal wetland complex	Temporarily or seasonally flooded, herbaceous or scrub communities characterized by poorly-drained, clay-rich soils with a high residual salt content. These often comprised the upland edge of perennial wetlands.	Natural Seasonal Wetland
Other upland	Stabilized interior dune vegetation	Vegetation dominated by shrub species with some locations also supporting live oaks on the more stabilized dunes with more well-developed soil profiles.	Inland Dune Scrub
	Grassland	Low herbaceous communities occupying well-drained soils and composed of native forbs and annual and perennial grasses and usually devoid of trees. Few to no vernal pools present.	Grassland
	Oak woodland or savanna	Oak dominated communities with sparse to dense cover (10-65% cover) and an herbaceous understory.	Valley/Foothill Woodland and Forest

Wildlife Habitat Relationship (WHR)	Representative types from California Terrestrial Natural Communities (CNDDB 2010)	Cowardin et al. (1979)/ USFWS Riparian Mapping System (USFWS 2009)	Hydrogeomorphic classification (HGM) (Brinson 1993)
Valley foothill riparian	*Salix gooddingii* Alliance (61.211.00), *Salix laevigata* Alliance (61.205.00), *Salix lasiolepis* Alliance (61.201.00), *Salix lucida* Alliance (61.204.00), *Salix exigua* Alliance (61.209.00), *Cornus sericea* (Red osier thickets) Alliance (80.100.00), *Rosa californica* Alliance (63.907.00), *Acer negundo* (Box-elder forest) Alliance (61.440.00), *Cephalanthus occidentalis* (Button willow thickets) Alliance (63.300.00)	Palustrine forested wetland. Intermittently flooded, seasonally saturated. / Riparian scrub/ shrub deciduous.	Riverine wetland, surface flow, vertical fluctuations
Valley foothill riparian	*Quercus agrifolia* Alliance (71.060.00), *Quercus lobata* Alliance (71.040.00), *Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni)* Alliance (71.100.00), *Quercus wislizeni* Alliance (71.080.00), *Juglans hindsii and Hybrids* Special stands (61.810.00), *Salix gooddingii* Alliance (61.211.00), *Salix laevigata* Alliance (61.205.00), *Salix lasiolepis* Alliance (61.201.00), *Salix lucida* Alliance (61.204.00), *Salix exigua* Alliance (61.209.00), *Acer negundo* (Box-elder forest) Alliance (61.440.00), *Cornus sericea* (Red osier thickets) Alliance (80.100.00), *Rosa californica* Alliance (63.907.00), *Platanus racemosa* Alliance (61.310.00), *Populus fremontii* Alliance (61.130.00), *Cephalanthus occidentalis* (Button willow thickets) Alliance (63.300.00)	Palustrine forested wetland. Intermittently flooded, seasonally saturated. / Riparian forested deciduous	Riverine wetland, surface flow, vertical fluctuations
Wet meadow	*Lasthenia californica - Plantago erecta - Vulpia microstachys* (California goldfields-dwarf plantain-six-weeks fescue flower fields) Alliance (44.108.00), *Elymus triticoides (*Creeping rye grass turfs) Alliance (41.080.00), *Ambrosia psilostachya* (Western ragweed meadows) Alliance (33.065.00), *Lotus purshianus* (Spanish clover fields) Provisional Herbaceous Alliance (52.230.00), *Juncus effusus* (Soft rush marshes) Alliance (45.561.00), *Juncus articus* (Baltic and Mexican rush marshes) Alliance (45.562.00)	Palustrine emergent wetland. Temporarily to seasonally flooded, seasonally saturated.	Depressional wetland, surface flow and groundwater, vertical fluctuations
Annual grassland	*Lasthenia fremontii - Downingia (bicornuta)* (Fremont's goldfields - Downingia vernal pools) Alliance (42.007.00), *Eryngium aristulatum* Alliance (42.004.00)	Palustrine nonpersistent emergent wetland.	Depressional wetland, surface flow and precipitation, vertical fluctuations
Alkali desert scrub	*Cressa truxillensis - Distichlis spicata* (Alkali weed - Salt grass playas and sinks) Alliance (46.100.00), *Lasthenia fremontii - Distichlis spicata* (Fremont's goldfields - Saltgrass alkaline vernal pools) Alliance (44.119.00), *Allenrolfea occidentalis* (Iodine bush scrub) Alliance (36.120.00), *Sporobolus airoides* (Alkali sacaton grassland) Alliance (41.010.00), *Elymus triticoides* (Creeping rye grass turfs) Alliance (41.080.00), *Frankenia salina* (Alkali heath marsh) Alliance (52.500.00)	Palustrine emergent saline wetland. Temporarily to seasonally flooded, seasonally to permanently saturated.	Depressional wetland, surface flow and precipitation, vertical fluctuations
Coastal scrub	*Lupinus albifrons* (Silver bush lupine scrub) Alliance (32.081.00), *Baccharis pilularis* (Coyote brush scrub) Alliance (32.060.00), *Lotus scoparius* (Deer weed scrub) Alliance (52.240.00)	N/A	N/A
Annual grassland, Perennial grassland	*Lasthenia californica - Plantago erecta - Vulpia microstachys* (California goldfields - Dwarf plantain - Six-weeks fescue flower fields) Alliance (44.108.00), *Elymus triticoides* (Creeping rye grass turfs) Alliance (41.080.00), *Nassella pulchra* Alliance (41.150.00), *Eschscholzia (californica)* (California poppy fields) Alliance (43.200.00), *Amsinckia* (Fiddleneck fields) Alliance (42.110.00), *Plagiobothrys nothofulvus* (Popcorn flower fields) Alliance (43.300.00)	N/A	N/A
Valley oak woodland, Blue oak woodland, Coastal oak woodland	*Quercus agrifolia* Alliance (71.060.00), *Quercus lobata* Alliance (71.040.00), *Quercus (agrifolia, douglasii, garryana, kelloggii, lobata, wislizeni)* Alliance (71.100.00), *Quercus wislizeni* Alliance (71.080.00), *Quercus douglasii* Alliance (71.020.00)	N/A	N/A

Table 3. Crosswalk for the datasets used to generate a complete modern Delta habitat type map.

	Original classifications, by dataset (with relevant field)		
Crosswalked habitat type	CDFG 2007 Delta Vegetation ("MAPUNIT")	CDWR 2012 CVRMP ("DELTAVEG" [priority] or "NVCSNAME")	WWR 2013 CSCCA Natural Communities & CDWR 2013 BDCP Natural Communities ("SAIC_TYPE")
Agriculture/ Non-native/ Ruderal	*Acacia - Robinia* Agriculture Eucalyptus Exotic Vegetation Stands Giant Cane (*Arundo donax*) Horsetail (*Equisetum* spp.) Intermittently or Temporarily Flooded Deciduous Shrublands *Lepidium latifolium - Salicornia virginica - Distichlis spicata* Microphyllous Shrubland Pampas Grass (*Cortaderia selloana - C. jubata*) Perennial Pepperweed (*Lepidium latifolium*) Poison Hemlock (*Conium maculatum*) Ruderal Herbaceous Grasses & Forbs Sparsely or Unvegetated Areas; Abandoned orchards Tobacco brush (*Nicotiana glauca*) mapping unit	Agriculture Californian warm temperate marsh/seep Exotic Vegetation Stands Giant Cane (*Arundo donax*) Intermittently or Temporarily Flooded Deciduous Shrublands Introduced North American Mediterranean woodland and forest Mediterranean California naturalized annual and perennial grassland Pampas Grass (*Cortaderia selloana - C. jubata*) Ruderal Herbaceous Grasses & Forbs Sparsely or Unvegetated Areas; Abandoned orchards	Agricultural
Alkali seasonal wetland complex	Alkali Heath (*Frankenia salina*) Alkaline vegetation mapping unit *Allenrolfea occidentalis* mapping unit *Distichlis spicata - Salicornia virginica* *Frankenia salina - Distichlis spicata* *Juncus bufonius* (salt grasses) Pickleweed (*Salicornia virginica*) *Salicornia virginica - Cotula coronopifolia* *Salicornia virginica - Distichlis spicata* Salt scalds and associated sparse vegetation Saltgrass (*Distichlis spicata*) *Suaeda moquinii* - (*Lasthenia californica*) mapping unit	Pickleweed (*Salicornia virginica*) Saltgrass (*Distichlis spicata*) Southwestern North American salt basin and high marsh	
Freshwater emergent wetland	American Bulrush (*Scirpus americanus*) Broad-leaf Cattail (*Typha latifolia*) California Bulrush (*Scirpus californicus*) Common Reed (*Phragmites australis*) Hard-stem Bulrush (*Scirpus acutus*)	Arid West freshwater emergent marsh Mixed *Scirpus* / Submerged Aquatics (*Egeria-Cabomba-Myriophyllum* spp.) complex *Scirpus acutus - Typha angustifolia* *Scirpus acutus* Pure	Tidal Brackish Emergent Wetland Tidal Freshwater Emergent Wetland

	Original classifications, by dataset (with relevant field)		
Crosswalked habitat type	CDFG 2007 Delta Vegetation ("MAPUNIT")	CDWR 2012 CVRMP ("DELTAVEG" [priority] or "NVCSNAME")	WWR 2013 CSCCA Natural Communities & CDWR 2013 BDCP Natural Communities ("SAIC_TYPE")
Freshwater emergent wetland	Mixed *Scirpus* / Floating Aquatics (*Hydrocotyle - Eichhornia*) Complex Mixed *Scirpus* / Submerged Aquatics (*Egeria-Cabomba-Myriophyllum* spp.) complex Mixed *Scirpus* Mapping Unit Narrow-leaf Cattail (*Typha angustifolia*) *Polygonum amphibium* *Scirpus acutus* - (*Typha latifolia*) - *Phragmites australis* *Scirpus acutus - Typha angustifolia* *Scirpus acutus* Pure *Scirpus acutus -Typha latifolia* *Scirpus californicus - Eichhornia crassipes* *Scirpus californicus - Scirpus acutus* *Scirpus* spp. in managed wetlands Smartweed *Polygonum* spp. - Mixed Forbs *Typha angustifolia - Distichlis spicata*		
Grassland	*Bromus diandrus - Bromus hordeaceus* California Annual Grasslands - Herbaceous Creeping Wild Rye Grass (*Leymus triticoides*) Italian Rye-grass (*Lolium multiflorum*) *Lolium multiflorum - Convolvulus arvensis* Tall & Medium Upland Grasses	California annual forb/grass vegetation California Annual Grasslands - Herbaceous Italian Rye-grass (*Lolium multiflorum*)	Grassland
Interior dune scrub	*Lotus scoparius* - Antioch Dunes *Lupinus albifrons* - Antioch Dunes		
Managed wetland			Managed Wetland
Urban/Barren	Levee Rock Riprap Urban Developed - Built Up	Barren Urban Urban Developed - Built Up	Developed
Valley foothill riparian	Black Willow (*Salix gooddingii*) - Valley Oak (*Quercus lobata*) restoration Coast Live Oak (*Quercus agrifolia*) Fremont Cottonwood (*Populus fremontii*) Hinds walnut (*Juglans hindsii*) Oregon Ash (*Fraxinus latifolia*) *Quercus lobata - Acer negundo* *Quercus lobata - Alnus rhombifolia* (*Salix lasiolepis - Populus fremontii - Quercus agrifolia*)	Black Willow (*Salix gooddingii*) Californian broadleaf forest and woodland Central and south coastal California seral scrub Coast Live Oak (*Quercus agrifolia*) Fremont Cottonwood (*Populus fremontii*) *Quercus lobata - Alnus rhombifolia* (*Salix lasiolepis - Populus fremontii - Quercus agrifolia*) *Quercus lobata - Fraxinus latifolia*	Valley/Foothill Riparian

Table 3 (continued). Crosswalk for the datasets used to generate a complete modern Delta habitat type map.

	Original classifications, by dataset (with relevant field)		
Crosswalked habitat type	CDFG 2007 Delta Vegetation ("MAPUNIT")	CDWR 2012 CVRMP ("DELTAVEG" [priority] or "NVCSNAME")	WWR 2013 CSCCA Natural Communities & CDWR 2013 BDCP Natural Communities ("SAIC_TYPE")
Valley foothill riparian	*Quercus lobata - Fraxinus latifolia* *Quercus lobata / Rosa californica* (*Rubus discolor - Salix lasiolepis / Carex* spp.) Restoration Sites *Salix gooddingii - Populus fremontii -* (*Quercus lobata-Salix exigua-Rubus discolor*) *Salix gooddingii - Quercus lobata* / Wetland Herbs Temporarily or Seasonally Flooded - Deciduous Forests Tree-of-Heaven (*Ailanthus altissima*) Valley Oak (*Quercus lobata*) Valley Oak (*Quercus lobata*) restoration	*Quercus lobata / Rosa californica* (*Rubus discolor - Salix lasiolepis / Carex* spp.) *Salix gooddingii - Populus fremontii -* (*Quercus lobata-Salix exigua-Rubus discolor*) *Salix gooddingii - Quercus lobata* / Wetland Herbs Southwestern North American riparian evergreen and deciduous woodland Valley Oak (*Quercus lobata*)	
Vernal pool complex	Vernal Pools	Californian mixed annual/perennial freshwater vernal pool/swale/plain bottomland	Vernal Pool Complex
Water	Algae Brazilian Waterweed (*Egeria - Myriophyllum*) Submerged Floating Primrose (*Ludwigia peploides*) Generic Floating Aquatics *Hydrocotyle ranunculoides* *Ludwigia peploides* Milfoil - Waterweed (generic submerged aquatics) Pondweed (*Potamogeton* sp.) Shallow flooding with minimal vegetation at time of photography Tidal mudflats Water Water Hyacinth (*Eichhornia crassipes*)	Algae Brazilian Waterweed (*Egeria - Myriophyllum*) Submerged Generic Floating Aquatics Riverine Water Western North American Freshwater Aquatic Vegetation	Alkali Seasonal Wetland Complex Non-Tidal Perennial Aquatic Tidal Perennial Aquatic
Wet meadow/ Seasonal wetland	Distichlis spicata - Annual Grasses Distichlis spicata - Juncus balticus Intermittently Flooded Perennial Forbs Intermittently or temporarily flooded undifferentiated annual grasses and forbs Juncus balticus - meadow vegetation Managed alkali wetland (Crypsis)	*Distichlis spicata* - Annual Grasses Intermittently or temporarily flooded undifferentiated annual grasses and forbs Naturalized warm-temperate riparian and wetland Rabbitsfoot grass (*Polypogon maritimus*) Seasonally Flooded Grasslands Seasonally flooded undifferentiated annual grasses and forbs	Other Natural Seasonal Wetland

	Original classifications, by dataset (with relevant field)		
Crosswalked habitat type	CDFG 2007 Delta Vegetation ("MAPUNIT")	CDWR 2012 CVRMP ("DELTAVEG" [priority] or "NVCSNAME")	WWR 2013 CSCCA Natural Communities & CDWR 2013 BDCP Natural Communities ("SAIC_TYPE")
Wet meadow/ Seasonal wetland	Managed Annual Wetland Vegetation (Non-specific grasses & forbs) Rabbitsfoot grass (*Polypogon maritimus*) Seasonally Flooded Grasslands Seasonally flooded undifferentiated annual grasses and forbs Temporarily Flooded Grasslands Temporarily Flooded Perennial Forbs	Temporarily Flooded Perennial Forbs	
Willow riparian scrub/ shrub	*Acer negundo - Salix gooddingii* *Alnus rhombifolia / Cornus sericea* *Alnus rhombifolia / Salix exigua* (*Rosa californica*) Arroyo Willow (*Salix lasiolepis*) *Baccharis pilularis* / Annual Grasses & Herbs Black Willow (*Salix gooddingii*) Blackberry (*Rubus discolor*) Box Elder (*Acer negundo*) California Wild Rose (*Rosa californica*) Coyotebush (*Baccharis pilularis*) Mexican Elderberry (*Sambucus mexicana*) Narrow-leaf Willow (*Salix exigua*) *Salix exigua* - (*Salix lasiolepis* - Rubus discolor - *Rosa californica*) *Salix gooddingii / Rubus discolor* *Salix gooddingii* / Wetland Herbs *Salix lasiolepis* - Mixed brambles (*Rosa californica - Vitis californica - Rubus discolor*) Santa Barbara Sedge (*Carex barbarae*) White Alder (*Alnus rhombifolia*) White Alder (*Alnus rhombifolia*) - Arroyo willow (*Salix lasiolepis*) restoration	*Baccharis pilularis* / Annual Grasses & Herbs Blackberry (*Rubus discolor*) Box Elder (*Acer negundo*) Narrow-leaf Willow (*Salix exiqua*) *Salix exigua* - (*Salix lasiolepis - Rubus discolor - Rosa californica*) *Salix gooddingii* / wetland herbs *Salix lasiolepis* - Mixed brambles (*Rosa californica - Vitis californica - Rubus discolor*) Southwestern North American introduced riparian scrub Southwestern North American riparian/wash scrub	
Willow thicket	Buttonbush (*Cephalanthus occidentalis*) California Dogwood (*Cornus sericea*) California Hair-grass (*Deschampsia caespitosa*) *Cornus sericea - Salix exigua* *Cornus sericea - Salix lasiolepis* / (*Phragmites australis*) *Salix lasiolepis* - (*Cornus sericea*) / *Scirpus* spp.- (*Phragmites australis - Typha* spp.) complex unit Shining Willow (*Salix lucida*)	Buttonbush (*Cephalanthus occidentalis*)	

Table 5. Table relating modern habitat type map units to non-native/invasive classifications. Values of '1' indicate that the map unit is classified as dominated or co-dominated by non-native or invasive vegetation; values of '0' indicate it is not.

Map unit	Non-native	Invasive	Non-native or invasive species
Acacia - Robinia	1	1	Acacia
Acer negundo - Salix gooddingii	0	0	
Agricultural	NA	NA	
Agricultural from 'Agriculture'	NA	NA	
Agricultural from 'Grain/Hay Crops'	NA	NA	
Agriculture	NA	NA	
Algae	0	0	
Alkali Heath (*Frankenia salina*)	0	0	
Alkaline vegetation mapping unit	0	0	
Allenrolfea occidentalis mapping unit	0	0	
Alnus rhombifolia / *Cornus sericea*	0	0	
Alnus rhombifolia / *Salix exigua* (*Rosa californica*)	0	0	
American Bulrush (*Scirpus americanus*)	0	0	
Arid West freshwater emergent marsh	1	0	
Arroyo Willow (*Salix lasiolepis*)	0	0	
Baccharis pilularis / Annual Grasses & Herbs	1	1	Grasslands assumed to be non-native/invasive
Barren	NA	NA	
Black Willow (*Salix gooddingii*)	0	0	
Black Willow (*Salix gooddingii*) - Valley Oak (*Quercus lobata*) restoration	0	0	
Blackberry (*Rubus discolor*)	1	1	*Rubus discolor*
Box Elder (*Acer negundo*)	0	0	
Brazilian Waterweed (*Egeria - Myriophyllum*) Submerged	1	1	*Egeria*, *Myriophyllum*
Broad-leaf Cattail (*Typha latifolia*)	0	0	
Bromus diandrus - Bromus hordeaceus	1	1	*Bromus diandrus*, *Bromus hordeaceus*
Buttonbush (*Cephalanthus occidentalis*)	0	0	
California annual forb/grass vegetation	1	1	Grasslands assumed to be non-native/invasive
California Annual Grasslands - Herbaceous	1	1	Grasslands assumed to be non-native/invasive
California Bulrush (*Scirpus californicus*)	0	0	
California Dogwood (*Cornus sericea*)	0	0	
California Hair-grass (*Deschampsia caespitosa*)	0	0	
California Wild Rose (*Rosa californica*)	0	0	
Californian broadleaf forest and woodland	0	0	
Californian mixed annual/perennial freshwater vernal pool/swale/plain bottom-land	0	0	
Californian warm temperate marsh/seep	0	0	
Central and south coastal California seral scrub	0	0	
Coast Live Oak (*Quercus agrifolia*)	0	0	
Common Reed (*Phragmites australis*)	0	0	
Cornus sericea - Salix exigua	0	0	
Cornus sericea - Salix lasiolepis / (*Phragmites australis*)	0	0	
Coyotebush (*Baccharis pilularis*)	0	0	
Creeping Wild Rye Grass (*Leymus triticoides*)	0	0	
Developed	NA	NA	
Distichlis spicata - Annual Grasses	1	1	Grasslands assumed to be non-native/invasive
Distichlis spicata - Juncus balticus	0	0	

Map unit	Non-native	Invasive	Non-native or invasive species
Distichlis spicata - Salicornia virginica	0	0	
Eucalyptus	1	1	*Eucalyptus*
Exotic Vegetation Stands	1	1	Exotic vegetation stands
Floating Primrose (*Ludwigia peploides*)	0	1	*Ludwigia peploides*
Frankenia salina - Distichlis spicata	0	0	
Fremont Cottonwood (*Populus fremontii*)	0	0	
Generic Floating Aquatics	0	0	
Giant Cane (*Arundo donax*)	1	1	*Arundo donax*
Grassland	1	1	Grasslands assumed to be non-native/invasive
Grassland from 'California Annual Grasslands - Herbaceous'	1	1	Grasslands assumed to be non-native/invasive
Grassland from 'Degraded Vernal Pool Complex - California Annual Grasslands - Herbaceous'	1	1	Grasslands assumed to be non-native/invasive
Hard-stem Bulrush (*Scirpus acutus*)	0	0	
Hinds walnut (*Juglans hindsii*)	0	0	
Horsetail (*Equisetum* spp.)	0	0	
Hydrocotyle ranunculoides	0	0	
Intermittently Flooded Perennial Forbs	1	1	*Lepidium latifolium* Semi-natural Stands
Intermittently or Temporarily Flooded Deciduous Shrublands	0	0	
Intermittently or temporarily flooded undifferentiated annual grasses and forbs	1	1	Grasslands assumed to be non-native/invasive
Introduced North American Mediterranean woodland and forest	1	1	Group level: could contain *Eucalyptus*, *Ailanthus*, and other non-native naturalized trees
Italian Rye-grass (*Lolium multiflorum*)	1	1	*Lolium multiflorum*
Juncus balticus - meadow vegetation	0	0	
Juncus bufonius (salt grasses)	0	0	
Lepidium latifolium - Salicornia virginica - Distichlis spicata	1	1	*Lepidium latifolium*
Levee Rock Riprap	NA	NA	
Lolium multiflorum - Convolvulus arvensis	1	1	*Lolium multiflorum*, *Convolvulus arvensis*
Lotus scoparius - Antioch Dunes	0	0	
Ludwigia peploides	0	1	*Ludwigia peploides*
Lupinus albifrons - Antioch Dunes	0	0	
Managed alkali wetland (*Crypsis*)	1	0	*Crypsis*
Managed Annual Wetland Vegetation (Non-specific grasses & forbs)	1	1	Undefined, but "likely to be completely dominated by non-natives"
Managed Wetland	NA	NA	
Managed Wetland from 'Agriculture'	NA	NA	
Managed Wetland from 'Rabbitsfoot grass (*Polypogon maritimus*)'	1	0	*Polypogon maritimus*
Mediterranean California naturalized annual and perennial grassland	1	1	Grasslands assumed to be non-native/invasive
Mexican Elderberry (*Sambucus mexicana*)	0	0	
Microphyllous Shrubland	0	0	
Milfoil - Waterweed (generic submerged aquatics)	1	1	Milfoil
Mixed *Scirpus* / Floating Aquatics (*Hydrocotyle - Eichhornia*) Complex	1	1	*Eichhornia*, *Hydrocotyle*
Mixed *Scirpus* / Submerged Aquatics (*Egeria-Cabomba-Myriophyllum* spp.) complex	1	1	*Egeria*, *Cabomba*, *Myriophyllum*
Mixed *Scirpus* Mapping Unit	0	0	
N/A; Agriculture/Non-native/Ruderal	NA	NA	
N/A; Urban/Barren	NA	NA	

Table 5 (continued). Table relating modern habitat type map units to non-native/invasive classifications. Values of '1' indicate that the map unit is classified as dominated or co-dominated by non-native or invasive vegetation; values of '0' indicate it is not.

Map unit	Non-native	Invasive	Non-native or invasive species
N/A; Water	NA	NA	
Narrow-leaf Cattail (*Typha angustifolia*)	1	0	*Typha angustifolia*
Narrow-leaf Willow (*Salix exigua*)	0	0	
Narrow-leaf Willow (*Salix exiqua*)	0	0	
Naturalized warm-temperate riparian and wetland	NA	NA	
Non-Tidal Perennial Aquatic	NA	NA	
Non-Tidal Perennial Aquatic from 'Agriculture'	NA	NA	
Non-Tidal Perennial Aquatic from 'Water'	NA	NA	
Oregon Ash (*Fraxinus latifolia*)	0	0	
Other Natural Seasonal Wetland	0	0	
Pampas Grass (*Cortaderia selloana - C. jubata*)	1	1	*Cortaderia selloana*, *Cortaderia jubata*
Perennial Pepperweed (*Lepidium latifolium*)	1	1	*Lepidium latifolium*
Pickleweed (*Salicornia virginica*)	0	0	
Poison Hemlock (*Conium maculatum*)	1	1	*Conium maculatum*
Polygonum amphibium	0	0	
Pondweed (*Potamogeton* sp.)	1	1	*Potamogeton* sp.
Quercus lobata - Acer negundo	0	0	
Quercus lobata - Alnus rhombifolia (*Salix lasiolepis - Populus fremontii - Quercus agrifolia*)	0	0	
Quercus lobata - Fraxinus latifolia	0	0	
Quercus lobata / Rosa californica (*Rubus discolor - Salix lasiolepis / Carex* spp.)	1	1	*Rubus discolor*, *Carex*
Rabbitsfoot grass (*Polypogon maritimus*)	1	0	*Polypogon maritimus*
Restoration Sites	0	0	
Riverine	NA	NA	
Ruderal Herbaceous Grasses & Forbs	1	1	*Silybum marianum*, *Brassica nigra*
Salicornia virginica - Cotula coronopifolia	1	1	*Cotula coronopifolia*
Salicornia virginica - Distichlis spicata	0	0	
Salix exigua - (*Salix lasiolepis - Rubus discolor - Rosa californica*)	1	1	*Rubus discolor*
Salix gooddingii - Populus fremontii - (*Quercus lobata-Salix exigua-Rubus discolor*)	1	1	*Rubus discolor*
Salix gooddingii - Quercus lobata / Wetland Herbs	0	0	
Salix gooddingii / Rubus discolor	1	1	*Rubus discolor*
Salix gooddingii / Wetland Herbs	0	0	
Salix gooddingii / wetland herbs	0	0	
Salix lasiolepis - (*Cornus sericea*) / *Scirpus* spp.- (*Phragmites australis - Typha* spp.) complex unit	0	0	
Salix lasiolepis - Mixed brambles (*Rosa californica - Vitis californica - Rubus discolor*)	1	1	*Rubus discolor*
Salt scalds and associated sparse vegetation	0	0	
Saltgrass (*Distichlis spicata*)	0	0	
Santa Barbara Sedge (*Carex barbarae*)	0	0	
Scirpus acutus - (*Typha latifolia*) - *Phragmites australis*	0	0	
Scirpus acutus - Typha angustifolia	1	0	*Typha angustifolia*
Scirpus acutus Pure	0	0	
Scirpus acutus -Typha latifolia	0	0	
Scirpus californicus - Eichhornia crassipes	1	1	*Eichhornia crassipes*
Scirpus californicus - Scirpus acutus	0	0	
Scirpus spp. in managed wetlands	0	0	

Map unit	Non-native	Inva-sive	Non-native or invasive species
Seasonally Flooded Grasslands	1	1	Grasslands assumed to be non-native/invasive
Seasonally flooded undifferentiated annual grasses and forbs	1	1	Grasslands assumed to be non-native/invasive
Shallow flooding with minimal vegetation at time of photography	NA	NA	
Shining Willow (*Salix lucida*)	0	0	
Smartweed *Polygonum* spp. - Mixed Forbs	0	0	
Southwestern North American introduced riparian scrub	1	1	Group level: could contain *Arundo donax*, *Tamarix*, *Rubus*
Southwestern North American riparian evergreen and deciduous woodland	0	0	
Southwestern North American riparian/wash scrub	0	0	
Southwestern North American salt basin and high marsh	0	0	
Sparsely or Unvegetated Areas; Abandoned orchards	NA	NA	
Suaeda moquinii - (*Lasthenia californica*) mapping unit	0	0	
Tall & Medium Upland Grasses	1	1	Grasslands assumed to be non-native/invasive
Temporarily Flooded Grasslands	1	1	*Arundo*; Grasslands assumed to be non-native/invasive
Temporarily Flooded Perennial Forbs	0	0	
Temporarily or Seasonally Flooded - Deciduous Forests	0	0	
Tidal mudflats	NA	NA	
Tidal Perennial Aquatic	NA	NA	
Tidal Perennial Aquatic from 'Brazilian Waterweed (*Egeria* - *Myriophyllum*) Submerged'	1	1	*Egeria*, *Myriophyllum*
Tobacco brush (*Nicotiana glauca*) mapping unit	1	1	*Nicotaina glauca*
Tree-of-Heaven (*Ailanthus altissima*)	1	1	*Ailanthis altissima*
Typha angustifolia - *Distichlis spicata*	1	0	*Typha angustifolia*
Unknown	NA	NA	
Urban	NA	NA	
Urban Developed - Built Up	NA	NA	
Valley Oak (*Quercus lobata*)	0	0	
Valley Oak (*Quercus lobata*) restoration	0	0	
Vernal Pool Complex	0	0	
Vernal Pool Complex from 'California Annual Grasslands - Herbaceous'	1	1	Grasslands assumed to be non-native/invasive
Vernal Pool Complex from 'Vernal Pool - Enhanced'	0	0	
Vernal Pool Complex from 'Vernal Pool - Natural'	0	0	
Vernal Pool Complex from 'Vernal Pools'	0	0	
Vernal Pools	0	0	
Water	NA	NA	
Water Hyacinth (*Eichhornia crassipes*)	1	1	*Eichhornia crassipes*
Western North American Freshwater Aquatic Vegetation	1	1	Group level: could contain *Egeria*, *Myriophyllum*, *Ludwigia peploides*, *Cambomba*, or *Eichhornia crassipes*
White Alder (*Alnus rhombifolia*)	0	0	
White Alder (*Alnus rhombifolia*) - Arroyo willow (*Salix lasiolepis*) restoration	0	0	

Appendix B: Species

The table below lists the common and scientific names of the species mentioned in this report. Bay Delta Conservation Plan Public Draft (BDCP) covered species are marked with an asterisk (*). The Integrated Taxonomic Information System (ITIS) database was used as our nomenclatural reference, except for with names marked with a cross (†), which deviate from those validated by ITIS. The common names of all species are written in lower case, with the following exceptions: (1) the common names of all birds are capitalized, as per American Ornithologists' Union standards and (2) all proper nouns are capitalized. Although the word "Delta" is used as a proper noun throughout this report, we do not capitalize the common name of *Hypomesus transpacificus* (delta smelt), as per U.S. Fish & Wildlife Service standards.

Common name	Scientific name
Birds	
American Wigeon	*Anas americana*
Ash-throated Flycatcher	*Myiarchus cinerascens*
Black Tern	*Chlidonias niger*
Blue Grosbeak	*Passerina caerulea*
Brown-headed Cowbird	*Molothrus ater*
California Black Rail*†	*Laterallus jamaicensis coturniculus*
California Clapper Rail*	*Rallus longirostris obsoletus*
California Least Tern	*Sternula antillarum browni*
Canada Goose	*Branta canadensis*
Canvasback	*Aythya valisineria*
Cinnamon Teal	*Anas cyanoptera*
Common Moorhen	*Gallinula chloropus*
Cooper's Hawk	*Accipiter cooperii*
Downy Woodpecker	*Picoides pubescens*
European Starling	*Sturnus vulgaris*
Forster's Tern	*Sterna forsteri*
Gadwall	*Anas strepera*
Golden-crowned Sparrow	*Zonotrichia atricapilla*
Greater Sandhill Crane*†	*Grus canadensis tabida*
Greater White-fronted Goose	*Anser albifrons*
Green-winged Teal	*Anas crecca*
Hermit Thrush	*Catharus guttatus*
Horned Lark	*Eremophila alpestris*
Least Bell's Vireo*	*Vireo bellii pusillus*
Mallard	*Anas platyrhynchos*
Modesto Song Sparrow†	*Melospiza melodia mailliardi*†
Northern Harrier	*Circus cyaneus*
Northern Pintail	*Anas acuta*
Northern Shoveler	*Anas clypeata*
Oak Titmouse	*Baeolophus inornatus*
Red-shouldered Hawk	*Buteo lineatus*
Ross' Goose	*Chen rossii*

Savannah Sparrow	*Passerculus sandwichensis*
Sharp-shinned Hawk	*Accipiter striatus*
Short-eared Owl	*Asio flammeus*
Snow Goose	*Chen caerulescens*
Suisun Song Sparrow*†	*Melospiza melodia maxillaris*
Swainson's Hawk*	*Buteo swainsoni*
Tricolored Blackbird*	*Agelaius tricolor*
Tundra Swan	*Cygnus columbianus*
Western Burrowing Owl*†	*Athene cunicularia hypugaea*
Western Tanager	*Piranga ludoviciana*
Western Yellow-billed Cuckoo*†	*Coccyzus americanus occidentalis*†
White-tailed Kite*	*Elanus leucurus*
Willow Flycatcher	*Empidonax traillii*
Wilson's Warbler	*Cardellina pusilla*
Wood Duck	*Aix sponsa*
Yellow Warbler	*Setophaga petechia*†
Yellow-breasted Chat*	*Icteria virens*
Yellow Warbler	*Setophaga petechia*
Yellow-rumped Warbler	*Dendroica coronata*†

Fish

bluegill	*Lepomis macrochirus*
California roach	*Hesperoleucus symmetricus*
Chinook salmon*	*Oncorhynchus tshawytscha*
delta smelt*	*Hypomesus transpacificus*
green sturgeon*	*Acipenser medirostris*
hardhead	*Mylopharodon conocephalus*
hitch	*Lavinia exilicauda*
longfin smelt*	*Spirinchus thaleichthys*
Pacific lamprey*	*Entosphenus tridentatus*
Pacific staghorn sculpin	*Leptocottus armatus*
river lamprey*	*Lampetra ayresii*
Sacramento blackfish	*Orthodon microlepidotus*
Sacramento perch	*Archoplites interruptus*
Sacramento pikeminnow	*Ptychocheilus grandis*
Sacramento splittail*	*Pogonichthys macrolepidotus*
Sacramento sucker	*Catostomus occidentalis*
starry flounder	*Platichthys stellatus*
steelhead*	*Oncorhynchus mykiss*
striped bass	*Morone saxatilis*
thicktail chub	*Gila crassicauda*
tule perch	*Hysterocarpus traskii*
white catfish	*Ameiurus catus*
white sturgeon*	*Acipenser transmontanus*

Invertebrates

Asian clam	*Corbicula fluminea*
California linderiella*	*Linderiella occidentalis*
conservancy fairy shrimp*	*Branchinecta conservatio*
Lange's metalmark butterfly	*Apodemia mormo langei*
longhorn fairy shrimp*	*Branchinecta longiantenna*
midvalley fairy shrimp*†	*Branchinecta mesovallensis*
valley elderberry longhorn beetle*	*Desmocerus californicus dimorphus*
vernal pool fairy shrimp*	*Branchinecta lynchi*
vernal pool tadpole shrimp*	*Lepidurus packardi*

Mammals

American beaver	*Castor canadensis*
California ground squirrel	*Otospermophilus beecheyi*
California vole	*Microtus californicus*
coyote	*Canis latrans*
gray fox	*Urocyon cinereoargenteus*
grizzly bear	*Ursus arctos*
long-tailed weasel	*Mustela frenata*
mule deer	*Odocoileus hemionus*
North American river otter	*Lontra canadensis*
pronghorn	*Antilocapra americana*
ringtail	*Bassariscus astutus*
riparian brush rabbit*†	*Sylvilagus bachmani riparius*†
riparian woodrat*†	*Neotoma fuscipes riparia*
salt marsh harvest mouse*	*Reithrodontomys raviventris*
San Joaquin kit fox*†	*Vulpes macrotis mutica*†
San Joaquin Valley kangaroo rat	*Dipodomys nitratoides*
Suisun shrew*†	*Sorex ornatus sinuosus*
tule elk†	*Cervus elaphus nannodes*

Plants

alkali milkvetch*	*Astragalus tener* var. *tener*
Antioch Dunes evening primrose	*Oenothera deltoides* ssp. *howellii*
Boggs Lake hedge-hyssop*	*Gratiola heterosepala*
brittlescale*	*Atriplex parishii* var. *depressa*†
caper-fruited tropidocarpum	*Tropidocarpum capparideum*
Carquinez goldenbush*	*Isocoma arguta*
Delta button celery*†	*Eryngium racemosum*
Delta tule pea*	*Lathyrus jepsonii* var. *jepsonii*
dwarf downingia*†	*Downingia pusilla*
heartscale*	*Atriplex cordulata*
Heckard's peppergrass*†	*Lepidium latipes* var. *heckardii*
Himalayan blackberry†	*Rubus armeniacus*†
iodinebush	*Allenrolfea occidentalis*
legenere*†	*Legenere limosa*†
Mason's lilaeopsis*	*Lilaeopsis masonii*
saltgrass	*Distichlis spicata*

San Joaquin spearscale*†	*Extriplex joaquinana*
side-flowering skullcap*†	*Scutellaria lateriflora*
slough thistle*	*Cirsium crassicaule*
soft bird's-beak*	*Chloropyron molle* ssp. *molle*
Suisun Marsh aster*	*Symphyotrichum lentum*
Suisun thistle*	*Cirsium hydrophilum* var. *hydrophilum*
Welsh mudwort*	*Limosella australis*
western wallflower	*Erysimum capitatum* var. *capitatum*

Reptiles & Amphibians

California red-legged frog*	*Rana draytonii*
California tiger salamander*	*Ambystoma californiense*
giant garter snake*	*Thamnophis gigas*
Western pond turtle*	*Actinemys marmorata*

Endnotes

1 • Introduction

[1] Moyle et al. 2012.

[2] Delta Independent Science Board 2013. Notes that the goals of habitat restoration should emphasize enhancing ecosystem functions and resilience.

[3] Moyle et al. 2012, Cannon and Jennings 2014.

[4] Montgomery 2008. Jackson and Hobbs (2009) note that, "Both our ability to predict where novel ecosystems are heading, and the proactive management of these trajectories, require an understanding of the means by which novel ecosystems develop." The authors continue by stating, "Ecological restoration is rooted in ecological history. To facilitate the recovery of degraded or damaged ecosystems, knowledge of the state of the original ecosystem and what happened to it is invaluable."

[5] Whipple et al. 2012.

[6] Verhoeven et al. (2008) develop the concept of and criteria for determining Operational Landscape Units (OLUs) for restoration visions. This concept was explored for the McCormack-Williamson Tract in the Delta by Beagle et al. (2013), and recommended for further development by Delta Independent Science Board (2013).

[7] Novel ecosystems can be defined as occurring when species are found to exist "in combinations and relative abundances that have not occurred previously within a given biome (Hobbs et al. 2006)," and as the occurrence of assemblages of species that either have not co-occurred historically, or result directly and indirectly from human activities (Bridgewater et al. 2011).

[8] Hanak et al. (2013) report that most people questioned in a widely dispersed survey agreed that discharges of pollutants, direct fish management, changes in the flow regime, invasive species, and alteration of physical habitat have all contributed to the ecosystem decline.

[9] Balaguer et al. 2014.

[10] Atwater and Belknap 1980.

[11] Information on the ecological and physical processes of the historical Delta was gathered and detailed in the *Sacramento-San Joaquin Delta Historical Ecology Investigation* (Whipple et al. 2012)—the source for the summary of the historical Delta landscapes provided in this box.

2 • Project Framework and Methods

[1] Taylor et al. 1990, Brinson 1993, Smith et al. 1995, Jax 2005.

[2] NRC 1995.

[3] Smith et al. 1995.

[4] Hruby et al. 1999.

[5] Delany and Scott 2006.

[6] McGarigal 2002, Kupfer 2012.

[7] McGarigal 2002.

[8] McGarigal 2002.

[9] McGarigal 2002.

[10] Collins and Grossinger 2004.

[11] D'Eon et al. 2002.

[12] Spautz and Nur 2002, Spautz et al. 2005.

[13] Liu et al. 2012.

[14] Spautz and Nur 2002, Spautz et al. 2005.

[15] Gaines 1974.

[16] Kilgo et al. 1998.

[17] Laymon and Halterman 1989.

[18] Whipple et al. 2012.

[19] Hickson and Keeler-Wolf 2007.

[20] GIC 2012.

[21] Daniel Burmester, personal communication; Todd Keeler-Wolf, personal communication.

[22] Whipple et al. 2012.

[23] Whipple et al. 2012.

[24] Gibbes 1850, Ringgold 1850a, Ringgold 1850b.

[25] U.S. Geological Survey 2013. 'NHDArea' layer, high resolution, version 931v210.

[26] Wang and Ateljevich 2012.

[27] Whipple et al. 2012:90.

[28] See Appendix A, pages 96-97 for additional details and specific examples.

[29] Based on work of Hruby et al. (1999).

[30] Based on work of Hruby et al. (1999).

[31] Whipple et al. 2012.

3 • Overall Delta Landscape Changes

[1] Meese et al. 2014.

[2] Yoshiyama et al. 2001.

[3] Garone 2006.

[4] California Department of Water Resources 2013

[5] Mac Nally et al. 2010.

[6] Lund 2010.

[7] Kneib et al. 2008

[8] Whipple et al. 2012.

[9] See Chapter 4 (Life-History Support for Resident and Migratory Fish) for greater detail and references.

[10] Howe and Simenstad 2011.

[11] Couvet 2002, Cushman 2006.

[12] See Chapter 4 (Life-History Support for Resident and Migratory Fish) for greater detail and references.

[13] Lee and Jones-Lee 2004.

[14] Greene et al. 2011.

[15] See Chapter 4 (Life-History Support for Resident and Migratory Fish) for greater detail and references.

[16] Feyrer and Healey 2003.

[17] Atwater and Belknap 1980.

[18] Whipple et al. 2012.

[19] Hickson and Keeler-Wolf 2007.

[20] For example, there are more non-native than native fish species in some parts of the Delta (Feyrer and Healey 2003, Moyle et al. 2012). Species diversity as a restoration goal in the Delta should take into account the role of non-native species.

[21] Modern species-habitat type associations and life-history characteristics were largely derived from BDCP species accounts (California Department of Water Resources 2013), but also from other literature and best professional judgment. Best professional judgment was particularly important for species that today mostly use agricultural lands and managed wetlands. California Department of Water Resources 2013.

[22] Calflora 2013. The Calflora Database, http://www.calflora.org, accessed March 2013.

[23] California Invasive Plant Council (Cal-IPC) 2013. California Invasive Plant Inventory Database, http://www.cal-ipc.org/paf, accessed March 2013.

[24] It is likely that a class of lowest-order tidal channels existed in the Delta that was not represented by historical sources and was thus under-represented in the historical mapping of the Delta (Whipple et al. 2012). We estimate the length of these unmapped channels based on known channel densities in other freshwater marshes in the historical San Francisco Bay-Delta Estuary. See Appendix A for more detail.

[25] Thompson 1957, Enright et al. 2004, Enright 2008.

[26] Modern MLLW elevation was assumed to be 0.64 m NAVD88 (based on data from Cache Slough). Historical MLLW elevation was assumed to be 0.31 m NAVD88. We made the simplifying assumption that the only changes to MLLW since the historical period were from sea level rise (discounting any changes in water surface elevations associated with things like channel armoring, subsidence, and pumping). See Appendix A for additional details.

4 • Life-History Support for Resident and Migratory Fish

[1] Whipple et al. (2012) describe the heterogeneity within aquatic habitats of the historical Delta.

[2] Simenstad et al. (1983). Salmon in the Pacific Northwest used large channels for migration and off-channel habitat for rearing. Smokorowski and Pratt (2007) review how structural habitat complexity supports

diversity in freshwater fish. Features such as undercut banks may be particularly important because of the cover and refuge they provide (e.g., McMahon and Hartman 1989, Cowx and Welcomme 1998).

[3] Whipple et al. (2012) and sources therein.

[4] See Enright (2008) for a discussion of how complex channel networks supported gradients in residence time historically. Enright et al. (2013) explain how channel structure and marsh connection influenced water temperature through geomorphic mediation. Morgan-King and Schoellhamer (2013) describe the processes (e.g., tidal asymmetry) that contribute to the high suspended sediment concentrations observed in the "dead end channels" and "backwaters" of the Cache Slough region.

[5] Sommer et al. (2001a,b), Jeffres et al. (2008), and Opperman (2008) describe the benefits of Delta floodplains, specifically the Cosumnes River and Yolo Bypass, to native fish. Numerous other studies discuss increased prey availability for fish in floodplains in other regions (e.g., Gladden and Smock (1990)).

[6] Hering (2009) details movements of subyearling Chinook salmon to remain in small tidal channels while rearing within the Salmon River Estuary, Oregon. West and Zedler (2000) describe fish use of the marsh plain at high tide, though in a southern California salt marsh. Odum (2000) reviews support for the idea of marshes as productivity sources to estuaries and concludes that the extent of outwelling is related to the extent of marsh, tidal amplitude, and geomorphology, and that large outputs are likely occur as pulses related to storm events and spring tides.

[7] Whipple et al. 2012.

[8] Historical fish assemblages are assumed from modern fish distributions, habitat associations, and life-history requirements. See Moyle (2002) for species-specific information.

[9] Moyle 2002.

[10] Moyle 2002.

[11] Moyle 2002.

[12] Moyle 2002.

[13] Yoshiyama et al. 1998.

[14] Species habitat use is assumed from modern habitat associations and known life-history characteristics as described by Turner (1966), Moyle (2002), Moyle et al. (2004), Crain and Moyle (2011; references from Whipple et al. 2012).

[15] See Whipple et al. (2012:137-142) for discussion of salinity in the historical Delta.

[16] Wiens 2002.

[17] Sommer et al. (2005) discuss fish stranding risk in floodplains, noting that juvenile salmon seek out low-velocity areas on floodplains. The authors also note that although areas with engineered water control structures are associated with comparatively high stranding risk, overall floodplains provide a net benefit to salmon because of the rearing habitat they provide.

[18] See note 14 above.

[19] Hilborne et al. (2003), Greene et al. (2010), and Carlson and Satterthwaite (2011) describe portfolio effects in salmon.

[20] The relationship between residence time and productivity is reviewed in Lucas and Thompson (2012), who describe how the introduction of the invasive overbite clam has altered this relationship.

[21] See notes 4 and 20 above.

[22] Toft et al. 2003.

[23] Howe and Simenstad 2011.

[24] Dependent on allochthonous marsh materials, and likely more so historically. Howe and Simenstad (2011) used stable isotopes to link estuary consumers to primary producer groups in the SF Estuary and found that nearly all sampled organisms relied heavily on allochthonous marsh material. Whitley and Bollens (2014) studied stomach contents of fish at Liberty Island and found tidal marsh was important feeding habitat for many species, including delta smelt, which supplemented their zooplankton-based diet with larval insects in the spring and amphipods in the winter.

[25] Whitley and Bollens (2014) found that prey composition and biomass varied seasonally between fish species at Liberty Island (based on stomach content analysis). Fish maintained stomach fullness with little overlap in diet between species, potentially reducing competition through their flexibility in diet.

[26] Whipple et al. 2012, Opperman 2012.

[27] See note 5 above.

[28] See note 4 above.

[29] Odum (2000) and Kneib et al. (2008) discuss outwelling of organic matter from marshes, though neither discuss the impacts to turbidity directly.

[30] Kneib et al. (2008) and references therein, Howe and Simenstad 2011.

[31] Harmon et al. (1986) and Gregory et al. (1991), among others, review the benefits of large woody debris to anadromous fish. Whipple et al. (2012) describe the location of woody vegetation in the historical Delta.

[32] Sommer et al. 2013.

[33] McIvor and Odum 1988.

[34] Sommer et al. 2001b.

[35] Peter Moyle, personal communication. Also see note 60 below.

[36] Bottom et al. (2005) found that Chinook salmon in the Salmon River Estuary migrated to the ocean over a broader range of sizes and time periods after marsh restoration, suggesting that wetland restoration has expanded life-history variation in the population by allowing greater expression of estuarine-resident behaviors.

[37] See note 39 below. In addition to the loss of environmental cues, Kimmerer (2011) describes the increased risk for passively moving species from water diversions and entrainment.

[38] Bennett et al. (2002) investigated how fish behavior and distribution in multiple species enhanced transport to and retention in nursery habitats in the low salinity zone in the SF Estuary. Fish in this study exhibited behavioral flexibility in different environmental conditions to maximize retention and enhance feeding success. Hering (2009) found salmon moved into and out of tidal marsh channels mostly with the tide, but with some evidence of active movement to enter channels against ebb tides (possibly to maximize foraging efficiency on invertebrate prey exported from the marsh).

[39] Temporally predictable environmental variability can cue reproduction, migration, and other life-history events in Delta fauna (Jassby et al. 1995, Nobriga et al. 2005). See Drinkwater and Frank (1994) for a more general discussion of impacts of river regulation and diversion on fish.

[40] Enright et al. (2013) describes the greater "distance to difference" in modern channel conditions.

[41] Williams et al. 2009. As measured before (1935-1943) and after (1944-1995) the construction of the Shasta Dam.

[42] Whipple et al. 2012.

[43] Kimmerer 2011.

[44] E.g., Werner et al. 2000, Weston and Lydy 2010.

[45] Jassby et al. 2002, Lucas and Thompson 2012, Kimmerer and Thompson 2014.

[46] Toft et al. 2003.

[47] Toft et al. 2003, Brown 2003.

[48] E.g., Moyle 2002, Feyrer and Healey 2003, Nobriga et al. 2005.

[49] Feyrer and Healey (2003) mention striped bass and white catfish as non-natives associated with high flows. Peter Moyle (personal communication) also mentions channel catfish and American shad as additional examples.

[50] Sommer et al. (2013) suggests, however, that invasive species cannot be controlled by changes in hydrology alone.

[51] Peter Moyle, personal communication.

[52] Lab experiments conducted by Marchetti (1999) showed that native Sacramento perch showed reduced growth when placed with non-native bluegill, but only under conditions of food limitation. Peter Moyle (personal communication) notes that food limitation likely also intensifies predation of non-native species on natives. Stephanie Carlson (personal communication) notes that many non-native fish (especially the Centrarchids) are predators. Finally, Sommer et al. (2001a) hypothesize that following flood events the Yolo Bypass becomes a "clean slate" for native fish, who are more adapted to its flood cycle, and thus more able to take advantage of its resources.

[53] Roni et al. (2010) reviewed and modeled coho salmon and steelhead population responses to habitat restoration in Puget Sound and concluded that considerable restoration is needed to produce measurable changes in fish abundance at a watershed scale: "The percentage of floodplain and in-channel habitat that would have to be restored in the modeled watershed to detect a 25% increase in coho salmon and steelhead smolt production (the minimum level detectable by most monitoring programs) was 20%. However, given the large variability in fish response (changes in density or abundance) to restoration, 100% of the habitat would need to be restored to be 95% certain of achieving a 25% increase in smolt production for either species."

[54] Sommer et al. 2001a, Jeffres et al. 2008, Opperman 2008.

[55] Moyle (2002) lists habitat destruction as a possible contributing factor to the decline of Sacramento perch, along with embryo predation and interspecific competition. Thicktail chub "most likely became extinct because they were unable to adapt to the extreme modification of valley floor habitats," and because of the introduction of alien predators.

[56] The timing, frequency, and duration of inundation in the Yolo Bypass is better characterized as 'seasonal short-term flooding' than 'seasonal long-duration flooding.' Historically, water remained on the surface of the Yolo Basin and was available to floodplain-associated fish species for up to six months of the year (it was activated approximately one out of every two years). Since 1944, overflow events into the Bypass of seven days or

longer between mid-March and mid-May occurred in only approximately one out of every four years (Williams et al. 2009). When flooded, the Bypass drains quickly and the extent of inundated habitat varies substantially on the order of days (Sommer et al. 2004).

[57] Sommer et al. (1997) found that strong year classes of splittail, which are obligate floodplain spawners, are not produced unless there are at least three weeks of sustained inundation during the March-April spawning/rearing period. Waples et al. (2009) found that although salmon are equipped with life-history strategies that allow them to persist in disturbance prone environments and across a range of habitats, temporal and spatial access to these ranges of habitats has been limited, resulting in decreased resilience in populations.

[58] Whipple et al. 2012.

[59] This 1927 photograph of North Sacramento shows flooding along the Sacramento River. Photo by McCurry, courtesy of the California History Room, California State Library, Sacramento, California.

[60] Jeffres et al. 2008. This is important because larger juvenile salmon have a higher overall survival rate to adulthood and are more likely to return as spawning adults (Unwin 1997, Galat and Zweimüller 2001). Potential mechanisms for the observed beneficial effects of floodplains include the increased habitat area associated with inundated floodplains (relative to just the adjacent river habitat), which would be expected to reduce resource competition and predator encounter rates (Sommer et al. 2001b), and increase invertebrate prey availability (Gladden and Smock 1990, Sommer et al. 2001b).

[61] This figure represents the combined extent of areas classified as "seasonal short-term flooding" and "seasonal long-duration flooding."

[62] Based on a study from Vogel and Marine (1991) with input from Steve Lindley, personal communication.

[63] Yoshiyama et al. 2001 and Lindley et al. 2004 in Williams 2006:43.

[64] Commissioners of Fisheries 1875, McEwan 2001, and Moyle 2002, as cited in Williams 2006. Williams notes that "the Commissioners of Fisheries (1875:10) also described a summer-run that migrated up the San Joaquin River in July and August that appeared to be '. . . of the same variety as those in the Sacramento, but smaller in size.' The Commission was particularly interested in them because their tolerance of high water temperature '. . . would indicate that they will thrive in all the rivers of the southern states, whose waters take their rise in mountainous or hilly regions. . . .'"

[65] With the exception of spawning, the temporal distributions of the Chinook life-history stages are derived from Vogel and Marine 1991, figure 1, "Life History Characteristics of Sacramento River Chinook Salmon." The noted timing of spawning for each run is taken from Williams 2006 (page 119, table 6-1, "Sacramento River ranges" for fall run; page 120, table 6-2 for late-fall run; page 120, table 6-3 for winter run; and page 121, table 6-4 for spring run). Yoshiyama et al. 2001 and Lindley et al. 2004 in Williams 2006:43.

[66] McEwan 2001:11, figure 3, "Central Valley steelhead life stage periodicity."

[67] Adult migration timing is taken from Moyle et al. 2004, as cited in Kratville 2008:10. The temporal distributions for floodplain/river spawning, embryo and larvae, and juvenile floodplain use are taken from Kratville 2008:3, table 1, "Life stages by biological measures." The listed juvenile downstream migration timing is derived from Moyle et al. 2004, as cited in Kratville 2008:12. Kratville also notes a second life-history strategy for outmigrating juveniles that is not reflected in this table: "a less well studied strategy is to remain upstream through the summer into the next fall or spring and then migrate downstream (Baxter 1999, Moyle et al. 2004). This latter strategy occurs in Butte Creek and the main stem Sacramento River."

[68] Israel and Klimley 2008.

[69] Israel et al. 2009.

[70] USFWS 2012.

[71] Nobriga and Herbold 2009.

[72] Rosenfield 2010.

[73] Gray et al. 2002.

5 • Life-History Support for Marsh Wildlife

[1] Whipple et al. 2012, Vasey et al. 2012.

[2] Described from East Coast marshes by Odum (1988). Moyle et al. (2014) hypothesize that although tidal marshes have lower seed density than managed marshes the extensive acreage of historical marshes in the Bay and Delta would have led to an accumulation of seeds, providing abundant food resources for waterfowl and other wildlife.

[3] Odum 1988.

[4] Reviewed by the DRERIP Tidal Marsh Model and sources therein, Kneib et al. (2008). See Nur et al. (2006) for a description of effects of vegetative structure on the marsh bird community.

[5] Greenberg et al. 2006.

[6] See Herbold and Moyle (1989) and California Department of Water Resources (2013). Mammal species occupying the historical Delta are assumed from distribution of modern native species.

[7] Mitsch and Gosselink (1986) cited in Odum (1988).

[8] Grinnell et al. 1937, Seymour 1960, Gould 1977, Lanman et al. 2013. Description of beavers in the Delta as quoted in Lanman et al. 2013: "There is probably no spot of equal extent in the whole continent of North America which contains so many of these much sought animals (Farnham 1857:383)."

[9] See references in Chapter 4 (Life-History Support for Resident and Migratory Fish).

[10] See Jennings and Hayes (1994) and California Department of Water Resources (2013) for distribution and life-history information on Delta amphibians. These species all require upland habitat for part of their life, which likely prevented them from inhabiting the interior Delta marshes.

[11] See references in Chapter 8 (Life-History Support for Marsh-Terrestrial Transition Zone Wildlife).

[12] Odum 1988.

[13] Based on life-history account of giant garter snake in California Department of Water Resources (2013). Based on life-history account of the Modesto Song Sparrow in Shuford and Gardali (2008). The Modesto Song Sparrow distribution is only slightly broader than the Delta and distinct from the more riparian/upland associated subspecies.

[14] Milliken 1991, Anderson 2005, Manfree 2014 in Moyle et al. 2014.

[15] Whipple et al. 2012.

[16] Lindenmayer and Fischer 2006.

[17] Whigham 1988, Fuji 1998, and Werner et al. 2000.

[18] Lindenmayer and Fischer 2006.

[19] Lindenmayer and Fischer 2006.

[20] CDFG 2007.

6 • Life-History Support for Waterbirds

[1] Historical species occurrences are assumed from modern distributions, life histories and habitat associations. See Herbold and Moyle (1989), California Department of Water Resources (2013), Garone (2011).

[2] Assumptions about waterbird habitat use and ecology were discussed during two meetings with local waterbird experts (Dave Shuford, Daniel Burmester, Dan Skalos, Hildie Spautz, Dave Zezulak) on March 11, 2014 and April 22, 2014. Assumptions of habitat use for particular waterbirds were determined by the best professional judgment of these experts, with the acknowledgement that the magnitude of change in the Delta paired with the large scale at which most waterbirds use the landscape make it difficult to interpret some aspects of waterbird use of the historical Delta. Shorebird habitat associations and the degree to which smaller shorebirds used the Delta were highlighted as areas of particular uncertainty.

[3] Garone 2011.

[4] Central Valley Joint Venture 2006, Whipple et al. 2012.

[5] Garone 2011, Whipple et al. 2012.

[6] Central Valley Joint Venture 2006.

[7] Moyle et al. 2014.

[8] Herbold and Moyle 1989.

[9] See note 2 above.

[10] See note 2 above and Garone 2011.

[11] See note 2 above.

[12] Whipple et al. 2012.

[13] Garone 2011, Whipple et al. 2012.

[14] See note 2 above and Whipple et al. 2012.

[15] See note 2 above.

[16] Ivey et al. 2011, Ivey et al. 2014.

[17] See note 2 above.

[18] See notes 1 and 2 above.

[19] See note 2 above.

[20] Moyle et al. 2014.

[21] Moyle et al. 2014.

[22] Gaines 1980.

[23] Central Valley Joint Venture 2006.

[24] See Miller et al. 2000 and references therein (from Oklahoma). "Agricultural plants are often high in energy, and waterfowl spend more time feeding on crops in the evening to prepare for cold nights. However, feeding exclusively on agricultural crops may not satisfy their protein or mineral requirements. Waterfowl must also include foods that fulfill protein and lipid requirements. Natural plants found in wetlands and invertebrates constitute foods high in protein and amino acids, as well as many minerals."

[25] Mount and Twiss 2005.

[26] See note 2 above.

[27] Moyle et al. 2014.

[28] See notes 1 and 2 above.

[29] See notes 1 and 2 above.

[30] See note 2 above and Garone 2011.

[31] See note 2 above.

[32] Time ranges for wintering and migrating birds are multi-species approximations based on discussions with experts. The breeding waterfowl time range shown is for Mallards.

7 • Life-History Support for Riparian Wildlife

[1] Whipple et al. (2012) describe the position and structure of riparian forests in the historical Delta. The use of riparian forests as movement corridors is well-established (see Hilty and Merenlender (2004) and Fellers and Kleeman (2007) for examples in California).

[2] E.g., Finch 1989.

[3] E.g., Opperman 2002.

[4] Whipple et al. 2012. For Neotropical songbirds, willow-fern marshes may have provided habitat; however, for many less mobile or more terrestrial species, these habitats would have been inaccessible.

[5] See, for example, Brinson et al. (2002) for a discussion of the importance of riparian habitat as a movement corridor for wildlife.

[6] California Department of Water Resources 2013. These species are found primarily in the south Delta today. Whipple et al. (2012) found that the riparian brush rabbit occurred in riparian forests throughout the historical Delta as well.

[7] Gaines 1980 in Sands 1980.

[8] See note 7 above.

[9] See note 7 above.

[10] Geoff Geupel, personal communication.

[11] Thompson (1957) notes that where riparian cover developed historically, "the velocity of sediment laden water was checked," causing natural levees to build up and facilitate more growth of riparian vegetation (a positive feedback cycle).

[12] California Department of Water Resources 2013.

[13] Gaines 1980.

[14] Small 2005, Small et al. 2007, Golet et al. 2008.

[15] Whisson et al. 2007, California Department of Water Resources 2013.

[16] California Department of Water Resources 2013.

[17] Seavy et al. 2009.

[18] Laymon and Halterman 1989.

[19] Measured as the maximum geodesic distance (as the crow flies) an organism can travel away from a starting location within a single contiguous woody riparian habitat polygon (defined by the minimum mapping unit).

[20] The 100 m threshold for grouping riparian polygons into patches is based on the typical maximum gap crossing distance of dispersing songbirds, as determined by best professional judgment (Geoff Geupel, personal communication).

[21] Fischer 2000.

[22] Whipple et al. (2012) mapped the dominant habitat types, so while the Cosumnes area appears to be absent of woody riparian vegetation, there were likely some wooded sloughs and willow thickets that were too small to map.

8 • Life-History Support for Marsh-Terrestrial Transition Zone Wildlife

[1] Whipple et al. 2012, "Pattern of edge."

[2] Assumed from life-history characteristics. See BDCP species accounts (California Department of Water Resources 2013) and references therein.

[3] See Chapter 7 (Life-History Support for Riparian Wildlife) for greater detail and references.

[4] Whipple et al. 2012, "Tule elk breeding on dunes."

[5] Whipple et al. 2012, "Variable seasonal wetlands."

[6] California Department of Water Resources 2013. Species of Concern.

[7] See Chapter 6 (Life-History Support for Waterbirds) and California Department of Water Resources 2013.

[8] California Department of Water Resources 2013.

[9] Trapp 2011.

[10] Barbour et al. 2007.

[11] California Department of Water Resources 2013.

[12] Whipple et al. 2012.

[13] California Department of Water Resources 2013.

[14] Whipple et al. 2012, Schiffman 2011.

[15] Schiffman 2011, Trapp 2011, California Department of Water Resources 2013.

[16] Trapp 2011.

[17] Milliken 1991, Anderson 2005, Manfree 2014 in Moyle et al. 2014.

[18] Goals Project 2014 (in development).

Appendix A: Methods

[1] Whipple et al. 2012.

[2] Whipple et al. 2012.

[3] Whipple et al. 2012, available for download at http://www.sfei.org/sites/default/files/Delta_Historical_Ecology_GISdata_SFEI_ASC_2012.zip.

[4] Hickson and Keeler-Wolf 2007.

[5] GIC 2012.

[6] WWR 2013.

[7] California Department of Water Resources 2013.

[8] Whipple et al. 2012.

[9] Daniel Burmester and Todd Keeler-Wolf, personal communication.

[10] Whipple et al. 2012.

[11] Buck-Diaz et al. 2012.

[12] Daniel Burmester and Todd Keeler-Wolf, personal communication.

[13] CALFED 2000.

[14] Todd Keeler-Wolf, personal communication.

[15] Whipple et al. 2012.

[16] Hickson and Keeler-Wolf 2007.

[17] See California Department of Water Resources 2013, appendix 2.b for detailed methodology.

[18] See note 3 above.

[19] See note 3 above.

[20] U.S. Geological Survey 2013. 'NHDArea' layer, high resolution, version 931v210.

[21] CWS et al. 2014. Manuscript in preparation.

[22] Cordell 1867.

[23] California Debris Commission (Debris Commission) 1908-1913. Since the Debris Commission surveys took place after substantial alteration of Delta waterways from hydraulic mining debris, channel cuts, and dredging, we limited our use of Debris Commission bathymetric data to channel reaches with minimal apparent physical alteration.

[24] The maps produced by Ringgold (1850a & 1850b) and Gibbes (1850) lack the spatial accuracy of the USCS hydrographic sheet and have no known projection or features from which to establish reliable control points. We were thus unable to directly digitize historical soundings from georeferenced maps. The soundings recorded by Ringgold and Gibbes were instead georeferenced by matching channel meanders

and confluences on the historical maps with meanders and confluences in the Delta Historical Ecology channel centerline layer (soundings were generally taken at the apex of meanders) and placing the soundings relative to these features. Any soundings that were difficult to place were discarded.

[25] The parabolic channel shape was chosen after conversations with experts on tidal channel morphology. While this shape inevitably simplifies channel morphology, we felt it best represented channel cross-sectional area given the available data. CWS technicians applied the parabolic shape by calculating parabolic channel cross-sections between the historical channel thalweg and shoreline (set to a depth of 0 m/MLLW) at 100 m intervals and outputting these cross-sections as a series of points. These points were converted to modern fixed datum (NAVD88, see Appendix A, Section 4.1.4) and then used as TIN inputs to generate continuous DEM bathymetry.

[26] Atwater et al. 1977.

[27] Whipple et al. 2012.

[28] Wang and Ateljevich 2012, version 3.

[29] Wang and Ateljevich 2012.

[30] cbec 2010.

[31] Whipple et al. 2012.

[32] Phil Williams, personal communication.

[33] Grossinger 1995.

[34] Collins and Grossinger 2004.

[35] Whipple et al. 2012.

[36] cbec 2010.

[37] See Lopez et al. 2006.

[38] Simenstad 1983.

[39] Ashley and Zeff 1988.

[40] Simenstad 1983, Collins 1998.

[41] Ashley and Zeff 1988.

[42] Morgan-King and Schoellhammer 2013.

[43] E.g., Pethick 1992.

[44] Simenstad 1983, Collins 1998, Hood 2006.

[45] Cavallo et al. 2013.

[46] Whipple et al. 2012:331-333.

[47] Whipple et al. 2012:38.

[48] Alison Whipple, personal communication. Dense tidal channel networks served as an indicator of daily tidal inundation, especially in the lower/southern portion of the Yolo Basin tidal area. Historical quotes about tides flowing in and out of lower Grand, Staten, and Tyler islands increased confidence that the Cache Slough region experienced daily tidal inundation.

[49] Whipple et al. 2012:127-128.

[50] Rose et al. 1895 in Whipple et al. 2012:128.

[51] Most information on depth, duration, and timing is derived from Whipple et al. (2012). Additional information on the depth of historical inundation was obtained from historical General Land Office surveys of the Delta.

[52] Pasternak et al. 2004.

[53] D'Eon et al. 2002.

[54] Spautz and Nur 2002, Spautz et al. 2005.

[55] Liu et al. 2012.

[56] Spautz and Nur 2002, Spautz et al. 2005.

[57] Spautz and Nur 2002, Spautz et al. 2005.

[58] Geoffrey Geupel, personal communication.

[59] D'Eon et al. 2002.

[60] Laymon and Halterman 1989.

[61] Whipple et al. 2012:178-183.

[62] Gibbes 1850. See Whipple et al. 2012, figure 4.49.

[63] From Whipple et al. 2012, figure 4.50.

[64] DWR 2014. California Levee Database Centerlines, Version 3, Release 2.

[65] Whipple et al. 2012.

[66] Hickson and Keeler-Wolf 2007.

[67] CDFG 2011.

[68] Hickson and Keeler-Wolf 2007.

[69] Daniel Burmester, personal communication.

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Recent state policy sets ambitious goals for ecosystem restoration in the Sacramento-San Joaquin Delta. *The Delta Plan and California Water Code, as well as other regional documents, identify the need to go beyond small-scale habitat restoration to create larger functional landscapes of interconnected habitats. Yet there is little quantitative guidance available to help design the complex spatial systems that are likely to achieve these goals. This report provides the first analysis of landscape ecology metrics in the pre-disturbance and contemporary Delta to help define, design, and evaluate functional, resilient landscapes for the future.*

Exhibit C

SALMON SCOPING TEAM GAPS ANALYSIS REPORT

PRESENTATION TO CSAMP – OCTOBER 24, 2016

JOHN FERGUSON (Co-Chair)
CHUCK HANSON (Co-Chair)
PATRICIA BRANDES (USFWS)
REBECCA BUCHANAN (UW)
BARBARA BYRNE (NMFS)
SHEILA GREENE (Westlands Water)
BRETT HARVEY (DWR)
RENE HENERY (UNR, Trout Unlimited)
JOSHUA ISRAEL (USBR)
DAN KRATVILLE (DFW)
MICHAEL HARTY (Facilitator)
BRIANA SEAPY (Asst. Facilitator)

CONTEXT - VIABLE SALMONID POPULATIONS (VSP)

DEFINITION

- McElhany et al. (2000) Viable salmonid populations and the recovery of evolutionarily significant units. NOAA Technical Memorandum NMFS-NWFSC-42.

  - Abundance
  - Productivity
  - Spatial structure
  - Diversity (genotypic and phenotypic)

APPLICATION

- Monitoring: Crawford, B.A and S.M. Rumsey. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act. Idaho, Oregon, and Washington, National Marine Fisheries Service, NW Region.
- Recovery planning: Lindley et al . 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin basin. San Francisco Estuary and Watershed Science. Vol. 5, Issue 1 [February 2007]. Article 4.
- Harvest: Hilborn, R., T.P. Quinn, D.E. Schindler, and D.E. Rogers, 2003. Biocomplexity and fisheries sustainability. Proc. Nat. Acad. Sci. 100:6564-6568.

VALIDATION

- The "portfolio effect" of spreading risk across stocks
  - Schindler et al 2010. Population diversity and the portfolio effect in an exploited species. Nature 465:609-613.
- Strengthening population resilience to environmental variability (including climate change) requires expanding habitat opportunities to allow expression of life-history strategies
  - Bottom, D., K. Jones, C. Simenstad, and C. Smith, 2011. Reconnecting societal and ecological resilience in salmon ecosystems. In Pathways to Resilience; Sustaining Salmon Ecosystems in a Changing World. Oregon Sea Grant Report ORESO-B-11-001, pgs 3 39.
- Fry, parr, smolts all contribute to the spawning population, but saw greater fry contributions in the wetter year and greater smolt contributions in the drier year
  - Sturrock et al. 2015. Reconstructing the Migratory Behavior and Long-Term Survivorship of Juvenile Chinook Salmon under Contrasting Hydrologic Regimes. PLoS ONE 10(5)

SST - SCOPE AND REPORT STRUCTURE

Scope:

We focused narrowly on the effects of SWP and CVP operations on salmonid migration and survival in the Delta

- Inflow
- Exports
- Temporary Agriculture Barriers
- Delta Cross Channel
- Head of Old River Barrier

Volume I

- **FINDINGS AND RECOMMENDATIONS**

Volume 2

- **RESPONSES TO MANAGEMENT QUESTIONS**

PRESENTATION OUTLINE

- Primary findings and information gaps - Rebecca Buchanan (University of Washington)
- Responses to CAMT's management questions - Sheila Greene (Westlands Water) and Barb Byrne (NMFS)
- Technical disagreements - Pat Brandes (USFWS)
- Recommendations - Pat Brandes (USFWS)

SUMMARY

- Salmon survival in the South Delta is low
- A number of gaps have been identified
- The performance of various management actions on salmonid survival is uncertain
- The SST recommends:
  - Implement actions to improve survival at the SWP and CVP export facilities
  - Continue to monitor salmonid survival in the south Delta while completing additional analyses of existing data to provide a foundation for developing a long-term, hypothesis-based adaptive management program to experimentally assess salmonid migration, survival, underlying mechanisms, and management action performance
  - Develop and implement a long-term monitoring, research and adaptive management program

SCOPE AND REPORT STRUCTURE

Scope:

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- Exports
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- Head of Old River Barrier

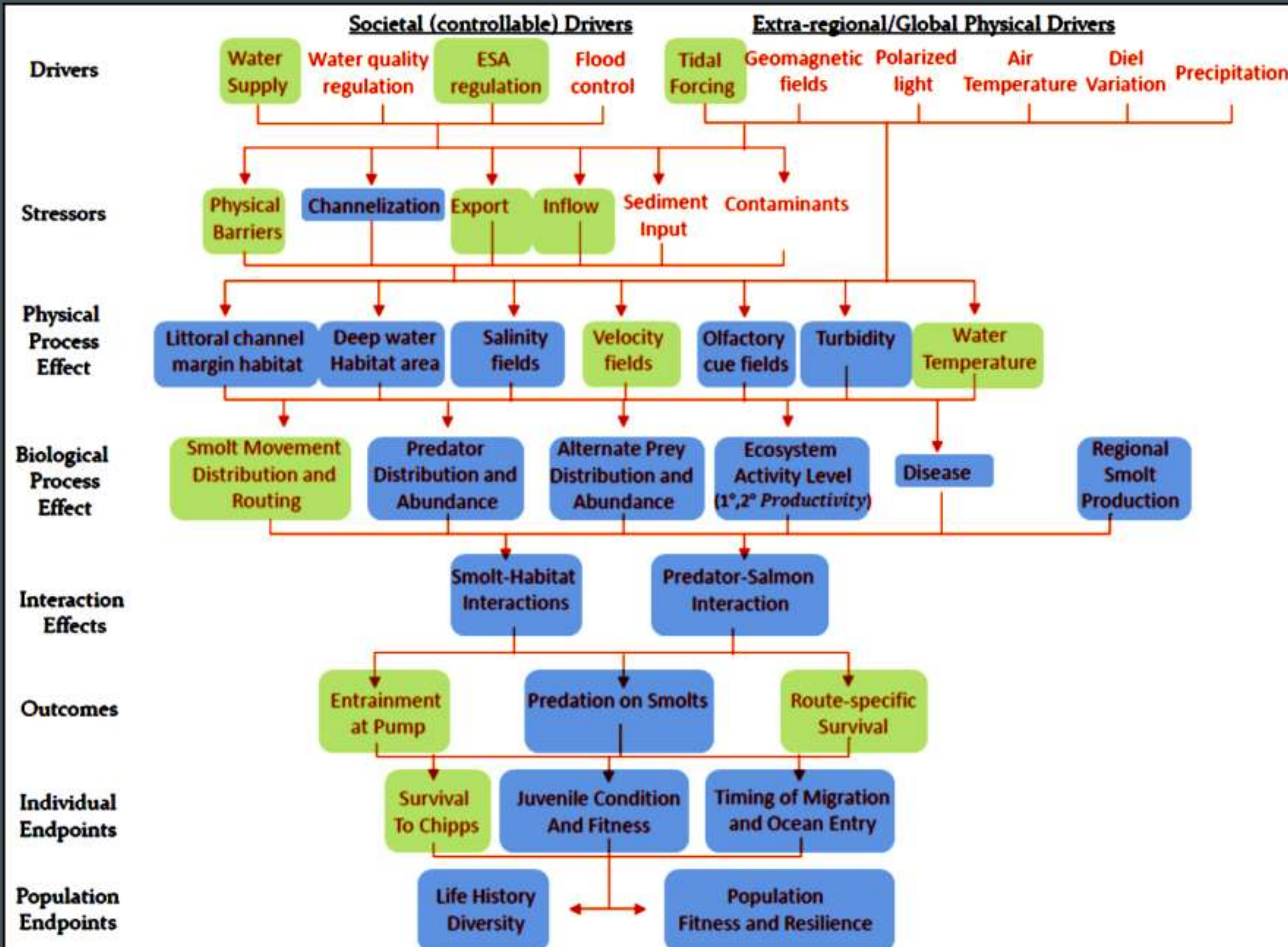
Volume 1

- **FINDINGS AND RECOMMENDATIONS**

Volume 2

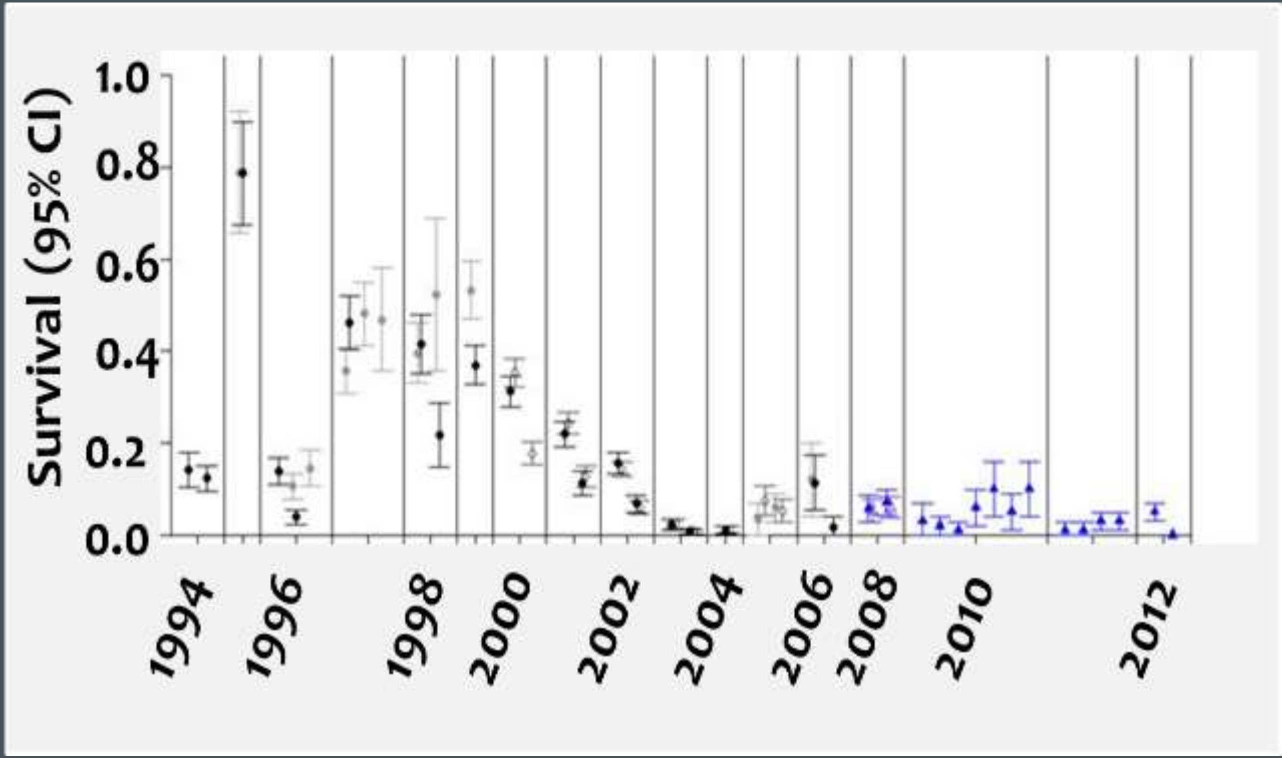
- **RESPONSES TO MANAGEMENT QUESTIONS**

CONCEPTUAL MODEL



THROUGH-DELTA SURVIVAL

- Through-Delta survival has been consistently low for San Joaquin River Chinook salmon



San Joaquin River Fall-Run Chinook Salmon

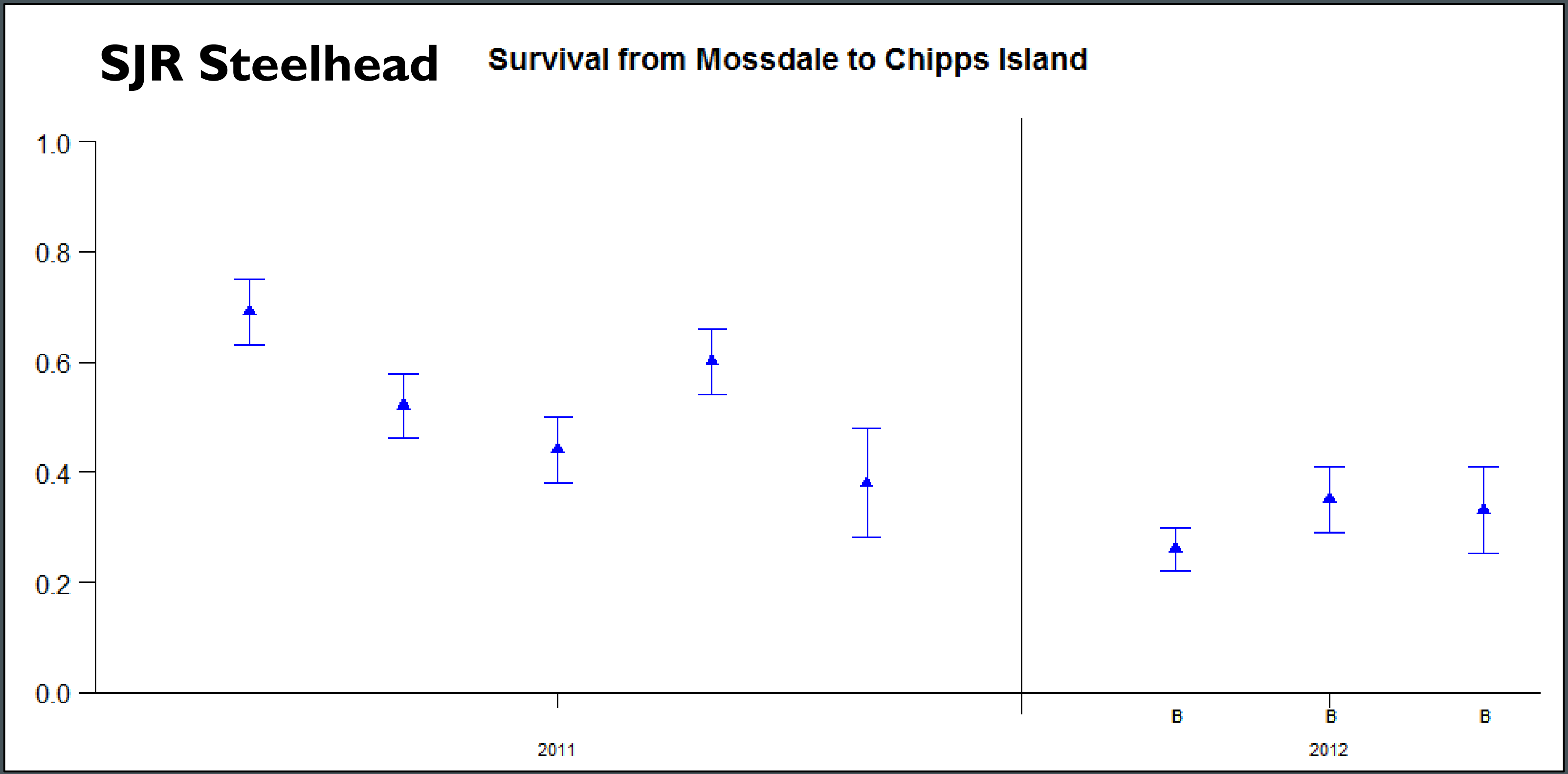
THROUGH-DELTA SURVIVAL

Sacramento River Chinook Salmon

Run	Year	Estimate
Winter	2013, 2014	0.32, 0.35
Spring	2013, 2014	0.30, 0
Fall/Spring	2013	0.17
Fall	2013	0
Late-Fall	Dec 2006, Jan 2007	0.351, 0.543
	Dec 2007, Jan 2008	0.174, 0.195
	Dec 2008, Jan/Feb 2009	0.368, 0.339, 0.64
	Dec 2009, Jan/Feb 2010	0.464, 0.374, 0.52

THROUGH-DELTA SURVIVAL: STEELHEAD

River Basin	Year	Estimate
Sacramento	2009, 2010	0.57, 0.47
San Joaquin	2011, 2012	0.54, 0.32



GAPS IN SURVIVAL DATA

- Most survival and migration data are from San Joaquin River fall-run Chinook salmon
- Only 2 years of San Joaquin River steelhead data analyzed (6 years collected)
- No time series of survival data for Sacramento River Chinook or steelhead
  - Have 2 to 4 years of data for each Sacramento River run/species
- We need data to estimate Delta survival

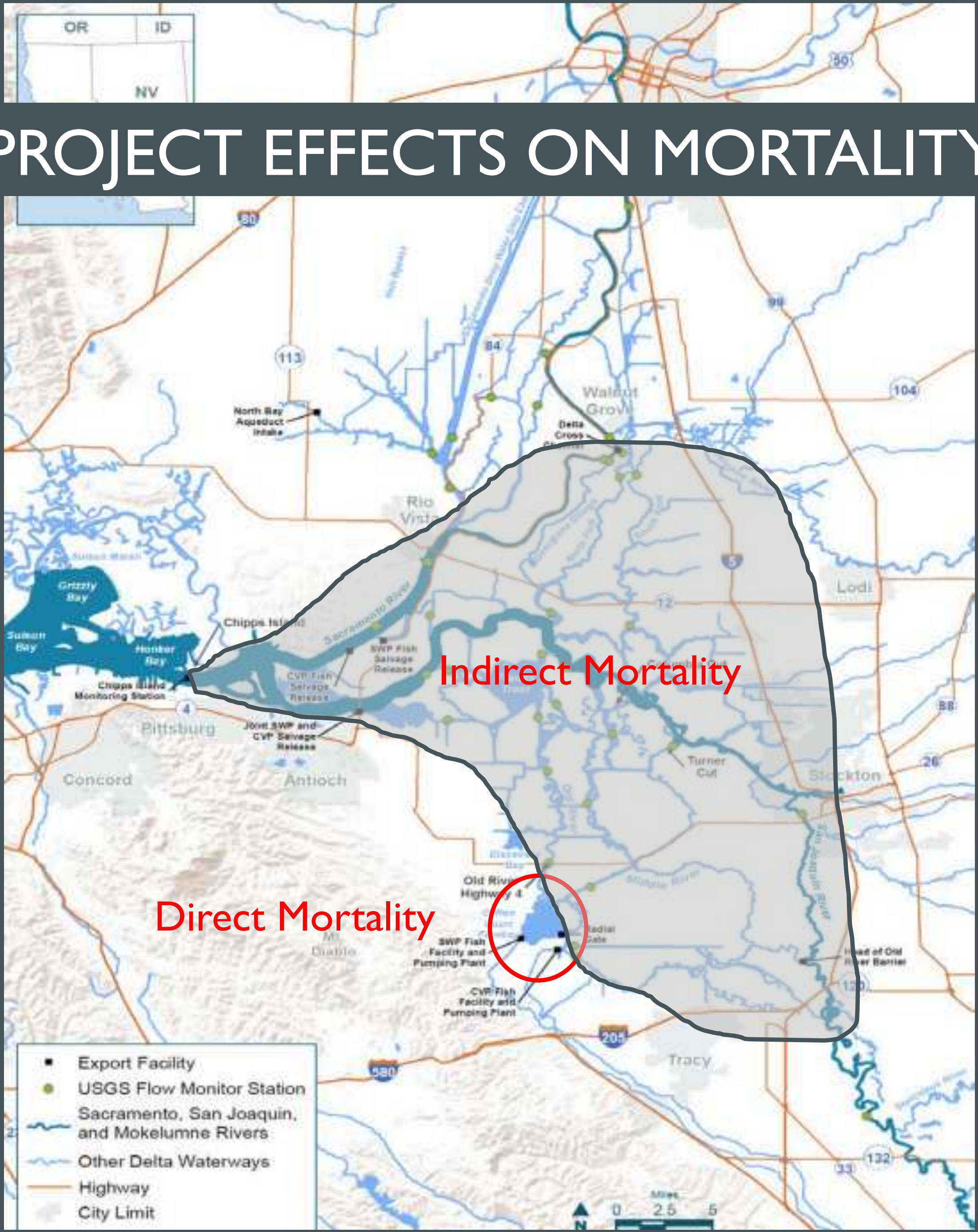
EFFECTS OF FISH SIZE

- Multiple lines of evidence indicate smaller fish respond to conditions differently and usually experience lower survival than larger fish
  - Larger fish have higher survival in the Delta
  - Louver (i.e. fish guidance) efficiency at CVP/SWP fish facilities depends on fish size

GAPS IN FISH SIZE AND SURVIVAL DATA

- Juvenile salmonids of all sizes use Delta throughout year
- Acoustic tags are not suitable for fry-sized fish (<70 mm)
- It is unknown if relationship between fish size and survival is the same for wild fish as for hatchery fish

PROJECT EFFECTS ON MORTALITY

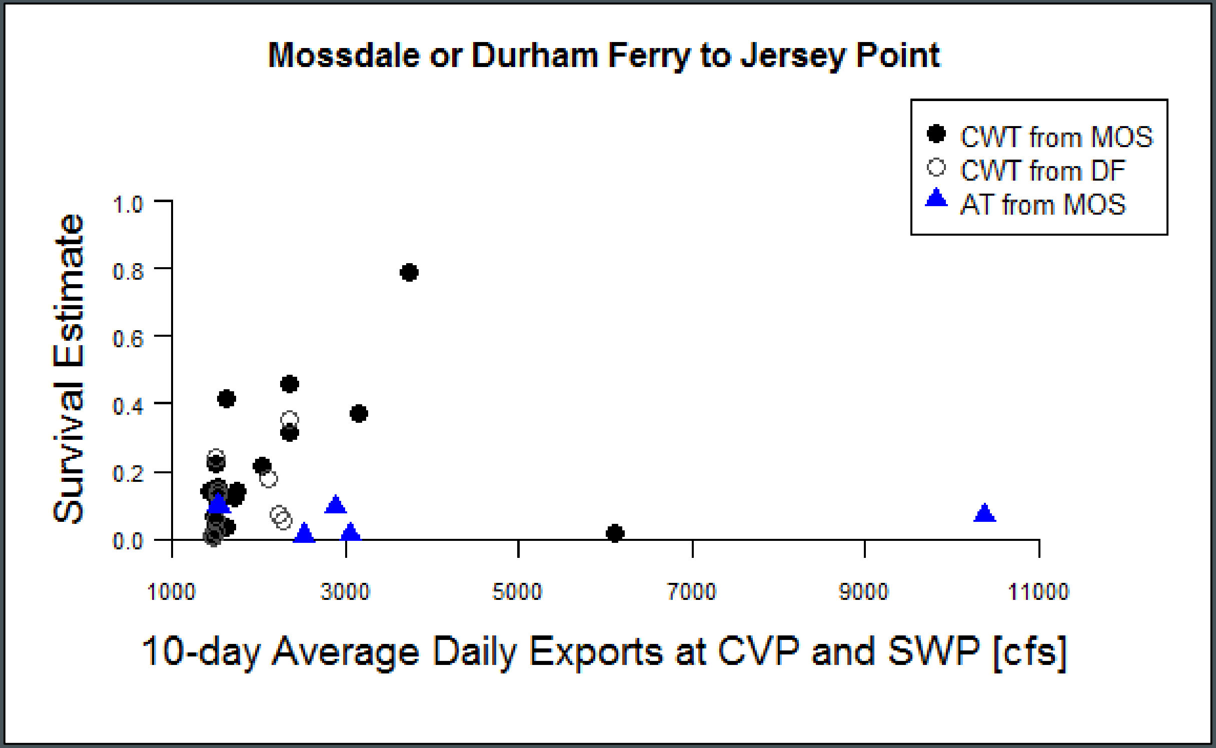


PROJECT EFFECTS ON MORTALITY

- Hypothesized mechanisms of indirect effects outside the facilities
  - Changes in local Delta hydrodynamics (flows, velocities), gate operations that affect routing
  - Delays or extended migration duration that increases exposure to predators
  - Changes in physical habitat conditions (e.g., channelization, riprap) that may increase predator effectiveness
- Despite efforts to reduce mortality via direct and indirect effects, through-Delta survival remains low (SJR Chinook)
- Inconclusive evidence of a relationship between exports and through-Delta survival

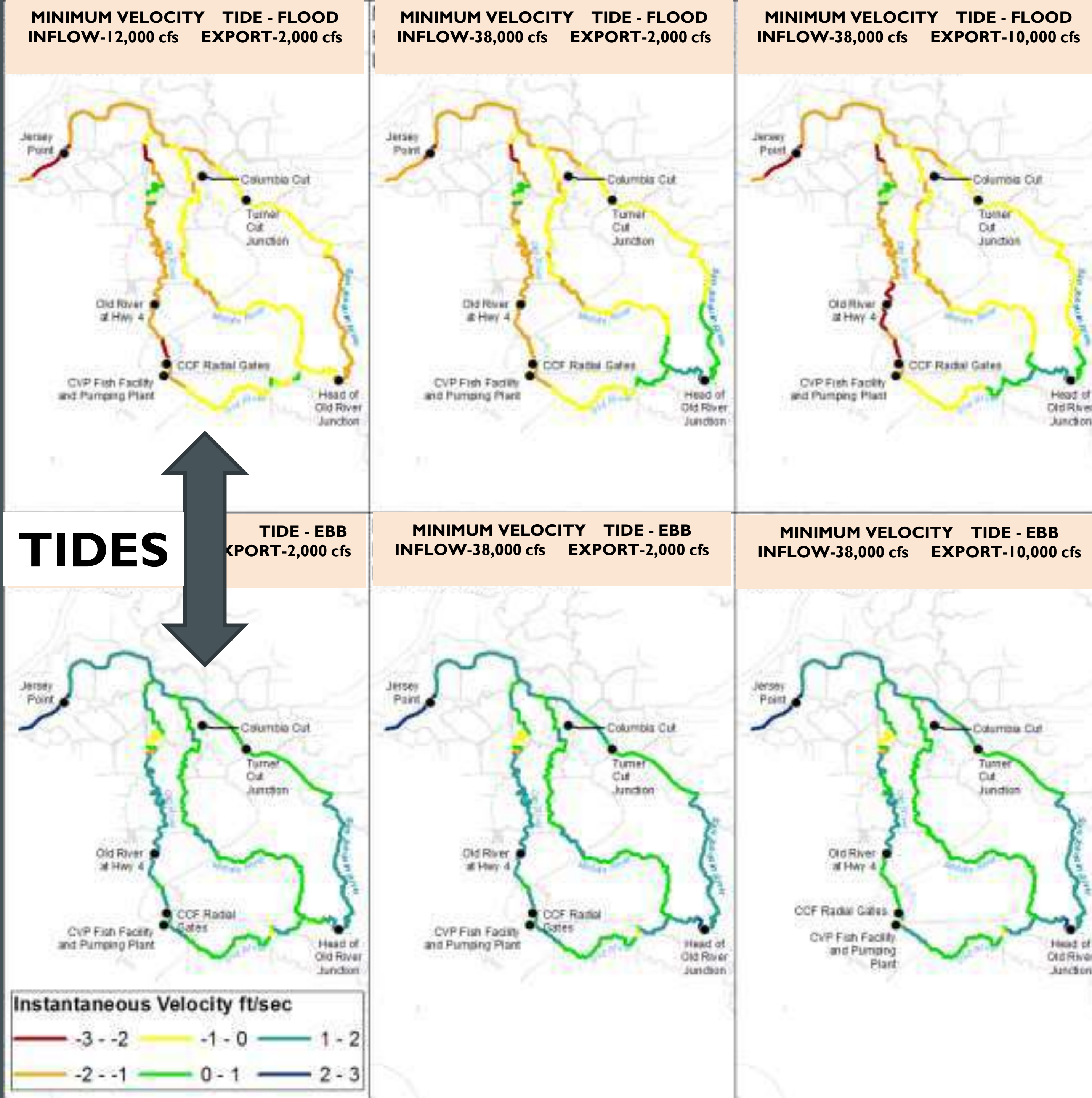
PROJECT EFFECTS ON MORTALITY

San Joaquin River Fall-Run Chinook Salmon



SPATIAL AND TEMPORAL COMPLEXITY

- The Delta is a complex and dynamic environment
- The relative influence of tides, inflow, and exports on hydrodynamic conditions (flow and velocity) varies temporally and spatially throughout the Delta


MINIMUM VELOCITY TIDE - FLOOD
INFLOW-12,000 cfs EXPORT-2,000 cfs
MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-2,000 cfs
MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-10,000 cfs
TIDES
TIDE - EBB
XPORT-2,000 cfs
MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-2,000 cfs
MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-10,000 cfs
Jersey Point
Columbia Cut
Turner Cut Junction
Old River at Hwy 4
CCF Radial Gates
CVP Fish Facility and Pumping Plant
Head of Old River Junction
Instantaneous Velocity ft/sec
-3 - -2
-1 - 0
1 - 2
-2 - -1
0 - 1
2 - 3

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-12,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-10,000 cfs

INFLOW

MINIMUM VELOCITY TIDE - EBB
INFLOW-12,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-10,000 cfs

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-12,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - FLOOD
INFLOW-38,000 cfs EXPORT-10,000 cfs

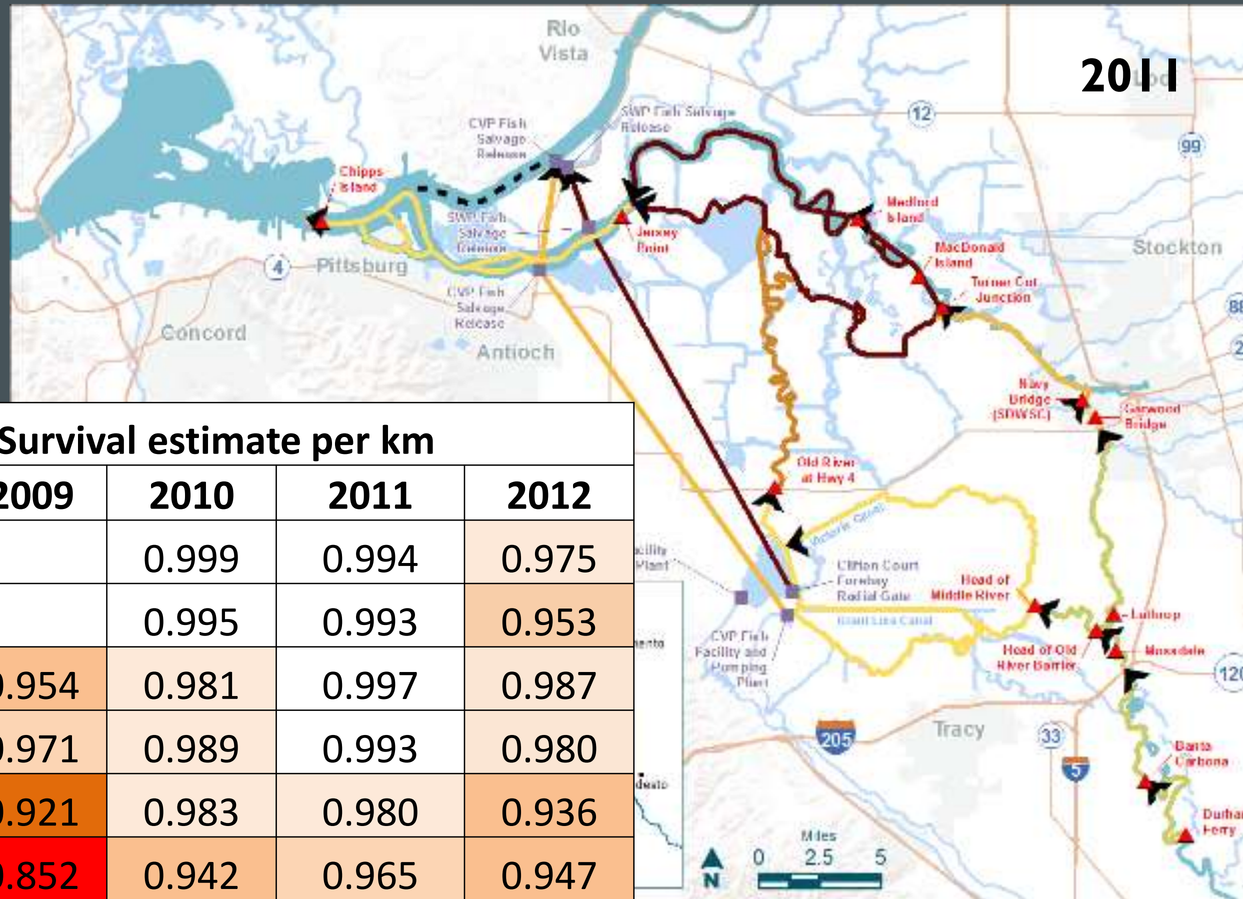
EXPORTS

MINIMUM VELOCITY TIDE - EBB
INFLOW-12,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-2,000 cfs

MINIMUM VELOCITY TIDE - EBB
INFLOW-38,000 cfs EXPORT-10,000 cfs

SPATIAL HETEROGENEITY IN SURVIVAL



SJR Fall-Run Chinook

	Survival estimate per km				
Reach	**2008**	**2009**	**2010**	**2011**	**2012**
DF to Banta Carbona			0.999	0.994	0.975
BCA to Mossdale			0.995	0.993	0.953
Mossdale to OR	0.967	0.954	0.981	0.997	0.987
Lathrop to Garwood	0.986	0.971	0.989	0.993	0.980
Garwood to SDWSC	0.955	0.921	0.983	0.980	0.936
SDWSC to Turner Cut	0.958	0.852	0.942	0.965	0.947
MacDonald to Medford			0.863	0.833	0.852
Turner Cut to Jersey Pt (Interior Route)	0			0	0
Medford to Jersey Pt				0.881	0.964
Jersey Pt to Chipps Is	0.981			0.983	0.971

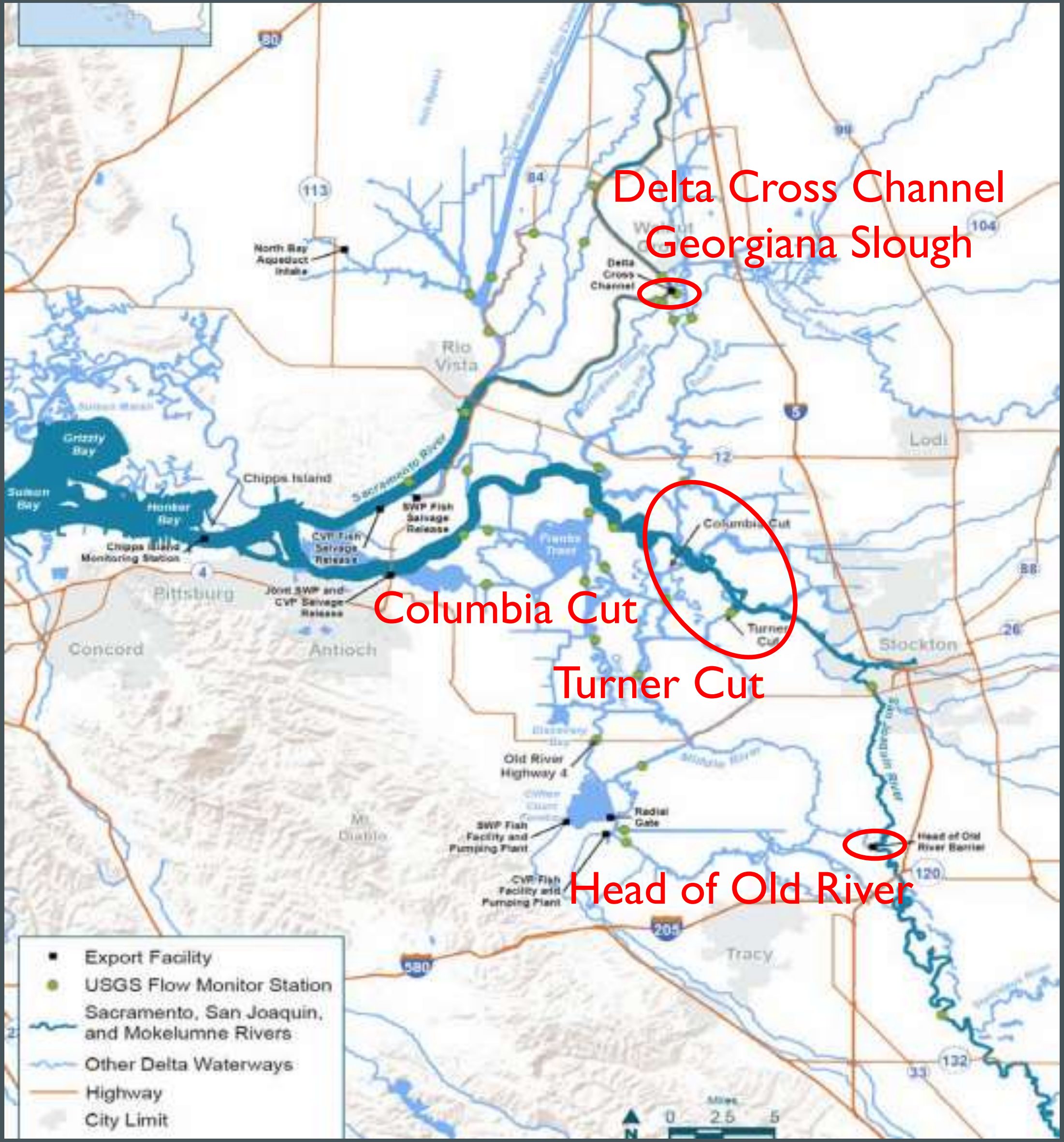
HYDRODYNAMIC MODELS

- The hydrodynamics models were developed for water project planning
  - They were calibrated and validated on a spatial and temporal scale appropriate for the intended purpose
- Calibration and validation at appropriate spatial and temporal scales are needed for the application to fish behavior
- There are some limitations common to all hydrodynamic models related to input data
  - e.g., Clifton Court inflow, bathymetry data, consumptive use data

CURRENT MANAGEMENT ACTIONS

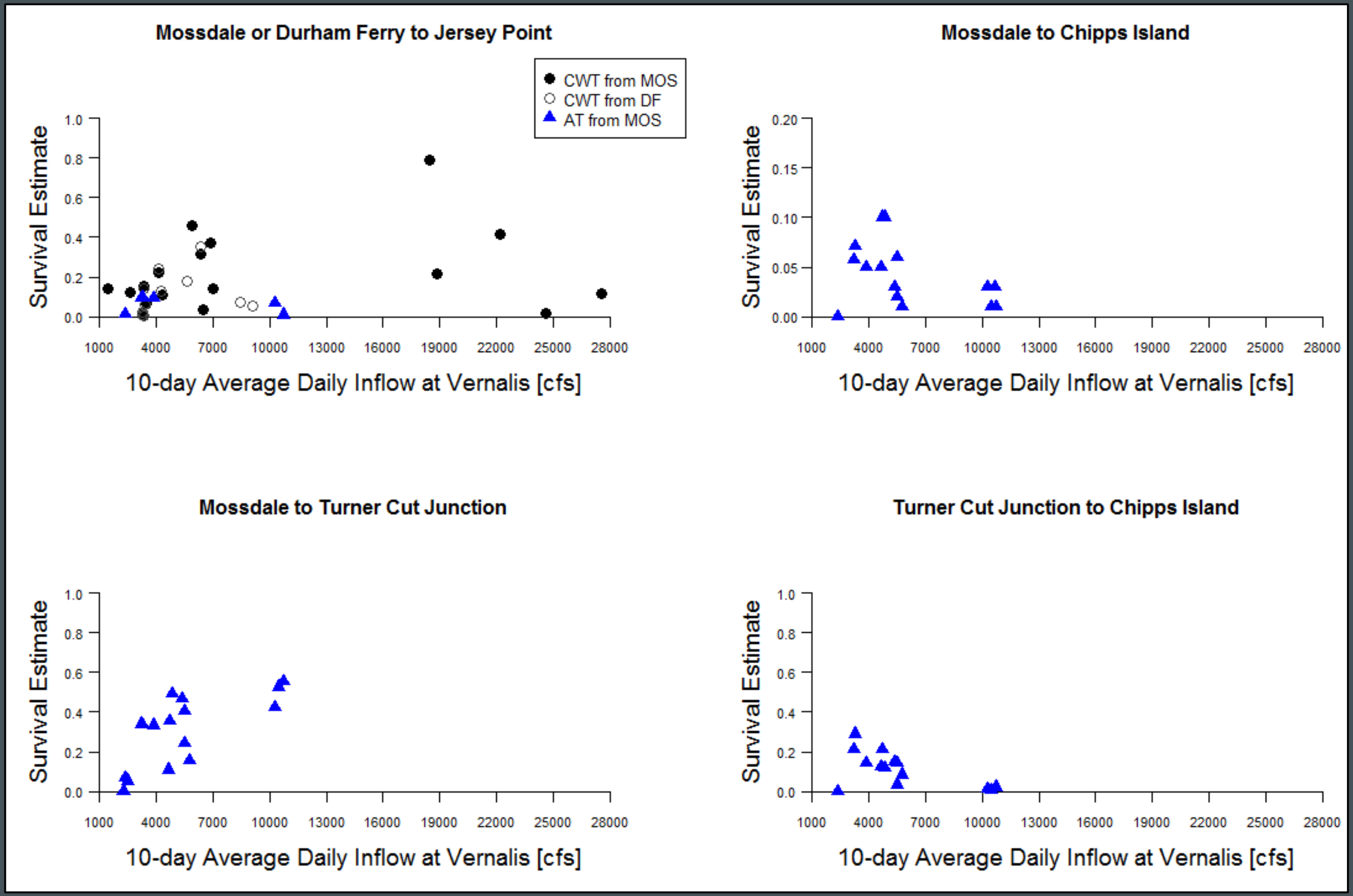
- Gates and barriers
- San Joaquin River inflow
- San Joaquin River I:E
- Reduced negative Old and Middle River (OMR) flows
- Delta E:I

GATES AND BARRIERS



DELTA SURVIVAL VS INFLOW

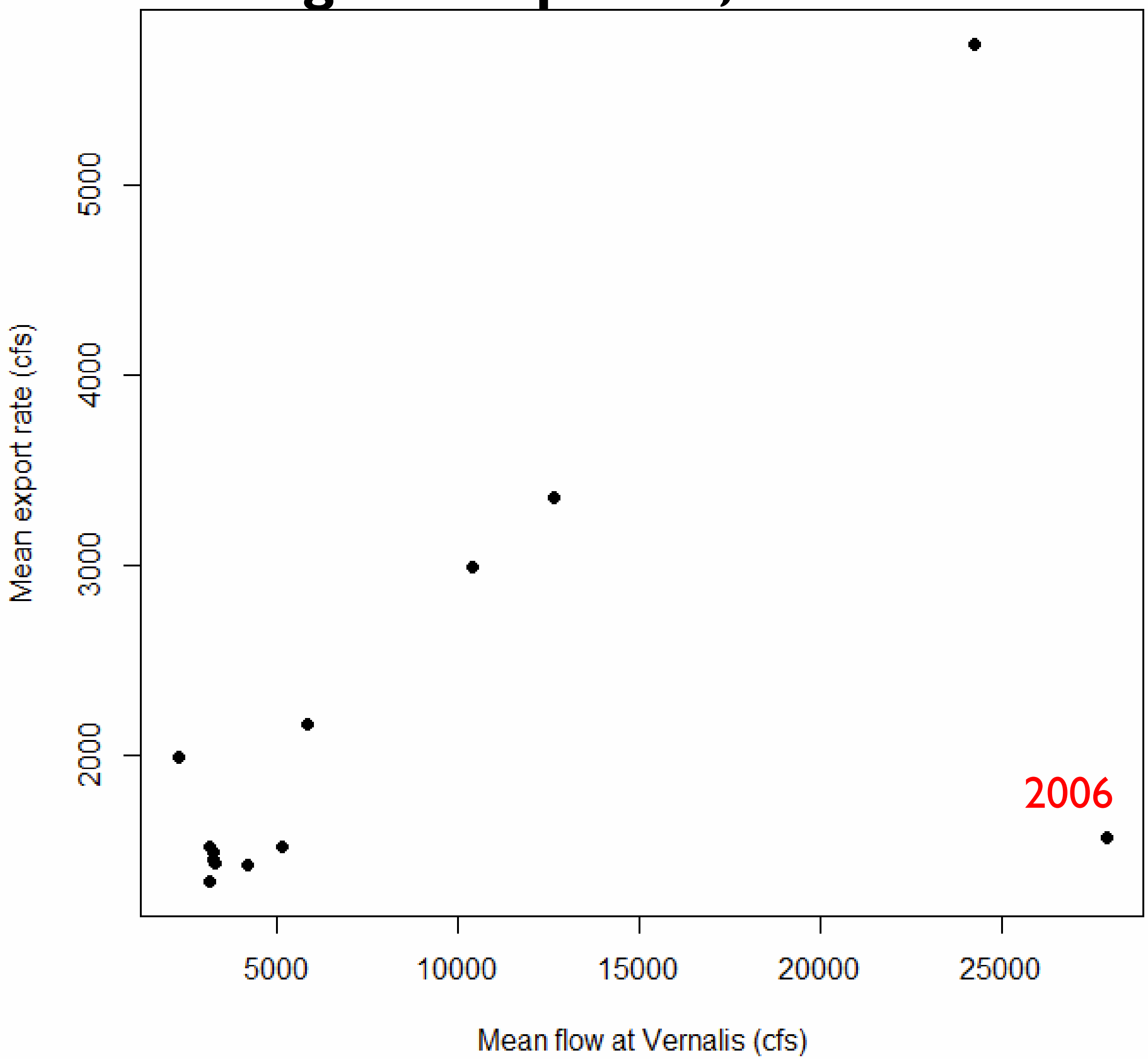
San Joaquin River Fall-Run Chinook Salmon



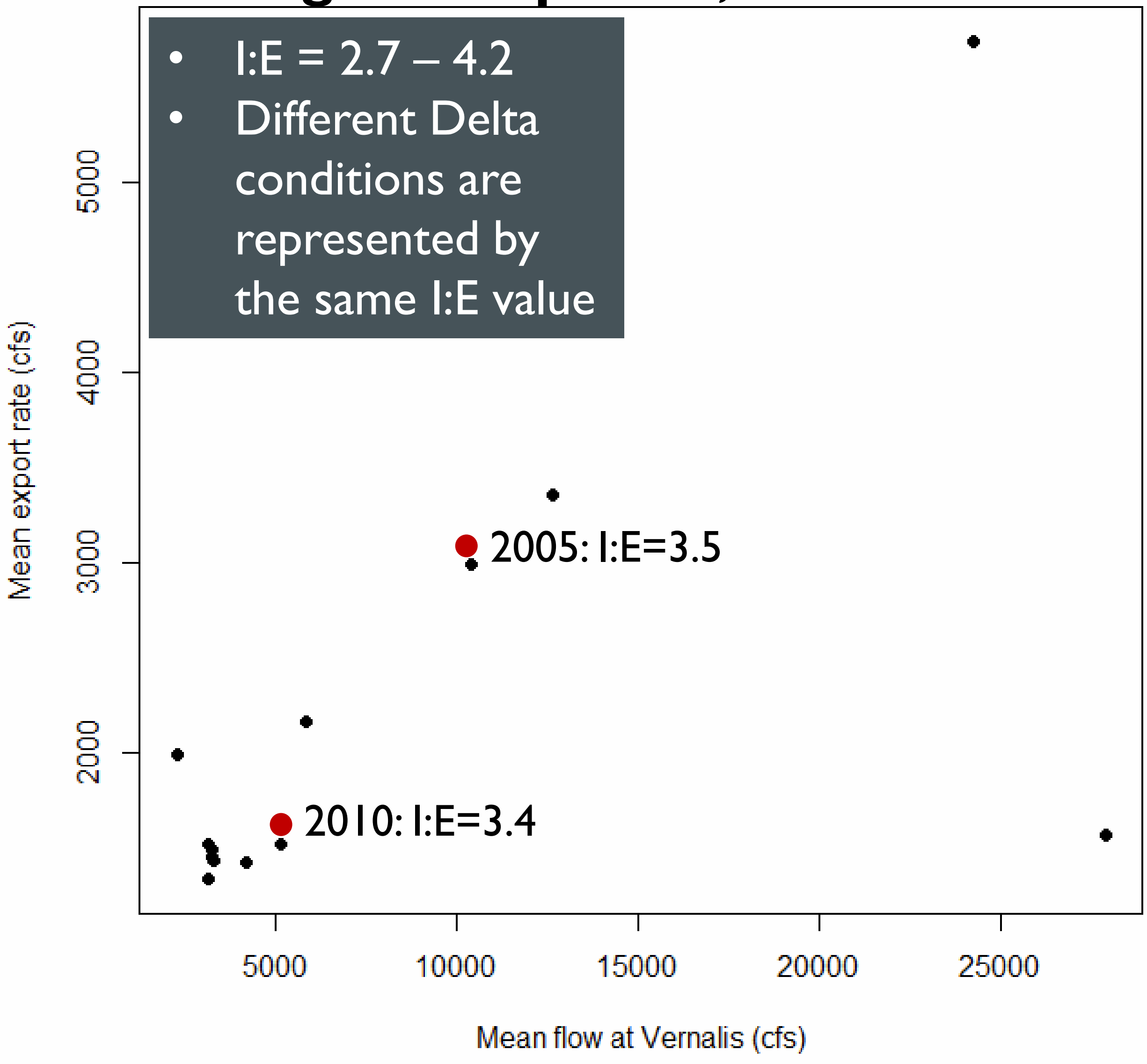
GAPS IN INFORMATION REGARDING MANAGEMENT ACTIONS

- Formal analysis of the relationships between I:E, inflow, exports, and survival is incomplete for existing data (SJR Chinook, steelhead)
- The variability in survival at higher levels of I:E, inflow, and exports is not well-characterized by available data
  - Those conditions have not occurred often during the studies
- Inflow and exports are correlated
  - → Isolating the survival effect of a single factor is difficult or impossible

Observed mean SJR inflow and exports during VAMP period, 2000 - 2011



Observed mean SJR inflow and exports during VAMP period, 2000 - 2011



CONSTRAINTS ON UNDERSTANDING

- All observations are in the presence of management operations (I:E, E:I, OMR restrictions), which makes it difficult to assess their effectiveness
- There has been low variability and limited replication in conditions during tagging studies
  - Most observations of smolt survival have been at low levels of inflow and exports
- Low overall survival makes it difficult to detect changes in survival
- Biological objectives for Delta survival have not been agreed to, which makes it difficult to design studies to test effectiveness of management actions (what is the target?)

SCOPE AND REPORT STRUCTURE

Scope:

We focused narrowly on the effects of SWP and CVP operations on salmonid migration and survival in the Delta

- Inflow
- Exports
- Temporary Agriculture Barriers
- Delta Cross Channel
- Head of Old River Barrier

Volume 1

- **FINDINGS AND RECOMMENDATIONS**

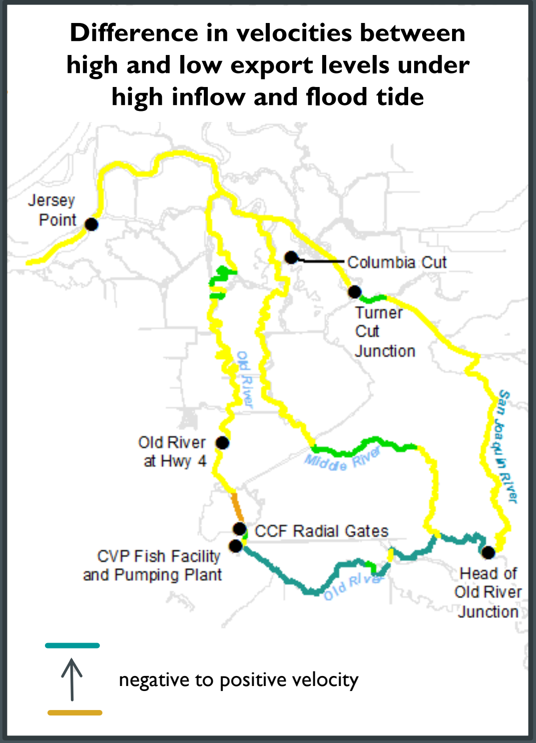
Volume 2

- **RESPONSES TO MANAGEMENT QUESTIONS**

RESPONSES TO 8 MANAGEMENT QUESTIONS FROM CAMT

EFFECTS OF EXPORTS ON FLOW AND VELOCITY

- Export effects vary with distance from facilities (decrease), export level (increase), inflow, and tides
- Largest export effect was estimated in Old River near the SWP and CVP intakes
- Almost no effect at junctions off Sacramento River such as Georgiana Slough
- Small effect at junctions leading off San Joaquin River, except for HOR

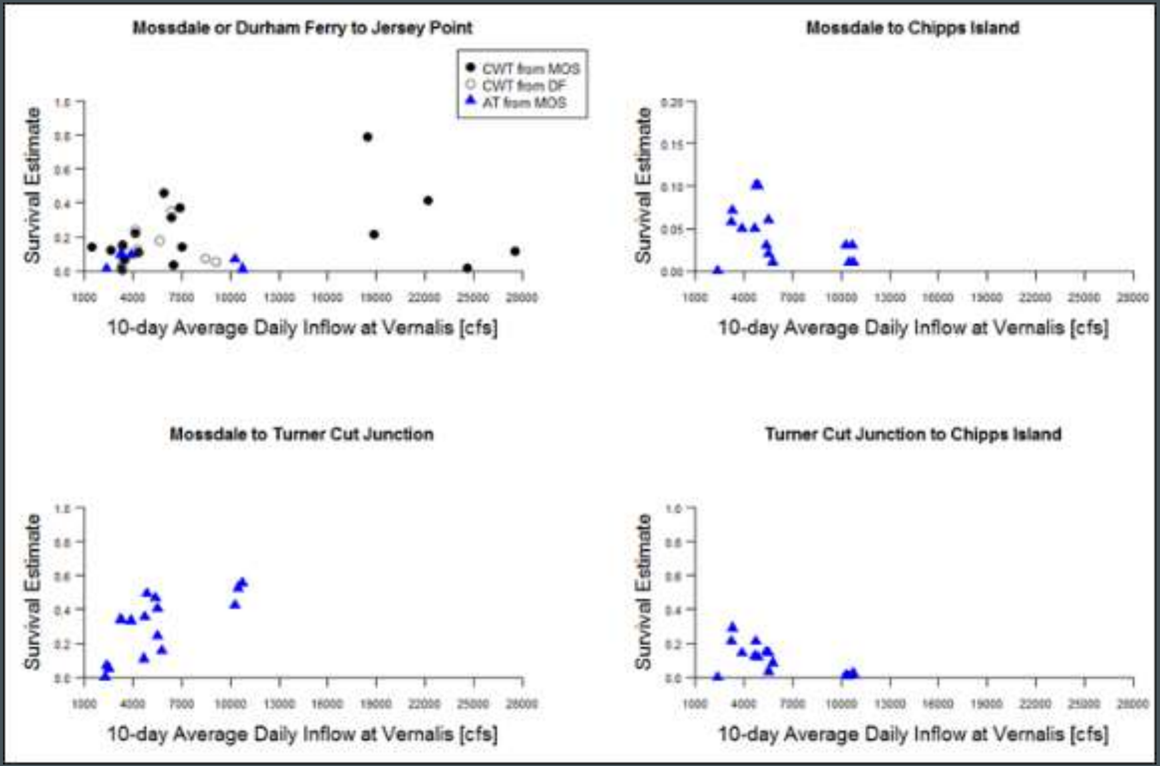


USE OF AVAILABLE HYDRODYNAMIC MODELS

- Useful for isolating one factor at a time by holding other factors constant
- Informed flow and velocity changes in Delta channels, but there is uncertainty for channels that were not validated
- Some limitations, common to all models, are related to input data such as outdated bathymetry, Delta consumptive use, Clifton Court radial gate measurements, and hydrologic monitoring station calibration (particularly at high flows)
- Their application for biological monitoring depends on the question, spatial/temporal resolution needed, and required accuracy for the location

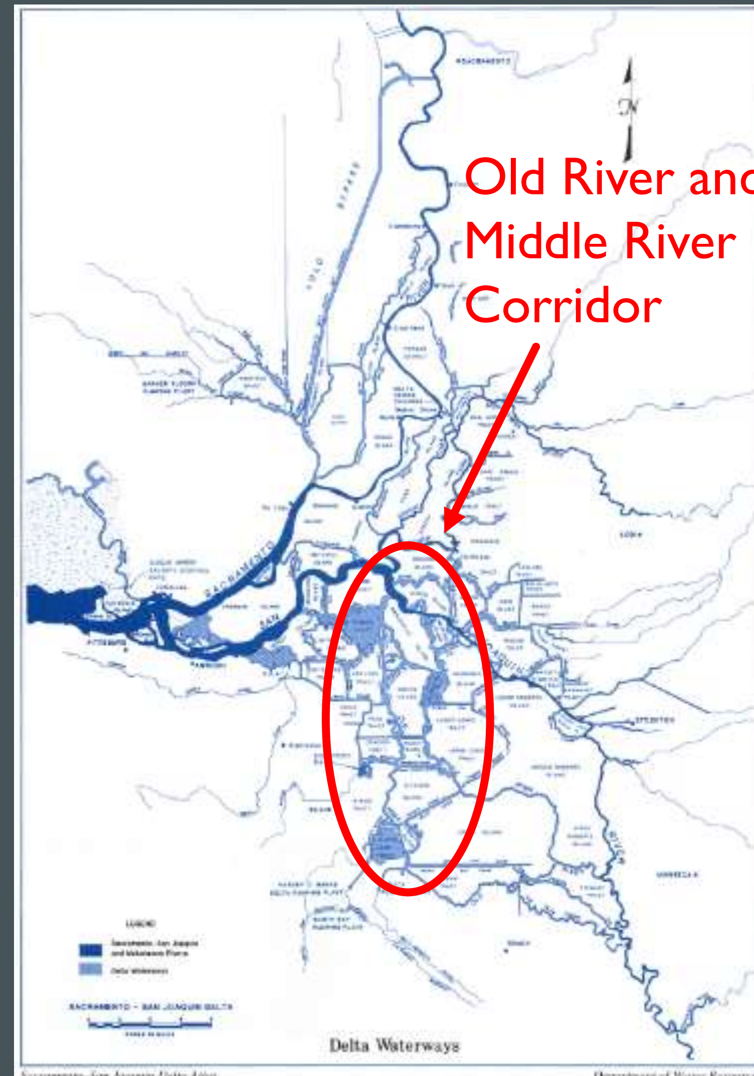
EFFECTS OF EXPORTS AND INFLOWS ON SAN JOAQUIN RIVER JUVENILE SURVIVAL

- Varies in space & time
- Limited data over entire flow range
- Uncertainties remain



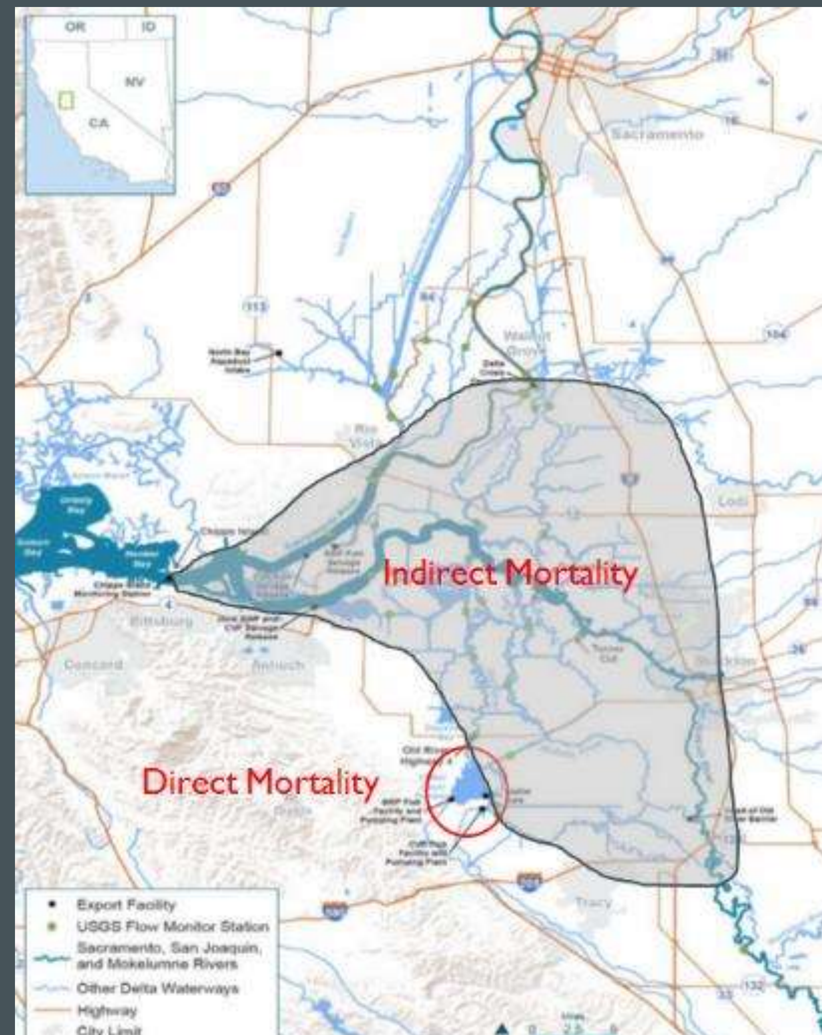
OMR FLOW MANAGEMENT: JANUARY 1st ONSET

- Coincides with juvenile presence in Delta of ESA-listed species in most years
- If based on first detection in Delta, would usually begin earlier



OMR FLOW MANAGEMENT: SALVAGE-DENSITY-BASED EXPORT RESTRICTIONS

- OMR restrictions likely reduce direct mortality
- Effects on indirect mortality are hypothesized; data are limited



ALTERNATIVE FLOW METRICS

- 5 metrics were identified that could be developed and tested to potentially refine water project operations to improve juvenile salmonid survival:
  - Net flow in the lower San Joaquin River (QWEST)
  - Hydraulic residence time in the South Delta
  - Percent positive flow in the OMR Corridor
  - Relative proportion of CVP exports
  - Proportion of Sacramento River water in exports

BIOLOGICAL RESPONSE METRICS

- 8 metrics were identified that could be developed and tested for assessing management actions to improve juvenile salmonid survival:
  - Fish routing into Interior Delta
  - Survival at the route and reach scale
  - Survival at the Delta scale
  - Condition of fish entering and leaving Delta
  - Contribution of fry rearing to survival and adult production
  - Probability of export facility entrainment
  - Direct (salvage) mortality relative to population abundance
  - Juvenile abundance exiting Delta

ADDRESSING CONCERNS ABOUT SURROGATES

- Few studies using wild salmonids are available to evaluate surrogate relationships
- Development of correction factors will require additional study
- Use of surrogates and questions about their use will continue until target populations are abundant or permitted for use in studies
- Surrogacy issue is best addressed on a case-by-case basis during study design development

CAMT MANAGEMENT QUESTIONS: NEXT STEPS

- Limited or inconclusive data for some questions

- Uncertainty and some disagreements

- Recommendation: Use this information to inform development of the long-term monitoring, research, and adaptive management plan

DISAGREEMENTS

- Very few SST disagreements were related to the interpretation of data
- Most disagreements were related to uncertainty due to limited data
- Disagreements were used to inform recommendation for long term study plan

SOME DISAGREEMENTS IN THE SST

1. Whether analysis of exports and relative survival for fish released into Georgiana Slough was conclusive of a relationship between survival and exports
2. The magnitude of change in flow or velocity needed to influence salmonid behavior or survival that is biologically relevant
3. Whether limiting OMR flow to -5,000 cfs prevents increased routing into the interior Delta and increases survival
4. Whether to recommend PIT tag technology in the Delta

OVERARCHING CONSIDERATIONS

- The Delta is a very complicated environment
- The Delta should not be perceived as a singular region, but a suite of regions defined by different physical forcing factors.
- Numerous key questions remain and will require new analyses and experimental approaches
- Questions should be integrated and shift to:

  what can be tested (science),

  what needs to be tested (management)

  what can be put into place for testing (operations)
- Future decisions will have to be made with uncertainty; need to develop tools to help

RECOMMENDATION 1

- Continue existing survival studies, monitoring, and analysis of data (foundation for expanded, future studies)
  - Current studies provide information about survival and junction-specific routing
  - Continuing to estimate through-Delta survival will provide continuity for assessing current status, inter-annual variability and long-term trends
  - Additional analyses of present data to further improve understanding of linkages between water project operations and migration and survival

RECOMMENDATION 2

- Implement short-term actions to improve salvage facility operations (disagreement on whether to recommend short term actions or premature to do so)
  - Determine if current operations at salvage facilities could be improved to reduce losses
    - Actions to reduce direct mortality
    - Other actions to reduce facility loss

RECOMMENDATIONS 3 AND 4

- Develop and implement a long-term monitoring, research, and adaptive management plan
  - To more fully assess the effects of water project operations
  - With stable and reliable funding for implementation for a period of at least 15 years.
  - Base it on monitoring, modeling, and direct manipulation of factors

RECOMMENDATIONS 3 AND 4

- Develop and implement a long-term monitoring, research and adaptive management plan
  - Requires a policy commitment to a range of management actions to be tested
  - Requires agreement on the level of precision needed
  - Requires agreement that operational experimental conditions can be achieved

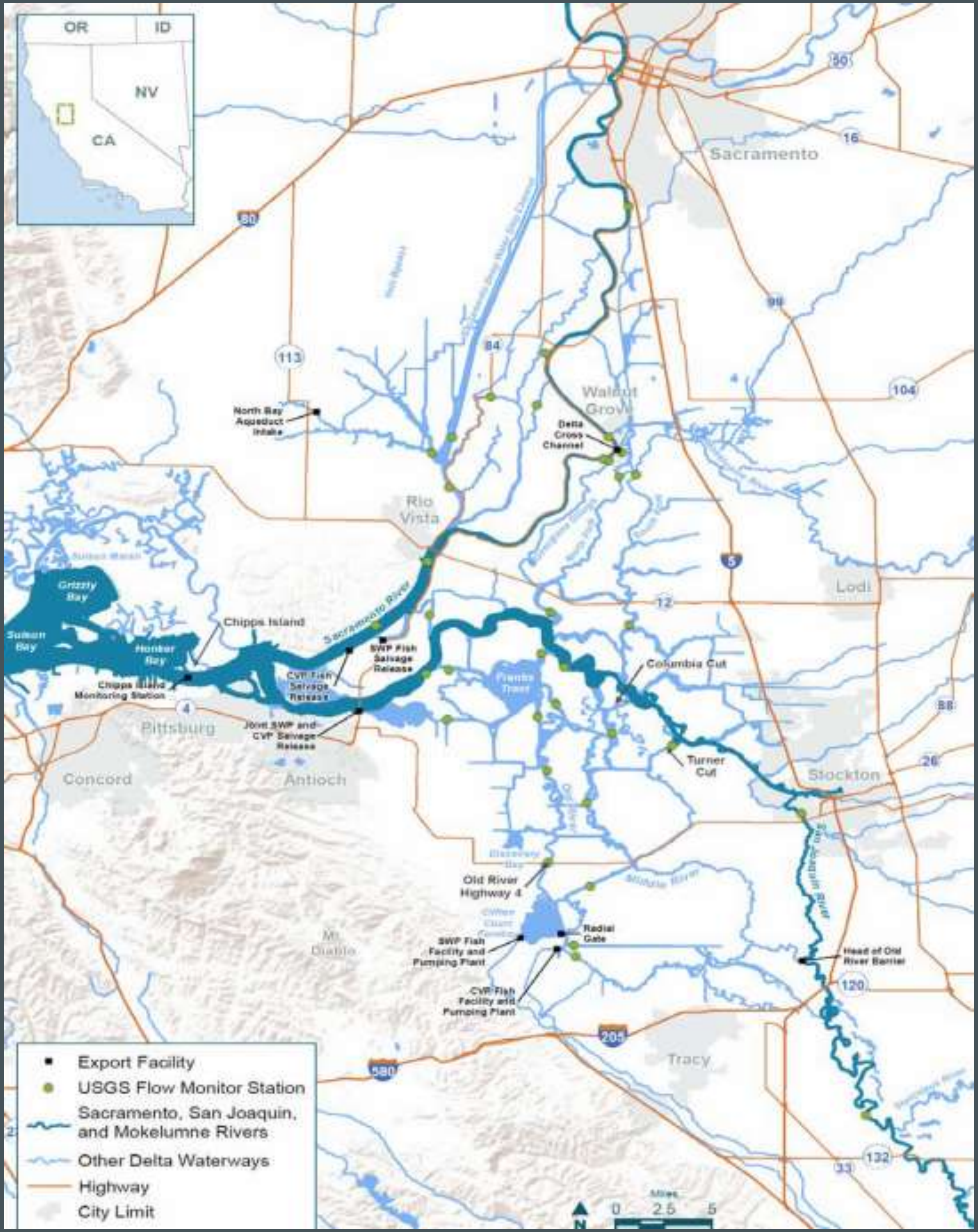
RECOMMENDATIONS 3 AND 4

- Develop and implement a long-term monitoring, research and adaptive management <u>plan</u>
  - Plan should augment and expand the scope of current studies in terms of breath, depth and number of analyses, monitoring studies and experiments conducted
  - A suite of integrated studies organized in hierarchical structure that is adjusted as new information is obtained.
  - Focus on causal mechanisms at appropriate time and space scales

SUMMARY

- Salmon survival in the South Delta is low
- A number of gaps have been identified
- The performance of various management actions on salmonid survival is uncertain
- The SST recommends:
  - Implement actions to improve survival at the SWP and CVP export facilities
  - Continue to monitor salmonid survival in the south Delta while completing additional analyses of existing data to provide a foundation for developing a long-term, hypothesis-based adaptive management program to experimentally assess salmonid migration, survival, underlying mechanisms, and management action performance
  - Develop and implement a long-term monitoring, research and adaptive management program

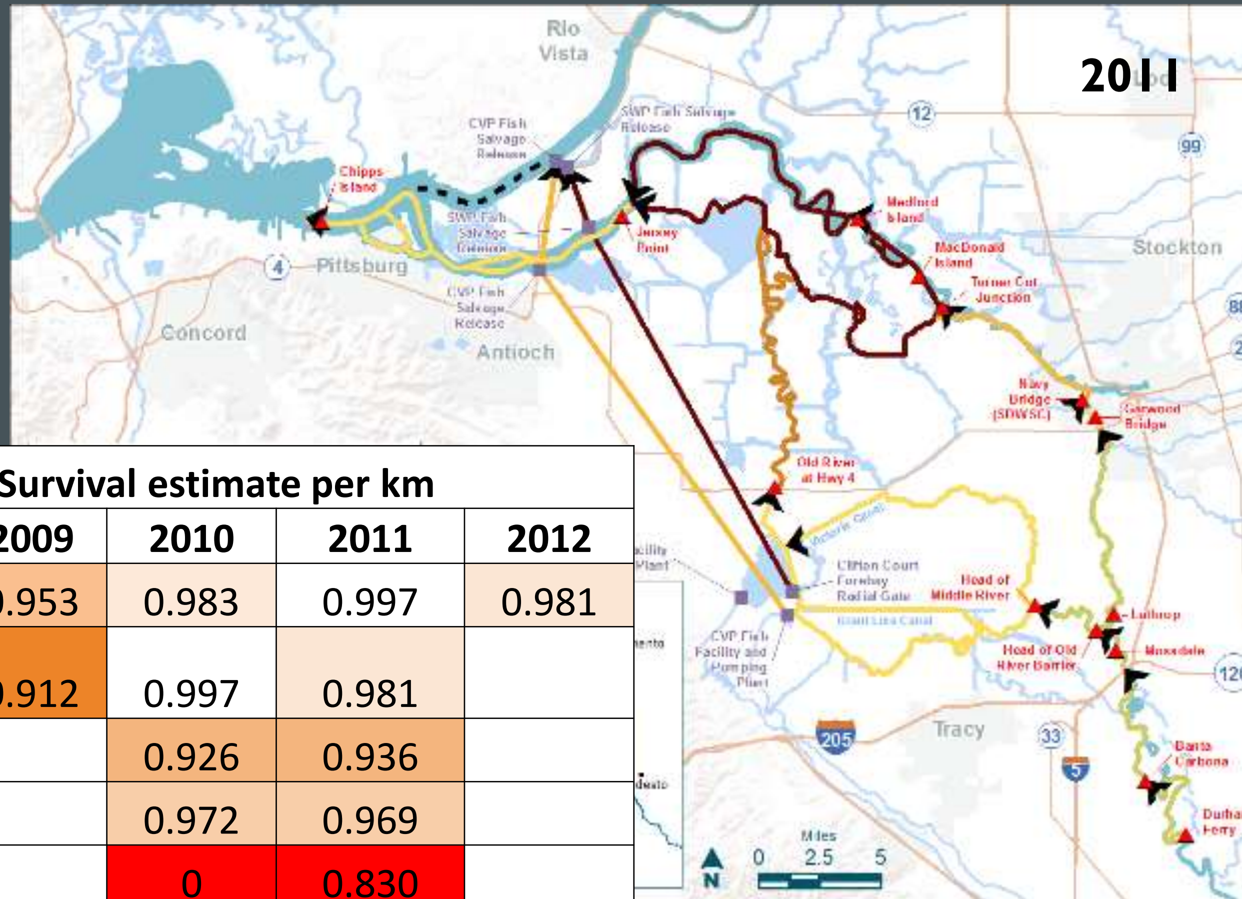
REFERENCE SLIDES


OR
ID
NV
CA
Sacramento
Walnut Grove
Rio Vista
Lodi
Stockton
Pittsburg
Concord
Antioch
Tracy
North Bay Aqueduct Intake
Delta Cross Channel
Chipps Island
Chipps Island Monitoring Station
Grizzly Bay
Suisun Bay
Honker Bay
Sacramento River
SWP Fish Salvage Release
CVP Fish Salvage Release
Joint SWP and CVP Salvage Release
Columbia Cut
Turner Cut
Franks Tract
Old River Highway 4
Radial Gate
SWP Fish Facility and Pumping Plant
CVP Fish Facility and Pumping Plant
Head of Old River Barrier
San Joaquin River
Middle River
Export Facility
USGS Flow Monitor Station
Sacramento, San Joaquin, and Mokelumne Rivers
Other Delta Waterways
Highway
City Limit
Miles
0 2.5 5

PROJECT EFFECTS ON MORTALITY

- Direct mortality contributes to salmonid mortality in the Delta
- … But direct mortality does not account for the majority of the mortality experienced in the Delta
- The mechanism and magnitude of indirect effects on Delta mortality is uncertain

SPATIAL HETEROGENEITY IN SURVIVAL



SJR Fall-Run Chinook

	Survival estimate per km				
Reach	**2008**	**2009**	**2010**	**2011**	**2012**
Old R to Middle R		0.953	0.983	0.997	0.981
Middle R to CVP/CCF/HWY4		0.912	0.997	0.981	
OR-HWY4 to Jersey Pt			0.926	0.936	
CVP tank to Chipps Is	0.845		0.972	0.969	
CCF gates to Chipps Is	0.904		0	0.830	

PRIMARY FINDINGS – FISH SIZE MATTERS

- Multiple lines of evidence indicate smaller fish respond to conditions differently and usually experience lower survival than larger fish
- Evidence that larger fish have higher Delta survival
  - CWT studies of Sacramento River Chinook (Newman and Rice 2002, Newman 2003; check direction; E.4.1.1)
  - CWT studies of San Joaquin River Chinook (Zeug and Cavallo 2013; water quality model performed as well; E.2.2)
  - AT study of Sacramento River late-fall-fun Chinook (Perry 2010)
  - Similar positive survival response to Delta inflow for different sized fish: 81mm (CWT, Newman 2003) vs. 156 mm (AT, Perry 2010)
  - In 2011 and 2012, AT steelhead had higher survival than AT Chinook (San Joaquin River) (Section E.2.1.2)

PRIMARY FINDINGS – COMPLEX EFFECTS OF WATER PROJECT OPERATIONS

- Water export operations contribute to salmonid mortality in the Delta via direct mortality at the facilities (Section E.3.1)
- 3 components of direct mortality
  - Prescreen mortality, entrainment into water project intakes, within-facility ("salvage") mortality
  - Predation occurs within the facilities – direct and indirect evidence
- Pre-screen mortality estimates:
  - At SWP: 0.64 – 0.99 for Chinook salmon (Gingras 1997), 0.78 – 0.82 for steelhead (Clark et al. 2009)
  - No estimates at CVP; assumed value is 0.15 (Anonymous 2013)
- Intake canal entrainment mortality and total facility mortality ("loss") are estimated as functions of salvage counts
  - Salvage rates increase with export rates (Kimmerer 2008, Zeug and Cavallo 2014)
  - No studies directly test relationship between salvage and total mortality at the facilities
- Efficiency of secondary louver system at CVP
  - 0.85 (Chinook), 1.00 (Steelhead): March 1996 – November 1997 (Bowen et al. 2004)
  - Higher louver efficiency for higher channel velocity (i.e., higher export rates) (Bowen et al. 2004, Sutphin and Bridges 2008): <40% for velocity < 1 ft/s, >80% for velocity > 4 ft/s (Sutphin and Bridges 2008)

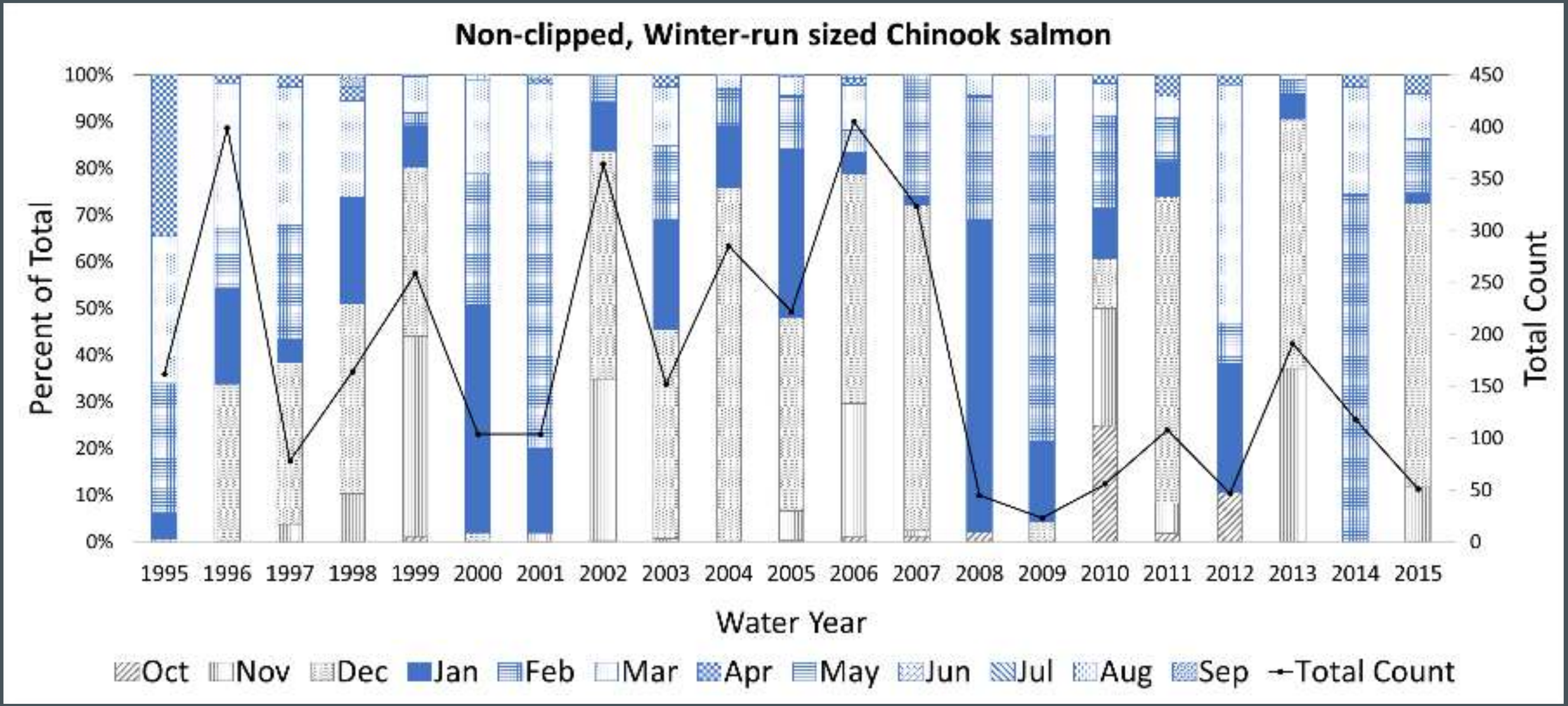
ACTIONS TO REDUCE DIRECT MORTALITY

- Control predator populations (CCF B and CVP trash racks);
- Control secondary louver efficiency (control of bypass velocities);
- Keep primary and secondary louvers free from debris; reduce time when they are inoperable for cleaning;
- Improve salmon passage within the CVP, and decrease predator passage within the CVP;
- Consider alternate truck release locations of salvaged fish to prevent large predator assemblages ;
- Verify the assumption that pre-screen losses at the CVP intake are 15% and substantially lower than losses at the SWP; and
- Test using the CVP for export instead of the SWP to reduce losses of salmonids in CCF.

OTHER ACTIONS TO REDUCE FACILITY LOSS

- Test how CCF radial gate openings affect velocities and fish entrainment
- Evaluate filling the scour hole inside the CCF radial gates reduce predator habitat and predation
- Review and potentially adjust the fish facilities design and operational criteria
- Review past studies and evaluate truck transport release alternatives

JANUARY 1ST ONSET OF OMR



Timing of Delta entry for

winter-run-sized Chinook salmon

JANUARY 1ST ONSET OF OMR

Table 4-1. Date of Earliest Salvage of Genetic Winter Run Chinook from 1997 to 2015

Water Year	Earliest Salvage
1997	11/26/1996
1998	10/3/1997
1999	10/25/1998
2000	11/22/1999
2001	11/6/2000
2002	12/5/2001
2003	12/23/2002
2004	12/8/2003
2005	12/21/2004
2006	12/20/2005
2007	12/30/2006
~~2008~~	~~1/26/2008~~
~~2009~~	~~2/21/2009~~
2010	12/8/2009
2011	12/6/2010
~~2012~~	~~2/14/2012~~
2013	12/13/2012
~~2014~~	~~03/03/2014~~
~~2015~~	~~no salvage~~

Timing of Delta entry for

genetic winter-run Chinook salmon

Exhibit D
List of published literature on salmonids in the Delta since 2009 BiOp

Andrews, Stephen W.; Gross, Edward S.; & Hutton, Paul H. (2016). A Water Balance Model to Estimate Flow Through the Old and Middle River Corridor. San Francisco Estuary and Watershed Science, 14(2). jmie_sfews_31636. Retrieved from: http://escholarship.org/uc/item/8c5574hf

Bowen, M. D., S. Hiebert, C. Hueth, and V. Maisonneuve. 2009. Effectiveness of a non-physical barrier at the divergence of the Old and San Joaquin Rivers (CA). U.S. Bureau of Reclamation technical memorandum 86-68290-09-05.

Bowen, M. D., and R. Bark. 2012. 2010 Effectiveness of a non-physical fish barrier at the divergence of the Old and San Joaquin Rivers (CA). U.S. Bureau of Reclamation technical memorandum 86-68290-10-07.

Buchanan, R. A., J. R. Skalski, P. L. Brandes, and A. Fuller. 2013. Route use and survival of juvenile Chinook salmon through the San Joaquin River Delta. North American Journal of Fisheries Management 33:216-229.

Cavallo, B., P. Gaskill, and J. Melgo. 2012. Investigating the influence of tides, inflows, and exports on sub-daily flow in the Sacramento-San Joaquin Delta. Available: http://www.fishsciences.net/reports/2013/Cavallo_et_al_Delta_Flow_Report.pdf.

Cavallo, B., J. Merz, and J. Setka. 2013. Effects of predator and flow manipulation on Chinook salmon (*Oncorhynchus tshawytscha*) survival in an imperiled estuary. Environmental Biology of Fishes 96:393-403.

Cavallo, B. et al. 2015. Predicting juvenile Chinook routing in riverine and tidal channels of a freshwater estuary. Environmental Biology of Fishes, 98(6): 1571-1582

Clark, K.W., M. D. Bowen, R. B. Mayfield, K. P. Zehfuss, J. D. Taplin, and C. H. Hanson 2009. Quantification of pre-screen loss of juvenile steelhead in Clifton Court Forebay. California Department of Water Resources, Sacramento, CA.

Delaney, D., P. Bergman, B. Cavallo, and J. Melgo. 2014. Stipulation study: steelhead movement and survival in the South Delta with adaptive management of Old and Middle River flows. Report to CDWR. Available: http://www.fishsciences.net/reports/2014/Final_Stipulation_Study_Report_7Feb2014.pdf.

del Rosario, R. B., Y. J. Redler, K. Newman, P. L. Brandes, T. Sommer, K. Reece, and R. Vincik. 2013. Migration patterns of juvenile winter-run-sized Chinook salmon (*Oncorhynchus tshawytscha*) through the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 11(1):1-22. Available: http://escholarship.org/uc/item/36d88128.

Harvey, B., and C. Stroble. 2013. Comparison of genetic versus Delta Model length-at-date race assignments for juvenile Chinook salmon at state and federal south Delta salvage facilities. California Department of Water Resources, Sacramento, CA.

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