Interactive comment on "Reconstructing the natural hydrology of the San Francisco Bay-Delta watershed" by P. Fox et al.

Authors Responses to Swanson Comments (SC 2025)

The comments are shown below with responses in italics below each comment. Sub comments have been identified within the original comments in brackets (e.g., [1], etc.) at the end of the comment to be addressed. Those specific comments are addressed within the response section.

1. The paper describes an effort to quantitatively estimate long-term, annual average Delta outflow under "natural" landscape conditions. This is an interesting exercise that may provide insight into the pre-development hydro-ecology of California's Central Valley. However, given the extensive physical and hydrologic alteration of the watershed, the universal recognition that the pre-development, "natural" system cannot be restored and is not the objective of current and future ecosystem restoration or regulation activities, and the coarseness of these model outputs (i.e., long-term average annual flow with no information on inter- or intra-annual variability), the results as presented have virtually no relevance to ongoing flow management and regulation, contrary to the authors' contentions.

We disagree with the reviewer's contention that "the results as presented have virtually no relevance to ongoing flow management and regulation" and refer the reviewer to our response to a similar comment by Bruce Herbold. Our results expose the myth that unimpaired flows are natural flows, a widely misused assumption used to assign causes to fishery declines and the basis of proposals to restore them. See, e.g., Fleenor et al. 2010[1]; SWRCB 2010. It also lays the foundation for more detailed monthly and interannual analyses by describing the natural hydrosphere (Fox and Sears 2014), mapping native vegetation, and developing peer-reviewed monthly and annual estimates of natural vegetation evapotranspiration (Howes et al. 2015).

While a complete return to pre-development flows is not a realistic goal (or even a possibility), characterizing natural or pre-development hydrology can provide useful information to guide future restoration planning activities in the estuary. The aquatic species of concern evolved in a highly productive system of sluggish river channels, large floodplains, oxbow and floodplain lakes, swamps, sloughs, and riparian corridors, not the highly channelized, rip-rapped and leveed rivers of today that carry high velocity pulse flows.[2] Restoring the habitat for these species will require understanding these natural conditions. We provide an example in our manuscript, at p. 3869, lines 16-27. The Comprehensive Everglades Restoration Plan in Florida used modeling of the natural system to guide restoration. Similarly, our work can help elucidate natural conditions to guide restoration activities being planned for the Bay-Delta system.

[1] William E. Fleenor, William A. Bennett, Peter B. Moyle, and Jay R. Lund, On Developing Prescriptions for Freshwater Flows to Sustain Desirable Fishes in the Sacramento-San Joaquin Delta, 2010.

[2] Peter B. Moyle, Inland Fishes of California, Revised and Expanded, 2002, pp. 29-30.

2. There are numerous other problematic issues with this manuscript, many already identified by other reviewers. My comments are limited to the fundamental mismatch between the research/model results, biological responses of Bay-Delta fish and invertebrate species to Delta outflow, and the regulation of annual and seasonal Delta outflow as a management and species protection tool. I am a biologist who has conducted research, published, and engaged in the regulatory policy arena as an expert in this system for more than 20 years. On the basis of my review of this manuscript, I conclude that there are substantial, foundational flaws in the authors' interpretation and suggested applications of their results. Therefore, this paper should not be considered for publication in Hydrology and Earth System Sciences without major revisions.

We disagree, as explained below.

Specific comments:

3. Based on their research and modeling, the authors report that the long-term, annual average Delta outflow under pre-development "natural" conditions was similar to the long-term average of current Delta outflow (using data from 1922-2009). The authors then conclude that, therefore, "it is unlikely that reductions in annual average Delta outflow have caused the decline in native freshwater aquatic species" (pg 3849) and "it is unlikely that reduced annual average freshwater flows have contributed to ecosystem decline in the estuary" (pg 3869). Similarly the authors' contention that "development has simply redistributed flows from natural vegetation to other beneficial uses" (presumably these other "beneficial uses" are local and out of basin urban and agricultural consumption; pg 3869) demonstrates a basic misunderstanding watershed and aquatic ecosystem function that undermines the authors' discussion and interpretation of their results. These conclusions, which stray very far from the actual utility and potential applications of the research, are fatally flawed for several reasons.

We disagree. The commenter has mis-stated the fundamental objectives of our work, which were: (1) to demonstrate that unimpaired Delta outflows are not natural outflows and (2) to determine whether claims by others that flow reductions, relative to long-term annual average unimpaired flows, had contributed to species declines, by exploring whether such reductions had in fact occurred. Our work demonstrates that unimpaired flows are not natural flows and thus, the relationship asserted by others is not valid. This is a very important distinction. Many have erroneously assumed unimpaired flows are equivalent to natural flows and thus asserted that declines in current outflows, relative to long-term annual average unimpaired outflows, is a cause of species declines. We are not proposing a new theory about the relationship between flows and species declines, but rather rebutting a theory proposed by others. This comment flips this, accusing us of asserting a theory when what we are actually doing is explaining why a widely held belief is wrong. We are not suggesting any replacement for that belief.

4. First, the relationship between Delta outflow and the survival and/or abundance of numerous fish and invertebrate species is based on surveys and monitoring results for the past approximately 50 years in the existing (i.e., post-development) system. We have no analogous quantitative data on biological responses to flow, whether seasonal, annual or

long-term annual averages, for the pre-development "natural" system. Therefore there is no logical or factual basis to conclude that the similarity in flow volumes between the authors' estimate for "natural" flows and current measured flow volumes precludes an effect of flow in the existing system on recently measured fish declines. [1] Native species may have "evolved under natural landscape conditions" (pg 3868) but they are responding to the existing system and actual flow levels on an annual basis. [2]

The reviewer is raising a baseline question that is similar to one raised in Mr. Herbold's Comment 5. The reviewer is referred to our response to Mr. Herbold.

[1] The surveys noted in this comment were initiated in an effort to determine the cause(s) for the declines in native species in the Bay-Delta estuary over the recent historical record. We note that correlations between species abundance and Delta outflow, based on these surveys, can be inherently misleading, as the system has continued to change over time.

It is an undisputed fact that under true natural conditions, the subject aquatic species, e.g., salmon, delta smelt, were abundant. Thus, a reasonable place to look for conditions that supported abundant populations of the subject species is the natural system itself, especially the hydrosphere in which they lived. We have taken the first step, qualitatively describing the functioning of that system and quantifying its output in terms that others have asserted contributed to the declines, long-term annual average Delta outflow. Quantitative species abundance data for the "natural" system is not required to assess conditions under which they flourished.

[2] The commenter appears to equivocate herself. In this comment she asserts: "Native species may have "evolved under natural landscape conditions" (pg 3868) but they are responding to the existing system and actual flow levels on an annual basis." However, in her third point, she supports the approach proposed by the SWRCB to restore aquatic species – the use of multi-day or monthly unimpaired flows as a dynamic benchmark for new standards for minimum Delta outflow to "provide (and protect) seasonal and inter-annual variation in flow to the ecosystem, the same characteristics of Delta outflow that fish population do respond to." Thus, on the one hand, she is arguing that species respond to existing conditions, but is advocating setting standards based on unimpaired conditions, which never existed, as a surrogate for "natural" conditions.

5. Second, the relationship between Delta outflow and species response, which is statistically significant, robust (multiple species and taxa), and persistent (the relationship has persisted for many decades and despite major ecological changes in the Bay-Delta), is based on inter-annual variations in Delta outflow, not long-term average annual Delta outflow. Therefore, it is both irrelevant and logically flawed to relate fish declines to long-term average flows, as the authors do. [1] Further, long-term averages, particularly of a variable like Delta flow, which is not normally distributed, can be notoriously misleading, masking large, unequal variations by lumping dry and wet years together and skewing distributions of the component annual flow data. [2] Instead, it is the inter-annual variations in flow, and in particular both the frequency and distribution of high and low flow conditions and magnitude of seasonal flows, rather than long-term average

annual flows that affect species and ecosystems. [3] During the recent multi-decade period for which we have measured fish declines, Delta outflows have been altered substantially, reduced in recent decades by 50% on an annual basis and by more than 60% during the ecologically important spring season. This in turn, has resulted in substantially increased frequency of years with man-made, drought-like flow conditions. [4] It is these measured changes in annual and seasonal Delta outflows, not the long-term average, that correlate significantly with the concurrently measured fish (and invertebrate) abundance and survival and are thought to be driving population declines. In addition, as the result of decades of complementary, multi-disciplinary research, we have good and growing understanding of the multiple physical and ecological mechanisms underlying this relationship. While the authors acknowledge that their results do not include estimates of any of these variables (i.e., inter- and intra-annual variability, frequency of low flow conditions) and that this constitutes a limitation of their study (pg 3869), this deficiency is serious. At a minimum, the authors' conclusions are unsupported by their results and, until they provide annual and seasonal Delta outflow model output, premature. [5]

[1] We are not relating fish declines to long term annual average flows. Rather, we are rebutting the work of others who have asserted that fish declines are due to long-term annual average unimpaired flows. We agree that inter-annual variations in Delta outflow are important in determining annual aquatic species abundance. However, many have and continue to argue that the decline in native aquatic species has been caused by a 50% to 60% decline in annual average Delta outflow due to in-basin water uses and exports. This decline is generally calculated relative to unimpaired flows. Our work is important, and, in fact, surprising to most, because it demonstrates that there has not been a 50% to 60% decline in annual average Delta outflow, compared to natural conditions. In fact, current in-basin uses and exports are about equal to pre-development evapotranspiration.

[2] We agree that the metric used to describe a data set can be reported in many different ways, depending upon the study goals. The purpose of our work was to investigate the claim by others that the decline in native aquatic species has been caused by a 50% to 60% decline in annual average Delta outflow, due to exports and in-basin water uses. Thus, the most reasonable metric for testing this theory is the metric used in the theory itself, a long term annual average.

[3] The reviewer appears to be dismissing the work reported in the manuscript because of its acknowledged limited scope of long term annual averages for assessing the abundance of aquatic species. However, as noted elsewhere, the purpose of our work was not to develop a model to assess species abundance, but rather to test a theory posed by others. The current manuscript acknowledges the need for future research on inter- and intra-annual variability in Delta outflow to investigate causes of species declines. No additions to the manuscript are proposed. We are currently developing methods to accurately estimate these shorter term flows. However, the starting point for this work is a long-term annual average water balance.

[4] The comment: "During the recent multi-decade period for which we have measured fish declines, Delta outflows have been altered substantially, reduced in recent decades by 50% on an annual basis and by more than 60% during the ecologically important spring season" is

ambiguous as the commenter fails to identify the basis of her 50% and 60% estimate. Is it 50% relative to unimpaired flows, or is it 50% in years x relative to years y? We presume relative to unimparied flows, based on the reported magnitude. See response [1] above.

[5] We disagree. The purpose of our work was not to develop a model to explain the decline in aquatic species, but rather to explore the widely asserted thesis by others that development of water resources, via in-basin uses and exports, had reduced long-term annual average Delta outflow by 50% to 60%, thus causing or contributing to species declines. Others asserted long term annual average declines in Delta outflow, calculated relative to unimpaired outflows, as a cause of species declines. Our work clearly demonstrates that development of the Valley Floor did not reduce Delta outflows by 50% to 60%. In fact, the surprising conclusion we reached is that current in-basin uses and exports are about equal to evapotranspiration under natural conditions. We agree that inter-annual and seasonal variability are important in explaining current species abundance data, but that was not the purpose of our work. We did not seek to determine causes of species declines, but rather, to rebut misleading claims by others.

6. Third, the authors have mischaracterized the regulatory approach currently being considered to use CDWR unimpaired flow estimates as a basis for setting new regulatory flow standards for Delta outflow. [1] They state that our understanding of the relationship between flow and fish population declines is based on unimpaired flows ("The reduced outflow hypothesis advanced by some as a cause of declines in native fish abundance is typically based on "unimpaired" flows of 34.3 billionm3yr published by CDWR (2007)." pg 3867). This statement is factually incorrect and conceptually implausible: the abundance of many native fish and invertebrate species is statistically related to actual Delta outflows, which are the only flow condition these organisms experience, not unimpaired outflows estimated on the basis of runoff in the watershed. [2] Instead, the approach currently being considered by the SWRCB to use multi-day or monthly unimpaired flows as a dynamic benchmark for new standards for minimum Delta outflow is intended the provide (and protect) seasonal and inter-annual variation in flow to the ecosystem, the same characteristics of Delta outflow that fish population do respond to. [3]

The reviewer appears to be criticizing the manuscript's assertion that unimpaired flows have frequently been used (incorrectly) as a surrogate for natural flows. However, we find the logic chain of her specific criticism difficult to follow. Clearly the reviewer believes that unimpaired flows are sufficiently robust to be used for setting Delta outflow standards, as evidenced by her last statement. It is the authors' hope that our manuscript will provide a basis for advancing the scientific debate on this subject.

[1] Our paper does not discuss the approach currently being considered to regulate Delta outflow. Rather, we quote from a report, submitted by the California State Water Resources Control Board (SWRCB) to the state legislature that recommends a flow criterion of 75% of unimpaired Delta outflow from January through June "in order to preserve the attributes of the natural variable system to which native fish species are adapted" as an example of the ways in

which unimpaired flows are misused. Manuscript at 3868, lines 5-10. See further discussion in response [3].

[2] We did not state nor do we believe that "our understanding of the relationship between flow and fish population declines is based on unimpaired flows…" This mischaracterizes our work. Rather, our point is that others have improperly used unimpaired flows as a surrogate for natural flows when discussing causes of species declines. See manuscript, p. 3867, line 5–to 3868, line 10.

Many have argued that exports out of the Delta have reduced Delta outflows by 50% to 60%, causing species declines. Cloern and Jassby (2012), for example, argue that "[f]low management in the San Francisco Bay-Delta watershed is so pronounced that a median 39% of its unimpaired runoff is consumed upstream or diverted from the estuary (), and the Sacramento-San Joaquin River system is thus classified as "strongly affected" by fragmentation….Responses to this fragmentation include annual exports sometimes exceeding 50% of inflow…These signs of ecosystem disturbance are related, at least partly, to altered flow regimes from water consumption and exports…The era of increasing water exports…has been marked by population declines of native aquatic biota across trophic levels from phytoplankton [] to zooplankton [] to pelagic fish [] and large shifts in biological communities []" Cloern and Jassby 2012, Sec. 3.3.

This conclusion from Cloern and Jassby (2012) is based on a long-term annual average comparison of historic Delta outflow with unimpaired Delta outflow, e.g., Dynesius and Nilsson (1994). One purpose of our paper is to demonstrate that the amount of water consumed upstream or diverted from the estuary under current conditions is about equal to the amount of water that was evapotranspired under natural conditions. Thus, the asserted 50% of the inflow that is now exported or otherwise used, which is typically based on a long term annual average, is unlikely to have caused the "estuary fragmentation "asserted by Dynesius and Nilsson (1994) and the resulting population declines, as a similar amount of water was consumptively used under natural conditions and never reached the Delta.

As another example of the misuse of unimpaired flows that our paper addresses, Fleenor et al (2010) argue in a report referenced by the SWRCB in its 2010 Flow Criteria Report: "[c]ontrasting flows from this period with unimpaired flows (when native fishes had more robust populations) and more recent flow conditions (when dam development was complete and native fishes fared worse) provides some indications for how much fresh water is needed to keep native fish populations healthy." Fleenor et al. p. 8. This is incorrect because unimpaired flows do not represent the amount of freshwater that was available to support native fish species under natural conditions. A significant amount of this water was used by native vegetation.

In assessing flows required to preserve fish abundance, these authors go on to argue: "Even without considering the additional effect of through-Delta exports, inflows to the Delta have been tremendously modified from natural conditions (represented here by unimpaired flows)" Fleenor et al. pp. 10-11. These authors use long-term annual averages to drive home their points. See, e.g., p. 6 and Fig. 6. These statements are wrong because unimpaired flows are not representative of natural flows. Our work is very important because it corrects this long-

running misinterpretation of unimpaired flows that has hindered finding reasonable solutions to the fishery declines.

[3]As stated in the manuscript, we agree that seasonal and inter-annual flow variations are important. However, the SWRCB is considering Delta outflow regulations based on unimpaired flows to protect aquatic species, rather than actual flows to which the species are currently acclimated or natural flows, under which they evolved. Their 2010 Flow Criteria Report cites work by others based on unimpaired flows used as a surrogate for natural flows. (Fleenor et al. 2010). These authors, for example, in summarizing various methods to establish Delta environmental flows, list the "advantages" of unimpaired flows as "[k]nown pre-development effectiveness" and the "contributions" as "general pattern of flows and magnitudes for original conditions." (Fleenor et al., Table 4).Our work demonstrates that unimpaired flows are a poor surrogate for natural flows, when considering the natural state of the pre-development Delta.

We are aware of no evidence that seasonal and inter-annual variation of unimpaired flows are reasonable surrogates for natural flows. Under true natural conditions, rim inflows were detained in low-lying basins and evapotranspired, which would have significantly modified the quantity and timing of their release to the Delta, thus shifting seasonal and inter-annual variation of Delta outflow, compared to unimpaired Delta outflows, which do not consider the detention nor the evapotranspiration. Work is currently underway to quantify the seasonal and inter-annual variation of natural Delta outflows, which we agree are important for understanding aquatic species abundance.

If the SWRCB is proposing to use "multi-day or monthly unimpaired flows as a dynamic benchmark for new standards for minimum Delta outflow to provide (and protect) seasonal and inter-annual variation in flow to the ecosystem", as asserted by the commenter, our work demonstrates that this is pre-mature and unsupported. Additional hydrologic and hydrodynamic modelling must be completed to determine actual natural seasonal and inter-annual Delta outflow variability because unimpaired outflows do not consider the natural hydroscape between rim inflows and the Delta. Our work demonstrates that the natural landscape/hydroscape would have modified both the monthly and inter-annual variation in Delta outflows due to low-lying basin detention and evapotranspiration. Vorster's Comment 2 agrees: "The findings from that work [TBI 1998] and subsequent analysis concurs with the observation that the unimpaired Delta outflow is not the same as the natural Delta outflow because vegetation conversion, levee building and elimination of flood basin storage altered the flow patter." However, significant additional work is required to quantify the magnitude of these effects on seasonal and inter-annual variability.