NMFS' White Paper on Central Valley Floodplain Management for Salmon: Considerations for Balancing Food Web Productivity and Fish Viability

Purpose

NMFS is interested in continued dialogue with scientists, restoration practitioners, other agencies and stakeholders on when and under what conditions to support active versus passive floodplain inundation management for juvenile salmon rearing and increased long-term viability of salmonid species in the Central Valley (CV). This paper's purpose is to advance the dialogue by summarizing current science, including areas of agreement and disagreement, and recommending considerations to help make choices about active versus passive floodplain restoration design. We define active floodplain inundation management as that which is achieved using infrastructure (*e.g.,* gate, weir, or berm) to stop or slow water movement; passive floodplain inundation management does not involve infrastructure. We acknowledge that all management actions occur on a highly modified landscape; the history of significant modifications to floodplain topography and water operations/diversions create background conditions for this dialogue.

Background

Wild Chinook salmon and steelhead were once abundant throughout the rivers and creeks in the CV. Prior to Euro-American settlement, an estimated 1-2 million Chinook would return to CV rivers each year (27). Such high abundance was achieved in large part because of unimpeded access to vast and diverse natural freshwater habitats, from which an unsurpassed diversity of Chinook life history strategies emerged.

CV rivers once carried runoff from large winter storms and spring snowmelt onto floodplains, slowing and spreading water into complex mosaics of riparian forest and wetlands, depositing sediment, and recharging groundwater (25). Large flood basins, floodplains, and tidal wetlands were often inundated for long periods in most years providing food-rich rearing habitat essential to support large salmonid populations. Inundation occurred for weeks to months at a time and the slow, highly productive floodplain waters provided ideal conditions for juvenile salmon to feed and grow before migrating to the ocean. Over the last 1.5 centuries, however, floodplain habitats have been reduced to about 5% of their historical extent. Valued for their rich soils, most of the CV's floodplains have been converted to agriculture and disconnected from their rivers by levees and dykes (24). In addition, most of these formerly activated floodplains that now support agriculture have been modified to alter drainage via some combination of berms, ditches, drains, canals, and tile.

Flow alteration from large upstream dams, especially the high flows reduction, has also limited the inundation duration and extent of remnant floodplain habitats. Prior to construction of Shasta Dam, the Sacramento River spilled onto flood bypasses for 1+ weeks each spring in nearly 8 of 10 years, whereas after Shasta Dam operations commenced, such overflow events occurred in roughly 2 of 10 years (19, 25). The total wetted-acre-days per year and the "average" inundation event have also been reduced. Overall, the loss of floodplain habitat, along with other limiting factors (*e.g.,* loss of spawning habitat, degradation of remaining accessible habitat), have taken a toll on CV Chinook so each distinct run is now at risk of extinction by the end of the century if present trends continue (15).

Floodplain Restoration & Management for Salmon Recovery

It is widely accepted that recovering viable salmon populations in the CV will require large-scale floodplain and wetland ecosystem restoration (14, 17, 4, 9). Restoring functional floodplain ecosystems requires addressing four primary elements: hydrological connectivity between the river and floodplain, a variable flow regime incorporating a range of flow levels, sufficient spatial scale for key natural processes to occur, and floodplain habitat quality (18). The natural processes occurring on functional floodplains that provide ecological benefits for salmon include decreased water velocity, sediment deposition, nutrient cycling, including routing carbon from basal algal and detrital sources into invertebrate food webs, increased water clarity, increased photosynthesis, and increased zooplankton and invertebrate production (18). Due to decreased water velocity and sediment deposition, floodplain water is often less turbid than river water and can thus support greater rates of photosynthesis from algae and phytoplankton (1). In turn, this primary productivity supports high zooplankton productivity and aquatic invertebrates (12, 18), which then provides food for rearing salmonids and other fish (23, 18).

Rearing salmonids' food production quality is influenced by inundation duration. Floods <1 week can provide feeding fish access to terrestrial invertebrates from soil and vegetation (14), but longer inundation and extended solar exposure of at least 2 weeks are key for aquatic productivity and fish growth (24, 8). Cosumnes River floodplain research showed that secondary productivity reached peak levels at ~21 days (8), after which it stabilizes or declines. Grosholz and Gallo (8) recommend a 2- to 3-week post-flood interval duration and repeated flood pulses to best support native fish (25). A significant portion of the trophic energy transfer in floodplains and similar off-channel habitats may also move through heterotrophic food webs driven by breakdown of plant detritus (2, 6, 17, 21, 22). Studies on the Yolo Bypass in California have found that detritivores, such as chironomid larvae, can be very abundant in floodplain habitats during flood events (3). After 6 weeks of inundation, zooplankton densities in rice fields in Yolo Bypass were documented at >150,000 individuals/m^3 of water, compared to approximately 50 /m^3 of water in the adjacent Sacramento River (5). The abundant floodplain food resources contribute significantly to the diets of juvenile salmonids accessing these off-channel habitats during flood events (3, 23), where they grow much more quickly than fish confined to adjacent leveed river channels (24, 10, 11).

While the need for restoring floodplains and the natural processes that occur with river-floodplain interactions is certain, there is considerable debate within the CV salmon restoration community on how best to fulfill that need. One key uncertainty is whether or not, and under what conditions, floodwaters should be slowed down by new or existing infrastructure. Slowing floodwaters to increase inundation time and maximize food productivity has clear benefits for juvenile salmon, but a berm or other infrastructure could add risks, particularly if fish migration is blocked or impeded (see bullets below). Both Fremont Landing and Bullock Bend floodplains were restored passively (no infrastructure) with reconnection designs that allow fish to enter and exit inundated habitat volitionally. There is broad support for continuing to develop and design those project types along the river.

A key consideration in any floodplain restoration habitat design is predicting the frequency and duration of water inundation. This can drive designed elevations of constructed habitat benches, sloughs, etc. Habitat design can also be integrated with water management decisions regarding reservoir operations. Water operators may create or extend natural pulses of water designed to allow fish to access these critical rearing habitats at key times, durations and locations (*e.g.*, there are extensive discussions regarding spring pulse flows in the San Joaquin and Sacramento rivers to assist juvenile salmonid rearing and outmigration).

Active Management of Floodplain Access and Inundation Duration with Gates, Berms, and Weirs

The "slow it down, spread it out, warm it up" approach for floodplain restoration includes active management with a downstream gate, weir, or berm in order to control water to maximize food web productivity, as demonstrated by the Knaggs Ranch experiments that examined plankton production and juvenile salmon growth on flooded rice fields (13). In that study, the mean growth rate of free-swimming hatchery planted fish (0.70 ± 0.01 mm/d) fell in between those recorded during natural flooding events on the Yolo Bypass in 1998 (0.80+/-0.06 mm/d) and 1999 (0.55+/-0.06 mm/d). Note: because the 1998 and 1999 studies relied on recapture of individuals downriver in the San Francisco Estuary at Chipps Island, the relative contribution to growth from floodplain and estuarine habitats is not known (24; 13). In at least one way, the active management approach likely mimics historical conditions in that floodwaters moved slower across the floodplain than they currently move through the flood bypasses. Existing bypasses have been designed and altered from their historical natural state to rapidly convey and drain water off land.

Despite this altered state, natural river-floodplain processes occur, plankton and invertebrate production increases, and juvenile salmon growth is enhanced when floodwaters overtop Fremont Weir allowing fish to access Yolo Bypass (24). Sommer et al. (24) showed that juvenile salmon released into the Yolo Bypass had significantly higher growth rates ($F = 20.67$, $p = 0.0007$) and attained significantly larger mean lengths ($F = 14.34$, $p = 0.0006$) than the Sacramento River release groups. This study indicates that under large, long-duration activation events, fish benefit without further controlling water with a weir or berm once they are on the bypass.

While juvenile salmon growth may increase by using downstream infrastructure to slow down water on floodplains, there are other potentially negative viability effects to consider, including increased risk of:

- Juvenile and adult stranding;
- Predation at structures;
- Disease susceptibility if spring air temperatures cause water temperatures to become too warm; and
- Unnatural emigration patterns leading to reduced life history diversity.

Potentially blocking or impeding juveniles from moving downstream with active floodplain management could reduce the temporal and spatial distribution of multiple populations, potentially decreasing the window of when juveniles enter the ocean. Homogenizing outmigration timing overall, and inhibiting separate cohorts of fish to vary independently with respect to juvenile rearing and outmigration weakens the portfolio effect, thereby reducing the likelihood for at least some juveniles to take advantage of ocean conditions when they are favorable (9). Conversely, if flow-through designs are effective in facilitating volitional passage, longer fish occupancy in a portfolio of off-channel habitats across the CV could be a primary driver of expanding the diversity of outmigration timing.

Recommended Considerations

Given the diversity of approaches and situations, NMFS proposes the following considerations to guide conversations and decisions related to CV floodplain restoration projects:

1. NMFS prefers passively managed floodplain restoration projects that allow volitional passage, are designed and linked to active water operations, and are based on the best available floodplain restoration science.
2. Designs should optimize inundation at a range of flow conditions that correlate to juvenile emigration timing.
3. Designs should avoid or minimize the potential for reduced adult fish passage, juvenile isolation and predation.
4. Innovative approaches that optimize infrastructure should be considered, particularly where landowners require ongoing seasonal agricultural operations to support restoration.
5. For active management proposals, effects need to be carefully evaluated and minimized through design considerations and monitoring (*e.g.*, stranding potential).
6. Effectiveness monitoring for floodplain restoration projects is especially important, allowing for adaptive management, should significant positive or negative effects occur.
7. An adaptive management program should be established that accomplishes the following: a) collectively defines floodplain habitat with specific measurable criteria, b) evaluates individual projects in a system-wide context, c) incorporates scientific peer review, d) links management actions and monitoring results to life cycle models and other decision support tools so the full potential benefits and risks of large-scale floodplain restoration can be modeled, e) prioritizes integrated studies to address key uncertainties, and f) identifies and implements adaptive management actions in response to program results.

Summary

Maximizing benefits to salmon viability that will come from restoring access to floodplains requires careful consideration to identify and minimize unintended risks. Research has demonstrated that juvenile salmon grow well in floodplain habitats (13) and outpace growth of salmon that stay in the Sacramento River, particularly in years with lengthy floodplain inundation periods (7). However, a restoration approach that adds water control infrastructure, or relies more heavily on it, introduces potential risks to fish. NMFS looks forward to working with our partners to collectively examine the benefits and risks of floodplain management approaches and site-specific project designs to restore salmon rearing habitat at a landscape scale.

Literature Cited

1. Ahearn, DS, Viers JH, Mount JF and Dahlgren RA. 2006. Priming the productivity pump: flood pulse driven trends in suspended algal biomass distribution across a restored floodplain. Freshwater Biology, 51: 1417-1433. https://doi.org/10.1111/j.1365-2427.2006.01580.x
2. Bastviken, D, J. Ejlertsson, I. Sundh, L. Tranvik. 2003. Methane as a source of carbon and energy for lake pelagic food webs. Ecology, 84(4):969-81.
3. Benigno GM and TR Sommer. 2008. Just add water: sources of chironomid drift in a large river floodplain. Hydrobiologia, 600(1):297-305.
4. Sacramento Valley Salmon Resiliency Strategy. 2017. California Natural Resources Agency. 16 pages
5. Corline NJ, TR Sommer, CA Jeffres, and J Katz. 2017. Zooplankton ecology and trophic resources for rearing native fish on an agricultural floodplain in the Yolo Bypass California, USA. Wetlands Ecology and Management, 25:533-545. doi: 10.1007/s11273-017-9534-2.
6. Deines P, PL Bodelier, G Eller. 2007. Methane-derived carbon flows through methane- oxidizing bacteria to higher trophic levels in aquatic systems. Environmental Microbiology, 9(5):1126-34.
7. Goertler, PAL, TR Sommer, WH Satterwaite, and BM Schreier. In press. Seasonal floodplain-tidal slough complex supports size variation for juvenile Chinook Salmon (*Oncorhynchus tshawytscha*), with implications for life history diversity. Ecology of Freshwater Fish. DOI: 10.1111/eff.12372.
8. Grosholz, E, and E Gallo. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. Hydrobiologia, 568: 91–109.
9. Herbold, B, SM Carlson, R Henery, RC Johnson, N Mantua, M McClure, PB Moyle, and TR Sommer. 2018. Managing for Salmon Resilience in California’s Variable and Changing Climate. San Francisco Estuary and Watershed Science, 16(2):23.
10. Jeffres CA, JJ Opperman, and PB Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes, 83(4):449-58. doi: 10.1007/s10641-008-9367-1. PubMed PMID: WOS:000261967500011.
11. Jeffres, C, EJ Holmes, TR Sommer, and JVE Katz. In review. Detrital Food Web Drives Aquatic Ecosystem Productivity in a Managed Floodplain. PLOS One.
12. Junk, WJ, PB Bayley, and RD Sparks. 1989. The flood pulse concept in river-floodplain systems, pp. 110-127, *in* DP Dodge [ed.]. Proceedings of the International Large River Symposium. Canadian Special Publication of Fisheries and Aquatic Sciences, 106.
13. Katz, JVE, C Jeffres, JL Conrad, TR Sommer, J Martinez, S Brumbaugh, N Corline, and PB Moyle. 2017. Floodplain farm fields provide novel rearing habitat for Chinook salmon. PLOS ONE, 12(6):e0177409. https://doi.org/10.1371/journal.pone.0177409.
14. Langhans, SD. 2006. Riverine floodplain heterogeneity as a controller of organic matter dynamics and terrestrial invertebrate distribution. Doctoral dissertation. Swiss Federal Institute of Technology Zurich.
15. Moyle, PB, W Bennett, J. Durand, W Fleenor, B Gray, E Hanak, J Lund, and J Mount. 2012. Where the Wild Things Aren’t: Making the Delta a Better Place for Native Species. San Francisco: Public Policy Institute of California. Available at www.ppic.org/main/publication.asp?i=1025.
16. Moyle, PB, RA Lusardi, PJ Samuel, and JVE Katz. 2017. State of the Salmonids: Status of California’s Emblematic Fishes. California Trout.
17. Murase, J and P Frenzel. 2007. A methane-driven microbial food web in a wetland rice soil. Environmental microbiology, 9(12):3025-34.
18. National Marine Fisheries Service. 2014. Final Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead. 427 pp. Sacramento, California.
19. Opperman, JJ, R Luster, BA McKenney, M Roberts and AW Meadows. 2010. Ecologically functional floodplains: connectivity, flow regime, and scale. Journal of American Water Research Association, 46: 211–226.
20. Opperman, JJ. 2012. A Conceptual Model for Floodplains in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science, 10(3). https://escholarship.org/uc/item/2kj52593
21. Palijan, G. 2012. Abundance and biomass responses of microbial food web components to hydrology and environmental gradients within a floodplain of the River Danube. Microbial Ecology, 64(1):39-53.
22. Sanseverino AM, D Bastviken, I Sundh, J Pickova, and A Enrich-Prast. 2012. Methane carbon supports aquatic food webs to the fish level. PLOS ONE, 7(8):e42723. Doi: 10.1371/journal.pone.0042723.
23. Sommer T, B Harrell, M Nobriga, R Brown, P Moyle, W Kimmerer, and LE Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries, 26(8):6-16. doi: 10.1577/1548- 8446(2001)026<0006:cyb>2.0.co;2. PubMed PMID: WOS:000170309000002.
24. Sommer, TR, ML Nobriga, WC Harrell, W Batham, and WJ Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: Evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences, 58(2):325-333.
25. Whipple A, T Grantham, G Desanker, L Hunt, A Merrill, B Hackenjos, and R Askevold. 2019. Chinook Salmon Habitat Quantification Tool: User Guide (Version 1.0). Prepared for American Rivers. Funded by the Natural Resources Conservation Service Conservation Innovation Grant (#69-3A75-17-40), Water Foundation and Environmental Defense Fund. A report of SFEI-ASC’s Resilient Landscapes Program, Publication #953. San Francisco Estuary Institute, Richmond, CA.
26. Williams, PB, E Andrews, JJ Opperman, S Bozkurt, and PB Moyle, 2009. Quantifying activated floodplains on a lowland regulated river: Its application to floodplain restoration in the Sacramento Valley. San Francisco Estuary and Watershed Science, 7(1). http://repositories.cdlib.org/jmie/sfews/vol7/iss1/art4, accessed February 20, 2010.
27. Yoshiyama, RM, FW Fisher, and PB Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management, 18:487-521