The Knaggs Ranch

Experimental Agricultural Floodplain Pilot Study 2011-2012

Year One Overview

A win, win, win for salmon, waterfowl and agriculture. **Photos: J. Katz**

A cooperative project of the

Center for Watershed Sciences at the
University of California, Davis
&
California Department of Water Resources

In cooperation with landowner partners

Cal Marsh and Farm Ventures, LLC
Knaggs Ranch, LLC

Supported by

CalTrout
U.S. Bureau of Reclamation
NOAA Southwest Fisheries Science Center

prepared by Jacob Katz
May 29, 2012

Introduction

Managed seasonally for native fish and waterfowl habitat as well as rice production and flood control, the Nigiri Project is the first stage towards a new multi-use management paradigm for the Yolo Bypass. Innovative use of existing agricultural infrastructure allows seasonal creation of floodplain habitat for endangered native fishes and waterfowl during winter and spring each year on fields that remain in agricultural production in summer and fall. Centered on the 1,700-acre Knaggs Ranch at the northern end of the Yolo Bypass, approximately 11 miles northwest of Sacramento, California, the Project proposes to incrementally develop a flood-neutral management approach for agriculture, fish, and waterfowl over thousands of acres in the Yolo Bypass.

Evaluating growth of juvenile Chinook salmon in flooded agricultural fields is a key component of the Nigiri project. Towards this objective, the Agricultural Floodplain Pilot Study was initiated in winter of 2011-2012 and is scheduled to expand over the coming years. Growth rates for juvenile salmon in Year One were among the highest recorded in freshwater Central Valley habitats (Kjelson 1982, Snider & Titus 2000, Sommer et al. 2001b, Jeffres et al. 2008). Additionally, fish body condition after 6 weeks of rearing in the experimental fields was similar to those observed for juvenile Chinook foraging in the food rich waters of the coastal ocean during summer (McFarlane et al. 2002). These results indicate that seasonal inundation of agricultural lands can provide excellent food-rich rearing habitat for Chinook salmon.

Background

The California Central Valley was once dominated by vast stretches of marshlands which flanked the Sacramento River and its tributaries, extending over hundreds of thousands of acres of the valley floor. During most winters, the valley's rivers could be counted upon to overflow their banks and spread out, creating a vast seasonal wetland. The large percentage of watershed area encompassed by floodplain was a defining character of the Central Valley. At the extreme southern limit of the distribution of Chinook salmon, the Central Valley might have been expected to be marginal habitat for the species. Instead the valley hosted one of the largest and most genetically and phenotypically diverse stocks of Chinook salmon on the Pacific coast (Yoshiyama et al. 1998). What unique quality of the Central Valley explains this surprising productivity?

Highly productive rearing habitats in both fresh and seawater are surely part of the explanation. Historically, winter and spring floodwaters washed young salmon, only a few inches long, out of the river channels and onto the floodplains. Sheltered from the current of the main river and supplied with abundant food resources, these “off-channel” habitats provided environmental conditions that were optimal for growth. Substantial scientific evidence for many species of salmonids (e.g., Atlantic salmon, steelhead, Chinook) indicates that the size of fish at ocean entry is an important, if not the primary, indicator of an individual’s probability of returning to spawn (Unwin 1997, Hayes et al. 2008, Satterthwaite et al. 2012). Floodplain habitats allow juvenile salmon to grow large and strong during the winter and early spring months before temperatures on the floodplain become too warm. Young salmon which remain in the main channel of rivers grow at a slower rate (Jeffres et al. 2008, Limm & Marchetti 2009). As a result, young salmon that rear in off-channel habitats tend to be larger and in better condition when they head out to sea than are fish confined to the river channel.

While the detrimental effects of dams on salmon have long been obvious, Californians are just beginning to understand how levee systems have also fundamentally altered salmon habitat in the Central Valley. The relationship between salmon and valley floor marshes has long been misunderstood, with the State’s focus having long been placed on the stranding of a minority of juvenile Chinook on floodplains instead of the benefit provided to the majority (Scofield 1903). This popular misconception, that salmon belong in rivers and that rivers belong in their banks, has persisted into the present day. The development of the Central Valley during the last century is largely a story of the drainage of the tule seasonal floodplains for agriculture. Today, only 5% of historic seasonal marshland remains and both the Delta and the valley floor are a patchwork of agricultural lands and communities protected from their rivers by high, steep levees which sever connectivity between Central Valley rivers and their adjacent wetlands. Consequently, most former marshlands only experience floodwaters in extraordinary flood years, and salmon are seldom able to access the ancestral rearing habitats which were once the engine of the Valley’s abundant salmon runs.

A chain is only as strong as its weakest link and winter floodplain habitat is today a vital (and missing) link between upstream gravel beds where salmon spawn and the ocean where they spend the majority of their lives. Accordingly, a high priority for the Bay Delta Conservation Plan and a Reasonable and Prudent Alternative of the National Marine Fisheries Service’s Biological Opinion on the Coordinated Long Term Operation of the Central Valley Project and State Water Project is the restoration of off-channel habitats. Yet substantial data gaps need to be filled in order to design and operate restoration plans, and to develop performance criteria for evaluation of floodplain restoration actions. The Agricultural Floodplain Pilot Study is designed to investigate the biological and physical parameters of fish habitat, as well as the relationships between habitat, growth, and survival. Such information is essential to the development of Bypass rearing habitat for Chinook at appropriate temporal and spatial scales. Preliminary results from the first year of study are reported below.

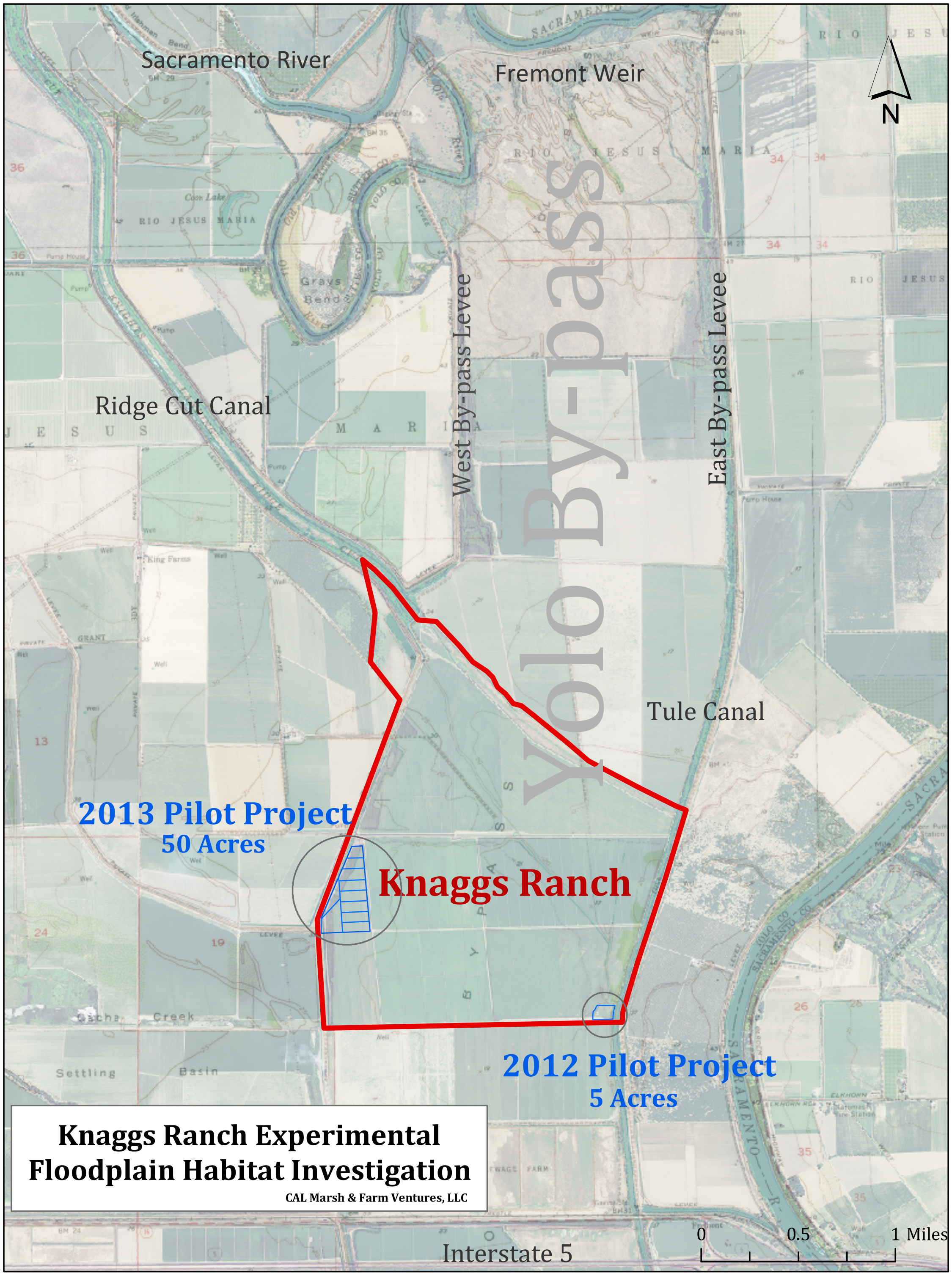


Figure 1. Location of the 17,000-acre Knaggs Ranch and Pilot Project field sites in the northernYolo Bypass, approximately 6 miles north west of Sacramento.

Methods

Study Location - Knaggs Ranch, Yolo Bypass

Located in Yolo and Solano Counties approximately five miles west the city of Sacramento, the Yolo Bypass functions to prevent flooding by relieving pressure from the Sacramento River at high flows. The entire area is covered by floodway easements held by the State of California making all other land uses subservient to flood control. The Bypass is the Delta's largest contiguous floodplain at 59,000 acres and provides critical fish and wildlife habitat (Sommer et al. 2001a). Flooding in two thirds of years on average, typically during winter and spring, the Yolo Bypass represents one of most frequent large-scale connections of river and floodplain left in the Central Valley. When flooded, the Bypass is a critical link for waterfowl migrating through the Pacific Flyway and supports more than 45 fish species—15 of which are native—including the Sacramento splittail and Chinook salmon (Sommer et al. 2001b).

A major land use in the Yolo Bypass is agriculture and rice is the primary crop. Additionally, wild rice, processing tomatoes, corn, safflower, melons, are grown and substantial areas are in irrigated pasture or kept fallow. Extensive areas within the Bypass are also managed for waterfowl habitat and hunting.

The Agricultural Floodplain Pilot Study is located on the Knaggs Ranch (Figure 1). The Knaggs property is an agricultural parcel with a total acreage of 1,703.55 acres. The site is near the top of the Yolo Bypass, north of Interstate 5. A drainage canal called the Knights Landing Ridge Cut enters the Knaggs property at its northwest corner. This canal was built early in the 20th century to connect the Colusa Basin Drain with the Yolo Basin, allowing accumulated floodwaters to flow into the Yolo Bypass while minimizing flooding of neighboring lands. Currently 1,571.6 acres of the ranch are under lease and farmed to rice, with an average yield of 88 sacks per acre. The rice is irrigated with water from the Colusa Basin Drain/Knights Landing Ridge Cut and supplemented with groundwater from on-site wells.

Chinook salmon

Juvenile Chinook salmon were reared in winter and early spring in a harvested 5-acre rice field. Approximately 10,000 juvenile fish, averaging 48 mm and 1.1 g, were planted into the field on January 31, 2012. All fish were procured from Oroville Hatchery on the Feather River, where their adipose fins were clipped and coded wire tags were inserted to identify them as a unique group. Fish were transported to the experimental site via tanker truck. Beach seine nets were used to recapture 50 fish subsamples on a weekly basis.

A sample of 299 fish was implanted with passive integrated transponder (PIT) tags at the field site, allowing us to track performance of individual fish. 139 PIT-tagged fish were released into the field, while the remaining 160 PIT-tagged fish were placed into eight 10-by-15-foot enclosures distributed throughout the field—20 fish per enclosure for a stocking density of 7.5 ft^2/fish (0.70 m^2/fish). Enclosures were made from 1/8 inch extruded plastic mesh and open to the sky. Two enclosures were placed over four different types of field substrate: newly ploughed soil (disked), rice stubble cut to an average of 2 inches (low stubble), rice stubble cut to a length of 14 inches (high stubble), and weedy herbaceous vegetation (fallow). The enclosures allowed researchers to reliably re-capture the same individuals in order to track and compare individual growth rates across different substrates. Parallel measurements of PIT tagged fish outside of the enclosures provided a comparison to ensure that enclosures did not stunt or otherwise substantially alter growth rates. Fish in the enclosures were recaptured using seine nets every two weeks for the six-week duration of the study. After 42 days the field was drained into the adjacent canal which connects to the Sacramento River. Fish were captured in a fyke net and counted as they exited the field. A subsample of 50 fish without PIT tags was measured for fork length while all PIT-tagged fish were weighed and measured.

Figure 2. Site preparation of the Agricultural Floodplain Pilot Study. Knaggs Ranch, January 2012 Photo: J. Katz

Results

PIT-tagged free-swimming fish

Upon termination of the 42-day experiment, the mean length and weight of free swimming PIT-tagged fish were 78.0 ± 0.5 mm and 5.74 ± 0.11 g (n = 50), respectively. These values translate to mean growth rates of 0.70 ± 0.01 mm/day and 0.11 ± 0.01 g/day. Fulton's condition factor, a ratio of length to weight used as an index of body condition, was determined to be 1.21 ± 0.01, indicating the fish were extremely robust. Condition factor did not vary significantly across the substrates ($P = 0.091$) or by pen ($P = 0.117$).

Penned fish

Mean length and weight of pen-reared fish at study's end were 75.5 mm ± 0.35 and 5.11 ± 0.07 g, respectively, translating to mean growth rates of 0.68 ± 0.01 mm/day and 0.10 ± 0.00 g/day (n = 107). Growth rates varied significantly across both pens (length, $P < 0.01$; weight, $P < 0.01$) and substrate treatment (length, $P < 0.01$; weight, $P < 0.01$). However, Tukey post hoc analysis revealed these effects to be driven by poor growth performance in two pens, one in low stubble and one in high stubble. Neither depth nor substrate seem to explain these observed variations in growth. Mean Fulton's condition factor was 1.18 ± 0.01 and was not significantly different across the substrates ($P = 0.09$) or by pen ($P = 0.12$).

The mean rate of body weight increase was significantly higher for free-swimming fish than for penned fish (FS = 5.74 ± 0.11 g/day, Pen = 5.11 ± 0.07; $P < 0.01$). This trend was also observed for mean rate of body length increase, but to a lesser degree (FS = 0.70 ± 0.01 mm/day, Pen = 0.68 ± 0.01 mm/d; $P < 0.05$). This presumed "pen effect" may have been due to differences in diet, density, or both. Analysis of gut contents from samples collected from both groups is ongoing.

<u>Survival</u>

We discovered a hole in the entry screen on March 3. In addition, on two occasions in late March perimeter levees partially failed due to wave action generated by high winds. Before these breaches were fixed a significant but unknown number of fish to escaped. Consequently, we were not able to derive estimates of mortality and survival during the study period. However, good recoveries of fish at the end of the study indicate that survival was likely excellent. Of the approximately 10,000 fish stocked into the study area, 5,835 (~58%) were recovered.

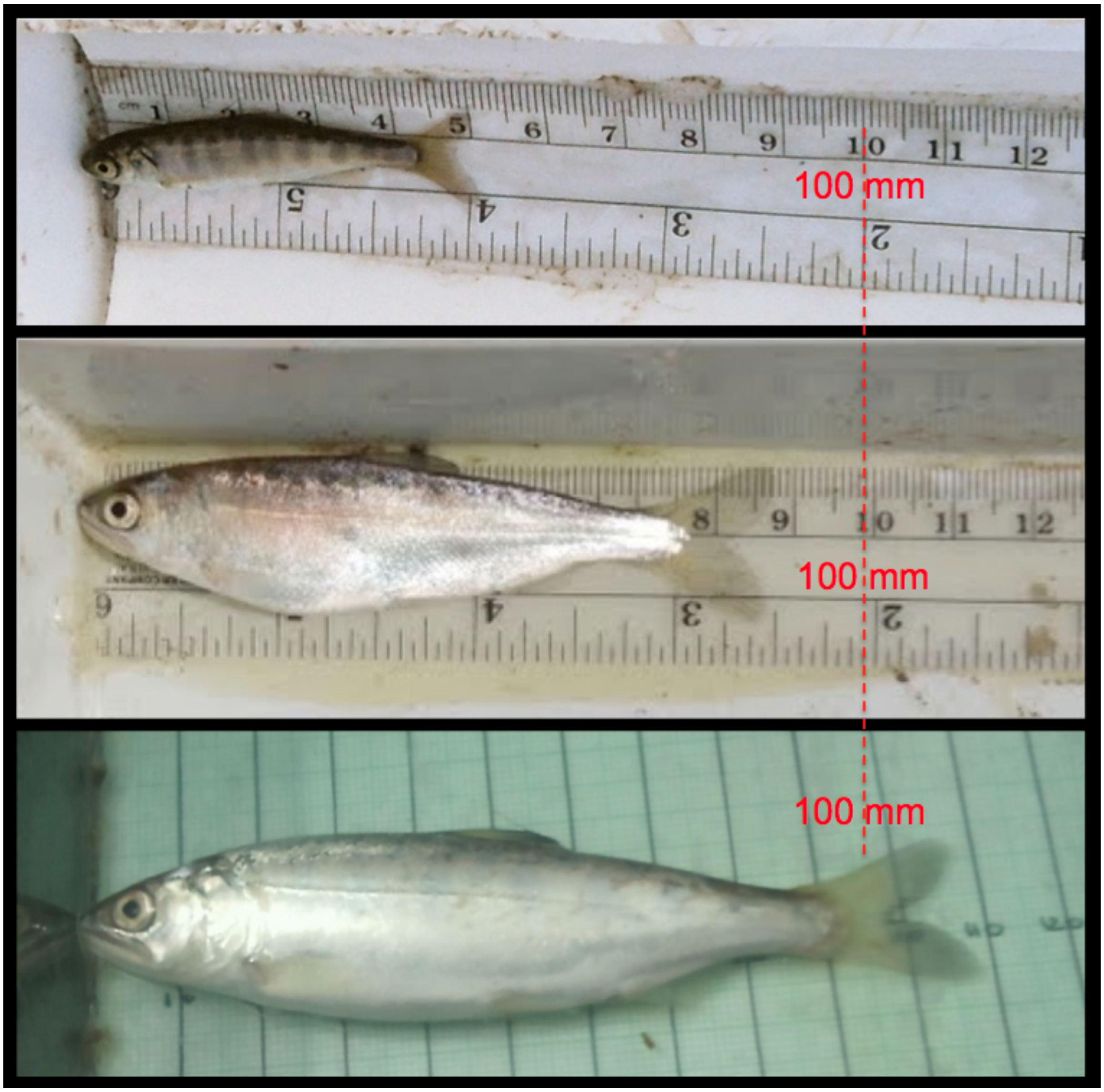


Figure 3. Juvenile Chinook salmon before (top), after (middle) rearing for six weeks on the Knaggs Ranch experimental agricultural floodplain on Yolo Bypass. The photos were taken on January 31 and March 12, 2012, respectively. Bottom picture is of a tagged Knaggs fish captured in the DWR rotary screw trap in the Yolo Bypass Toe Drain at Lisbon Weir, 16 miles downstream of the release site, April 13, 2012.

Photos: J. Brennan, J. Katz, N. Ikemiyagi

Discussion

The results of this study corroborate previous findings that rearing in off-channel habitat results in rapid growth for juvenile Chinook salmon (Sommer et al. 2001, Jeffres et al. 2008, Limm & Marchetti 2009). Past studies that examined growth in the Central Valley were conducted under "natural" flooding scenarios over a complex matrix of different habitat types. This study, in contrast, was conducted in a relatively homogenous post-harvest rice field. To put these observed growth rates in perspective, our penned juvenile Chinook grew substantially faster than those documented in a comparable study on another Central Valley floodplain. In that study, conducted during winter and early spring of 2004 and 2005 on the Cosumnes River floodplain, the fastest growth rates documented for penned juvenile Chinook were ~0.53 mm/d (C. Jeffres, unpublished data). The mean growth rate of free-swimming fish in our study falls in between those recorded during natural flooding events in 1998 (0.80+/-0.06 mm/d) and 1999 (0.55+/-0.06 mm/d) on the Yolo Bypass, although those studies relied on recapture in the Delta at Chipps Island, so the relative contribution of habitat in Yolo Bypass and the downstream Delta reach are not known (Sommer et al. 2001b).

<u>Timing, Size and Condition</u>

Timing, body condition and size at out-migration are directly affected by patterns of habitat use in freshwater. Lack of access to productive off-channel rearing habitats, for example, practically assures that naturally produced fish will out-migrate earlier and at smaller size than hatchery fish.

Floodplain rearing habitat is only available to juvenile Chinook during winter and spring when these seasonal habitats are inundated by flood events. Driven by flood pulses generated by storm events, the duration of connection between river channels and the floodplain is extremely variable. Often the pulse can be quite ephemeral: however, if river stage remains high for prolonged periods, floodplains may remain accessible and habitable well into spring. In such years the degradation of water quality parameters tends to initiate outmigration of native fishes before the floodplains drain (Moyle et al. 2007). Specifically, water temperature tends to exceed the thermal tolerances of Chinook by late April or May (Scolfield 1903, Sommer et al. 2001a) triggering exit from the floodplain.

Because occupancy of floodplains results in longer residency periods in fresh water (Sommer et al. 2001b), time of ocean entry is delayed for fish that gain access to off-channel habitats. This is particularly important in the Central Valley because the highly productive foraging conditions of the California Current in the Gulf of the Farallones are tied to seasonal upwelling of cold, nutrient-rich waters driven by spring and summer winds (Wilkerson et al. 2006). Timing of ocean entry is, therefore, critical to the survival of juvenile Central Valley Chinook salmon (Pearcy 1992, Lindley et al. 2009). If upwelling has begun and the food web it supports is well developed upon ocean entry, foraging conditions should be good, and growth and survival rates should be high. However, if upwelling has not started, poor feeding conditions may result in low growth or even in starvation. Weak upwelling events in April and May in the California Current have been correlated with low survival in CV fall-run Chinook (Lindley et al. 2009). The relatively high condition factor (increased fat reserves) of floodplain-reared smolts may also buffer against poor foraging conditions upon arrival in the marine environment, a hypothesis that we plan to test rigorously in coming years.

Monitoring data shows that nearly three-quarters of all out-migrant salmon from the Feather River in 1996 through 2007 were smaller than 50-mm fork length (DWR 2007), suggesting that majority of naturally produced fish are quite small upon leaving freshwater environments. Smaller individuals appear to be more vulnerable to predation and other causes of size-dependent mortality (Lindley et al. 2009). Entering the ocean at 60mm in February (naturally-produced fish) versus entering at 100+ mm in April (hatchery fish) could, therefore, be the difference between life and death.

The vast majority of naturally produced fish are confined to river channels, where food is relatively sparse and they must use limited energy reserves to fight the current. Hatchery fish, in contrast, grow large fed on pellets in hatchery runways. While migration timing varies across watersheds, the mean peak for naturally produced fish is usually between January and early March. In contrast, most Central Valley hatcheries release fish in April at a much larger size. Thus the hatchery paradigm itself is inadvertently standing in for off-channel habitat for these artificially reared fish, resulting in larger, fatter and later out-migrants when compared to natural fish. Unfortunately, naïve hatchery-reared fish are typically less fit for survival in the wild compared with naturally-produced fish (Berejikian et al. 1995, Araki, et al., 2008) and thus, despite being large and released in large numbers, hatchery fish are a poor surrogate for high-quality natural fish reared on productive floodplains.

<u>Route selection</u>
Rearing on the Yolo Bypass provides another benefit in that it routes fish away from pathways into the interior Delta where mortality rates increase significantly due to higher predation, poor water quality, and the possibility of entrainment in the large water export pumps (Perry et al. 2010). Fish from the bypass, on the other hand, enter Cache-Lindsay slough complex and then the mainstem Sacramento River, downstream of the major diversions into the central Delta.

Conclusions
The remarkable growth rates and condition of juvenile Chinook reared on the Knaggs experimental agricultural floodplain illustrate the potential for managing seasonally inundated habitat for Chinook salmon. Managed agricultural floodplain habitat appears to produce bio-energetically favorable rearing conditions, when compared to conditions in the Sacramento River. Our initial results provide strong evidence that juvenile Chinook permitted to access seasonally inundated floodplain on Yolo By-pass experience 1) more rapid growth, 2) substantially improved body condition, 3) delayed out-migration timing, and 4) a superior out-migration route. These floodplain benefits will results in higher quality out-migrants and likely improved rates of return. It is our conclusion that gaining access to floodplain rearing for millions of naturally produced fish is the first step in re-establishing self-sustaining stocks of Chinook salmon in the Central Valley.

Expansion of the Agricultural Floodplain Project: The 2012-2013 Field Season
With substantial support from the Bureau of Reclamation, the Knaggs Ranch Agricultural Floodplain Pilot Study will be expanded to multiple trials over approximately 50 acres, in the winter and spring of 2013. The University of California Davis, supported by interagency staff, will design and implement an experimental floodplain to test the effect of land use alternatives on the behavior, growth and survival of juvenile Chinook salmon. The experimental floodplain will consist of nine replicated 2-acre cells, each with one of three substrates: rice stubble, disked soil, or fallow herbaceous vegetation. An additional cell will contain all three substrates in order to rigorously assess habitat-use choices using radio frequency identification methods.

One of the contingencies of working in the Yolo Bypass is the threat a substantial flood event could affect the study. If it should flood we propose to use such an event as an opportunity to examine the benefits of extending the duration of a natural flood event using existing agricultural infrastructure. The tentative plan would be to extend the amount of time that one of the Knaggs fields remains inundated following the recession of the Sacramento River high flow event by augmenting flow with water from the

Knights Landing Ridge Cut delivered to the experimental flood pool via irrigation canal. Tagged hatchery fish may be stocked into the field to help evaluate the relative benefits of extending flooding.

The 2011-12 pilot inundation project used hatchery-origin fall run Chinook. In 2012-2013 we plan to supplement the project with modest numbers of natural-origin juvenile Chinook in order to assess the benefit of managed inundation to this target group. Approval and collaboration will also be needed from California Department of Fish and Game to use both natural-origin and hatchery fish. Our NOAA partners have already begun the permitting process. Assuming permits are secured, the tentative plan is that fish will be obtained from rotary screw trap operations on the Feather River operated by the California Department of Water Resources (DWR). Inundation will be experimentally manipulated at biologically appropriate durations and magnitudes in late winter and early spring.

Acknowledgements

An experiment conducted on this scale cannot be achieved without a large and cohesive team. Design and implementation of the pilot study were carried out by staff from UCD, Cal Marsh and Farm Ventures LLC (CMFV) and DWR including Ted Sommer, Louise Conrad, Steve Brumbaugh, Josh Martinez, Gina Benigno, Naoaki Ikemiyagi, Peter Moyle, Carson Jeffres, Nick Corline, Jason Emmons, and Craig Dietrich.

The project would never have gotten off the ground without Huey Johnson, Laney Thornton, John Brennan and David Katz of CMFV and Lance Matteoli of Knaggs Ranch, LLC. Curtis Knight, Jeff Thompson and Alan Roesberry of CalTrout, Joe Kiernan of NOAA and Josh Israel of BOR, Jason Roberts of DFG and Cathryn Lawrence of UCD provided logistical support and/or project guidance. Thanks to the Resource Renewal Institute for early support bringing this project idea into being.

Funding for Year One was provided by Cal Marsh and Farm Ventures LLC, Knaggs Ranch LLC, the Resources Legacy Fund, DWR, the Santa Clara Valley Water District and the Metropolitan Water District.

References

Araki, H., B.A. Berejikian, M.J. Ford, and M.S. Blouin. 2008. Fitness of hatchery-reared salmonids in the wild. Evolutionary Applications 1: 342-355.

Berejikian, B.A. 1995. The effects of hatchery and wild ancestry and experience on the relative ability of steelhead trout fry (Oncorhynchus mykiss) to avoid a benthic predator. Canadian Journal of Fisheries and Aquatic Sciences 52:2476-2482.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with passive integrated transponders in the Columbia River estuary: vulnerability of different salmonid species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385-396.

[DWR] California Department of Water Resources. 2007. Emigration of Juvenile Chinook Salmon (Oncorhynchus tshwytscha) in the Feather River, 2002-2004. 85 p.

Hayes, S.A., M.H. Bond, C.V. Hanson, E.V. Freund, J.J. Smith, E.C. Anderson, A.J. Ammann, and R.B. MacFarlane. 2008. Steelhead growth in a small central California watershed: upstream and estuarine rearing patterns. Transactions of the American Fisheries Society 137:114-128.

Jeffres, C.A., J.J. Opperman, and P.B. Moyle. 2008. Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83:449-458.

Katz, J., P.B. Moyle, R.M. Quiñones, J. Israel, and S. Purdy. 2012 Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes:1-18.

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1982. Life History of Fall-run Juvenile Chinook Salmon, Oncorhynchus Tshawytscha, in the Sacaramento-San Joaquin Estuary, California. Pages 393–411 Estuarine comparisons (V. S. Kennedy, ed.). Academic Press, New York, NY.

Kormos, B., Palmer-Zwahlen, M., and A. Low. 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. California Department of Fish and Game. Fisheries Branch Administrative Report 2012-02.

Limm, M.P., and M.P. Marchetti. 2009. Juvenile Chinook salmon (Oncorhynchus tshawytscha) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. Environmental Biology of Fishes 85(2): 141-151.

MacFarlane, R. and E. Norton. 2002. Physiological ecology of juvenile Chinook salmon (Oncorhynchus tshawytscha) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fishery Bulletin 100.

Moyle P.B., Crain P.K., Whitener, K. 2007. Patterns in the use of a restored California floodplain by native and alien fishes. San Francisco Estuary and Watershed Science 5 (3):1–27.

Pearcy, W.G. 1992. Ocean Ecology of North Pacific Salmonids. University of Washington, Seattle, WA.

Perry R.W., Skalski J., Brandes P., Sandstrom P., Klimley A., Ammann A., MacFarlane B. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30:142–156

Satterthwaite, W.H., S.A. Hayes, J.E. Merz, S.M. Sogard, D.M. Frechette & M. Mangel. 2012. State-Dependent Migration Timing and Use of Multiple Habitat Types in Anadromous Salmonids, Transactions of the American Fisheries Society 141:3, 781-794.

Scofield, N.B. 1913. A General Report On A Quinnat Salmon Investigation, Carried On During The Spring And Summer Of 1911. California Commission for Fish and Game Fish Bulletin 1:35-41.

Snider, B. and R.G. Titus. 2001. Lower American River Emigration Survey, October 1997- September 1998. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program, Technical Report No. 01-6.

Snider, B. and R.G. Titus. 2002. Lower American River Emigration Survey, October 1998- September 1999. California Department of Fish and Game, Environmental Services Division, Stream Evaluation Program, Technical Report No. 02-2.

Sommer, T.R., W.C. Harrell, M. Nobriga, R. Brown, P.B. Moyle, W.J. Kimmerer, and L. Schemel. 2001a. California's Yolo Bypass: evidence that flood control can be compatible with fish, wetlands, wildlife, and agriculture. Fisheries 26(8):6–16.

Sommer T.R., M.L. Nobriga, W.C. Harrell, W. Batham, W.J. Kimmerer. 2001b. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Unwin M.J. 1997. Fry-to-adult survival of natural and hatchery-produced Chinook salmon (Oncorhynchus tshawytscha) from a common origin. Canadian Journal of Fisheries and Aquatic Sciences 54:1246– 1254.

Wilkerson, F.P., A.M. Lassiter, R.C. Dugdale, A. Marchi, and V.E. Hogue. 2006. The phytoplankton bloom response to wind events and upwelled nutrients during the CoOP WEST study. Deep Sea Research Part II: Topical Studies in Oceanography 53:3023–3048.

Williamson, K., and B. May. 2005. Homogenization of fall-run Chinook salmon gene pools in the central valley of California, USA. North American Journal Fisheries Management 25:993–1009.

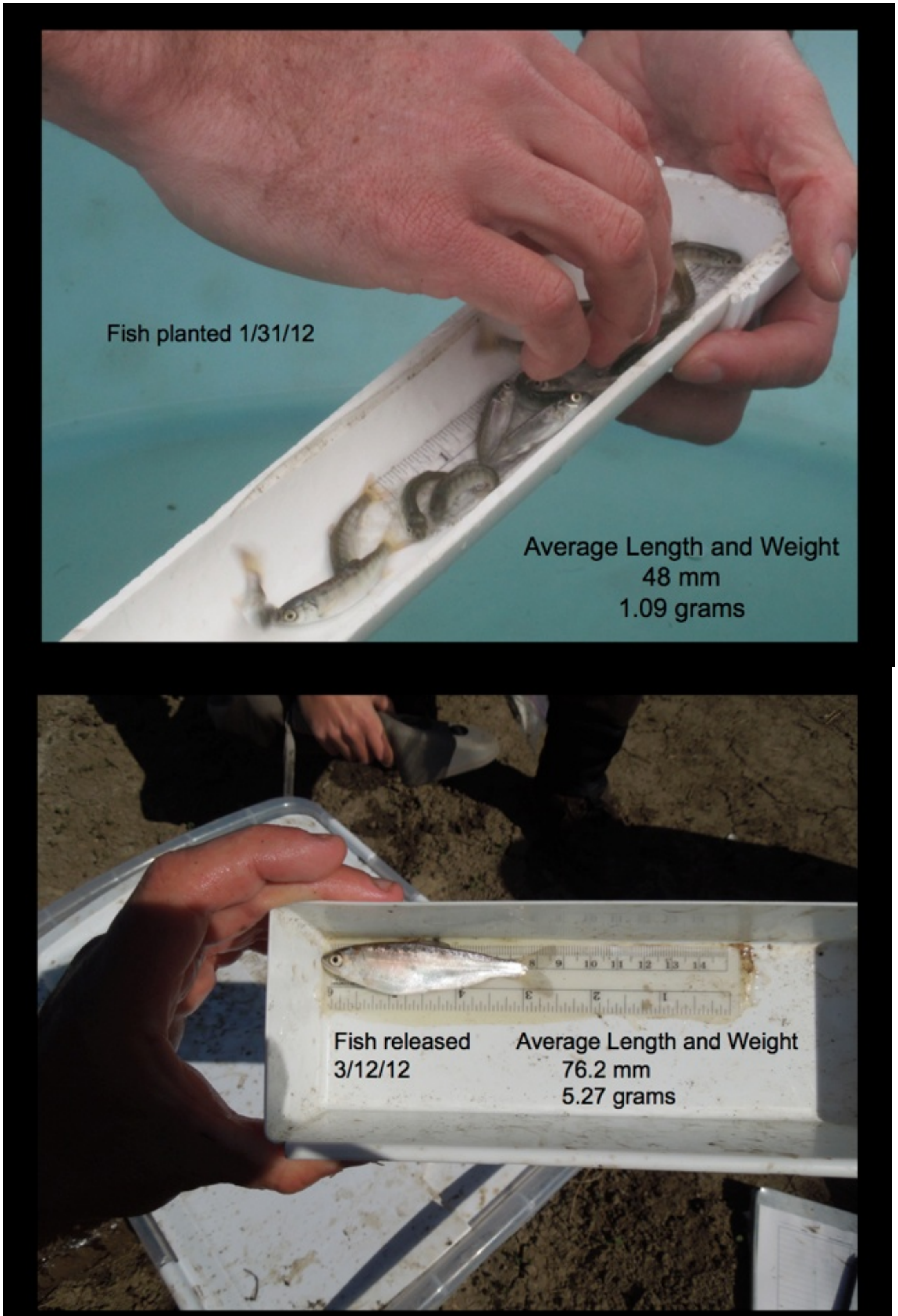
Yoshiyama, R.M., Moyle, P.B., Gerstung, E.R. and Fisher, F.W. 2000. Chinook Salmon in the California Central Valley: An Assessment. Fisheries 25:6-20.

Contact:

Jacob Katz
Center for Watershed Sciences
University of California
1 Shields Avenue
Davis, CA 95616

jvkatz@ucdavis.edu
office: (530) 752 0205
fax: (530) 752-4154
cell: (707) 477-9978

Handbill for the Knaggs Ranch Experimental Agricultural Floodplain



Juvenile Chinook salmon before (top) and after (bottom) rearing in the Knaggs Ranch experimental agricultural (rice) floodplain on Yolo Bypass for 6 weeks, January 31, to March 12, 2012. Contact: Jacob Katz, jvkatz@ucdavis.edu Photos: J. Katz