Supplemental Information [1]

Biological importance of habitat features included in our study

The following is a table of the physical Habitat Features included in the Chinook Smolt survival analysis and a description of their known biological importance to juvenile salmonids.

Habitat factor	Biological importance
Adjacent land use	Land use adjacent to riverine habitat impacts water conditions and habitat quality. Agriculture has been identified as a major factor affecting late fall run due to associated bank alteration and reductions of habitat for cover from predators (CDFW 2015). Further, Walser and Bart (1999) found that agriculture specifically increased sedimentation leading to decreased overall habitat complexity in a US river system and irrigation return water can impact habitat quality in the Sacramento River (US Army Corps of Engineers 1981)
Revetment	River erosion is a natural and ecologically beneficial process (Florsheim et al. 2008). Chinook salmon prefer natural bank types to riprapped ones (Garland et al. 2002, Jackson 1992). In the lower Sacramento, over half of all banks are riprapped, leading to severe degradation of habitat for aquatic organisms at both the site and reach level (US Fish and Wildlife Service 2004). Impacts include sedimentation, changes in food-web production and a reduction of large-woody debris (Schmetterling et al. 2001)- which juvenile salmon depend on- by more than 67-90% (US Fish and Wildlife Service 2004). Further, channelization of streams can reduce: the amount of available cover, sinuosity, wetted area and woody bank cover (Chapman and Knudsen 1980), factors which may affect the ability of juvenile salmon to evade detection from predators. Finally, the rock riprap that now forms an extensive levee system cut off the Sacramento River from surrounding floodplain habitat, leading to the mass reduction of floodplain habitat (The Bay Institute 1998) *(see off-channel for importance of off-channel habitat)*. Further, the structure created by riprap may provide increased predator habitat, especially for large-mouth bass (Cyril Michel, personal communication)
Diversion Density	Diversions pose some level of threat to out-migrating smolts through direct entrainment (CDFW 2015, Cramer et al. 1992, Cramer and Demko 1993, Hanson 2001, Kimmerer 2008, McNabb et al. 2003, Mussen et al. 2012, ICF Jones & Stokes 2008, Vogel 2013)as well as indirectly by providing structure for salmonid predators (Sabal et al. 2016)
Off-channel habitat	Floodplain habitat in the Central Valley confers ideal growth conditions for juvenile Chinook utilizing these habitats (Jeffres et al. 2008). Increased growth in these habitats is likely a result of warmer temperatures and increased prey availability (Limm and Marchetti 2009, Sommer et al. 2001), which could result in increased survival. However the utility of permanently wetted areas, like the off-channel defined in our study may not exhibit these same benefits, especially during the brief stage of outmigration. Off-channel habitat may also provide refuge from larger piscivorous predators, but may expose fish to a greater threat from avian predators. Finally, off-channel areas are thought to provide such important habitat, that restoration of side-channel habitat may be an effective management action to enhance juvenile salmonids (Decker 2002, Morley et al. 2005).

[1] Supplemental information for the final report: "Chinook salmon smolt mortality zones and the influence of environmental factors on out-migration success in the Sacramento River Basin, April 2017."

SRA- Shaded riverine aquatic cover	Shaded riverine aquatic cover, those areas of natural bank abutted by woody riparian vegetation (Adam Henderson 2013), were severely reduced by the 1880s due to overharvesting of timber and modifications to banks (The Bay Institute 1998). However, for those areas that still maintain some level of SRA, they provide important salmonid habitat because: a. They provide shade- a type of cover for salmon b. Temperature effects- the cover provided by the SRA can moderate local temperatures c. SRA provides greater terrestrial energy sources into the system which eventually provides greater feeding opportunities for salmon (USFWS 1992)
Sinuosity	Sinuosity is a basin-scale indication of river modification. In the Sacramento River system, reaches of high sinuosity are typically indicative of less modified areas, compared to channelized reaches. For biological impacts, please see "revetment" above.
Tributaries	Depending on conditions and season, juvenile salmonids are believed to utilize tributaries of the Sacramento River as important rearing habitat (CDFW 1978, Harvey 1997). Non-natal, seasonal, tributaries provide juvenile salmonids with increased prey densities and warmer temperatures- leading to increased growth (Limm and Marchetti 2009) and likely survival and productivity (Murray and Rosenau 1989, Walther 2009). At least twenty six small tributaries on the Sacramento River are utilized as non-natal rearing habitat in the Sacramento River system (Maslin et al. 1998).

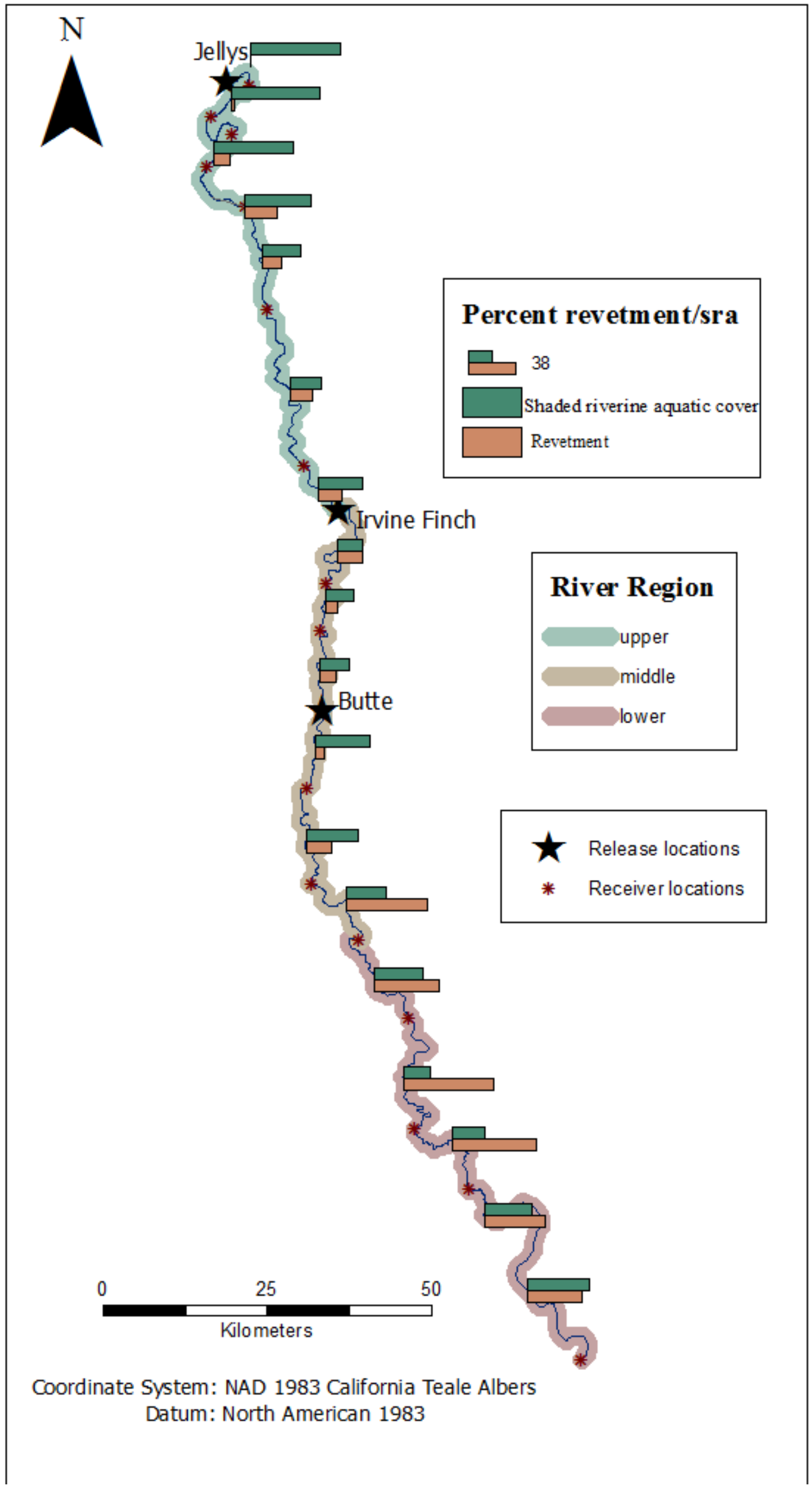
Spatio-temporal environmental factors

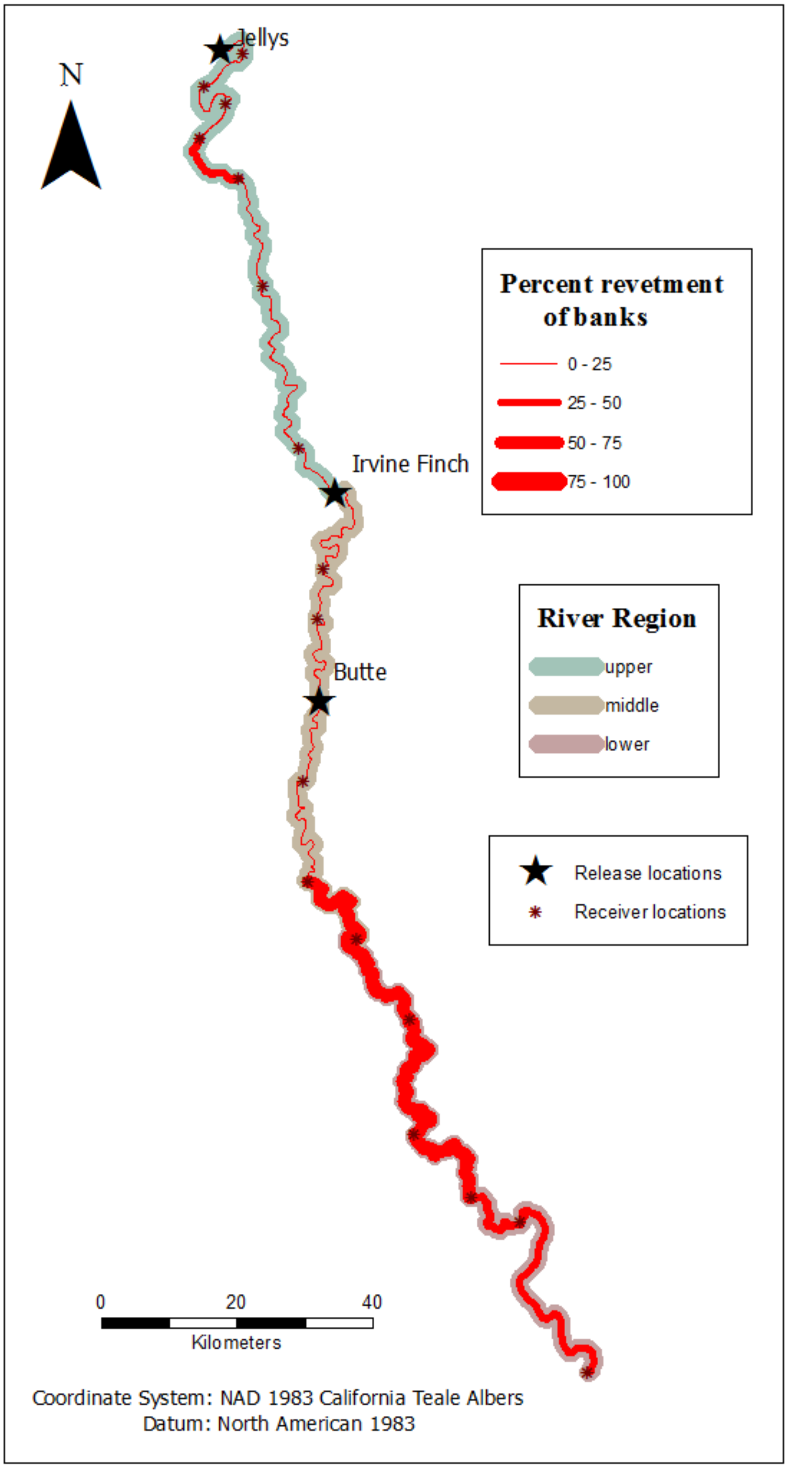
Variable	Biological Importance
Water Temp	Elevated temperatures increase physiological stress for out-migrating chinook in the Central Valley, leading to death at lethal levels of approximately 23.01 degrees C (Baker et al. 1995). Additionally, temperature may influence survival by reducing smolt evasion capacity while concurrently increasing predator bioenergetic needs (Lehman et al. 2017)
River Flow	Flow determines the amount of habitat available for juvenile salmon (USFWS 2005), as well as provides outmigration timing cues (Young et al. 2011). Flow has repeatedly been shown to be the most important factor effecting overall survival of Chinook in the Central Valley (Zeug et al. 2014, Kjelson and Brandes 1989, Michel et al. 2015), likely as a result of concurrent temperature, velocity and turbidity conditions which allow smolts to evade predation while staying within their physiological tolerances.
Water Velocity	Greater water velocity can stimulate faster out-migration rates for sub-yearling Chinook (in Snake River) (Tiffan et al. 2009), which may increase survivorship.
Depth	Depth can provide refugia for stream fishes against predation(Lonzarich and Quinn 1995) ** add nics paper here!!

Spatial analysis of habitat feature across the Sacramento mainstem

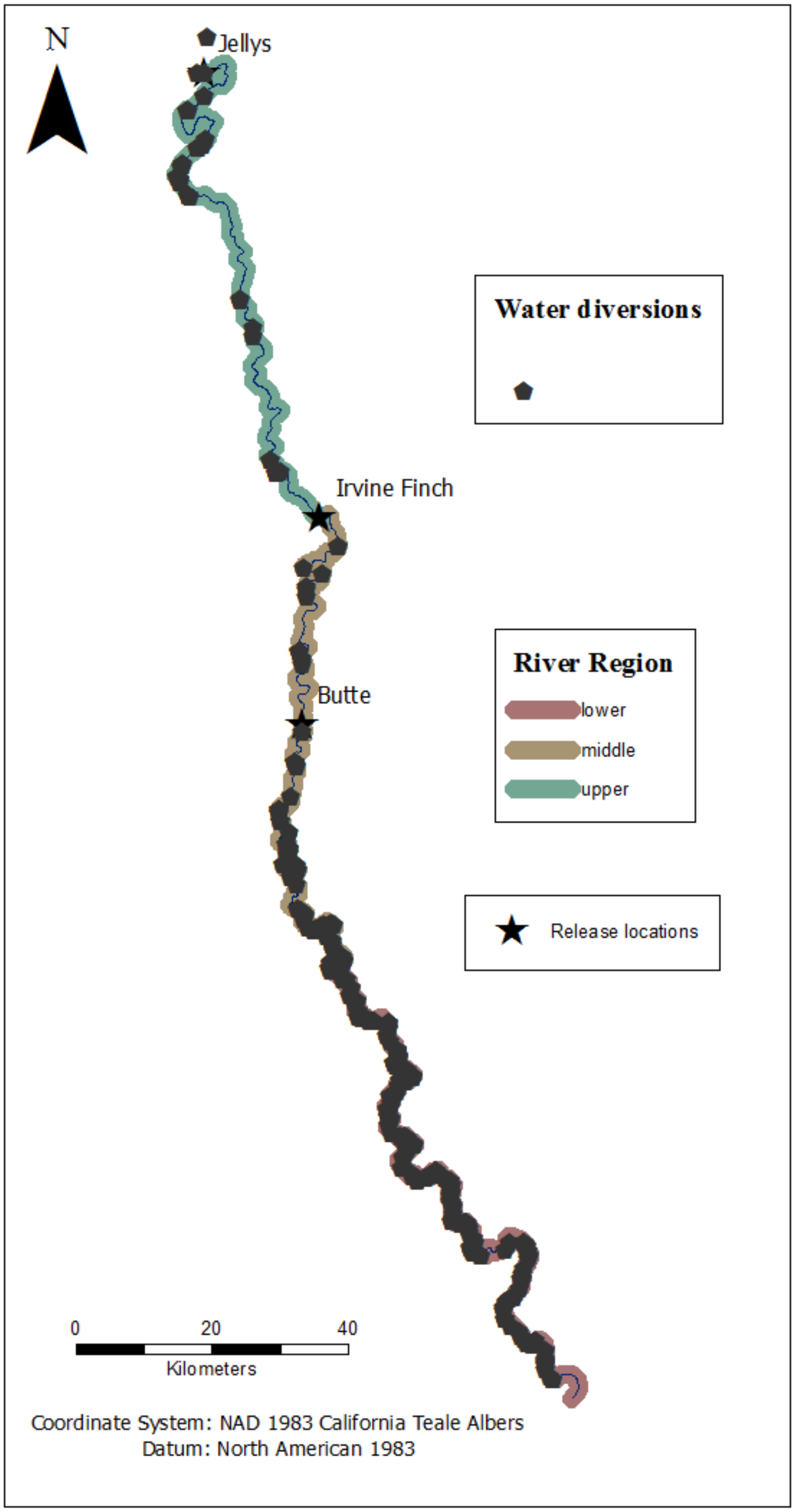
The following maps and figures aid in understanding the landscape level changes in available salmon habitat from the upper reaches of the Sacramento River to the end of our study area in Sacramento.

Map contrasting the percent of bank covered in shaded riverine aquatic cover (sra) and revetment (rip-rap) along the mainstem Sacramento River. Note the general trend of increasing rip-rap to the South, and the increase in sra to the Northern extent of our study area.





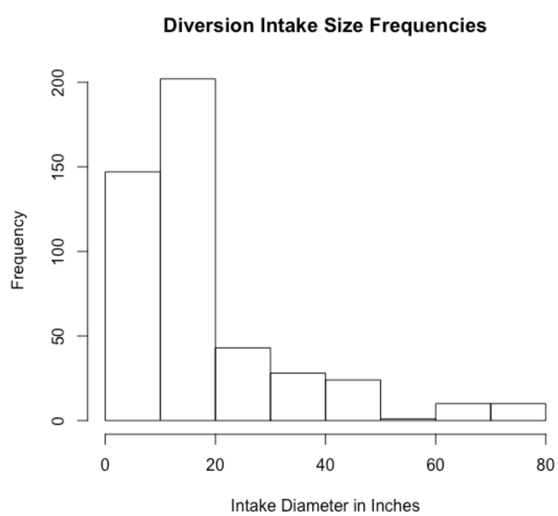
Map depicting the percent revetment for each of our study reaches. Note that the lower Sacramento River reaches are largely rip-rapped.



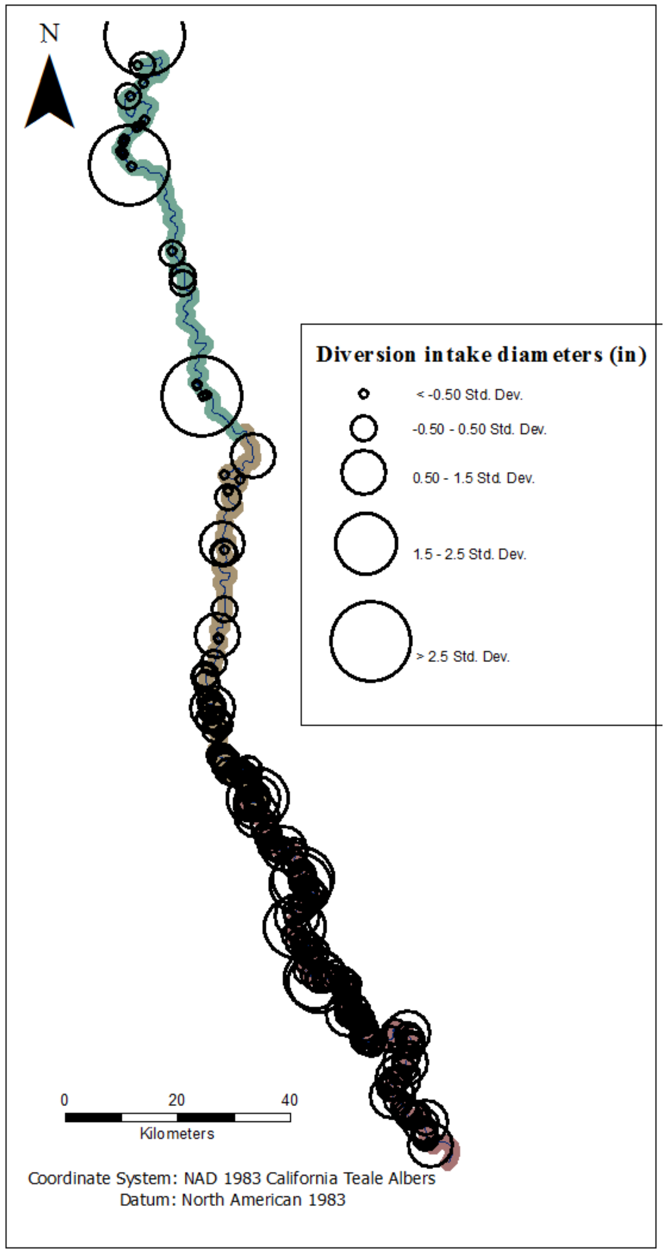
Map depicting individual water diversions along our study area. Note sections of river with large concentrations of diversions occurring consistently in the more southern reaches. Diverted water is typically utilized for agricultural and municipal purposes, so the greater density of diversions in the lower river regions is coincident to a larger human population and large-scale agriculture.

During our survey, we also recorded information about the intake size of individual diversions. We were interested in intake diameter as an index for pumping capacity. While our study only utilized the density information for diversions to examine what the role of this artificial structure had on outmigration survival- as predators are known to congregate around large artificial structures- the intake information is interesting spatially. Further, it is important to note that there was no reliable method for obtaining information regarding the quantity or timing of water pumping, and thus whether or not any of the diversions mapped posed a threat to out-migrating smolts during our study period.

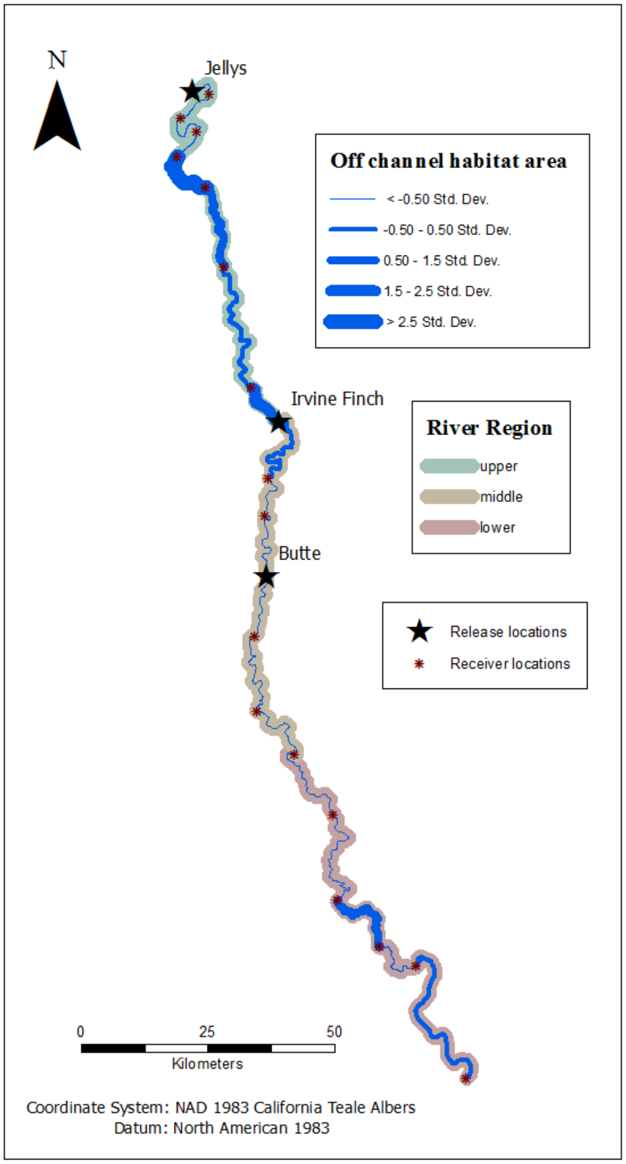
For all diversions surveyed during our field surveys of water diversions (from ACID diversion to the i80 bridge in Sacramento), we get the following intake size frequencies:



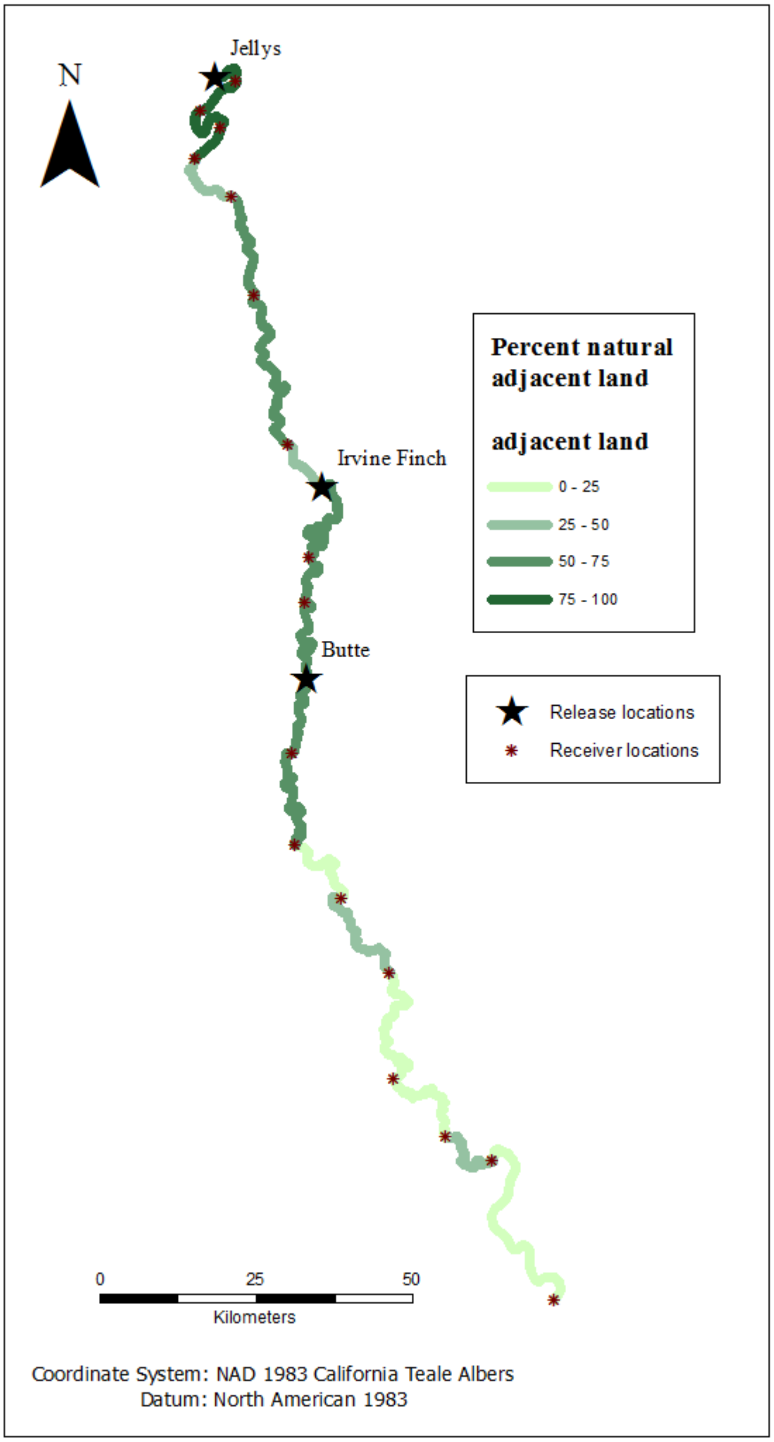
A histogram describing the frequencies of various intake diameter sizes for water diversions in the Sacramento mainstem. Note that the most frequent diversion intakes were under 20 inches**.**



This map depicts the location and size of diversions along the Sacramento River. Symbols are graduated by intake diameter size (inches), with larger circles representing diversions whose intake diameter is increasingly larger than the mean intake size. There is a much greater density of diversions in the middle and southern regions of the river compared to the upper. However, there are a couple large diversions which occur in the upper region of our study area. We were unable to determine during our survey whether or not individual diversions were screened or unscreened, so this map does not represent entrainment risk to outmigration smolts necessarily. Further, as stated before, data regarding the timing and volume of water pumping operations is not currently available, so it is unclear whether an individual diversion was operating during hatchery late-fall run outmigration.



This map describes the off channel habitat area, standardized by reach, for our study area. Off-channel area is defined in our study as those water bodies defined by the DWR land use survey (http://www.water.ca.gov/landwateruse/lusrvymain.cfm) within 50 meters of the Sacramento River. This method of defining "off-channel" areas was not without limitation. Specifically, we did not physical visit these sites and determine whether they were indeed accessible to outmigrating smolts. Additionally, off-channel water areas are significantly influenced by flow, and we did not take flow into account when determining these static features. That said, off-channel habitat may provide important refugia for out-migrating smolts, although this was not explicitly examined in this study. In the map above, off-channel area per reach is displayed across our study area. While there does not appear to be any trend among river regions, there is great spatial variability in the availability of off-channel habitat across our study extent.



The map above describes the percent "natural" bank per reach. Adjacent land was defined as land within 120 meters of the Sacramento River. Land use was determined by the National Land Cover Database https://www.mrlc.gov/nlcd2011.php. "Natural" was defined for our purposes and land use that was not “developed” or “agricultural.” The over-all trend in adjacent land use that is considered “natural” is a decline in this type of land as you move South across our study area, replaced by increasingly more developed, altered habitats in the Southern reaches.

References- Supplemental Information

CDFW (2015) Central Valley late fall-run chinook salmon *FSSC Account.*, California Department of Fish and Wildlife.

Walser, C.A. and Bart, H.L. (1999) Influence of agriculture on in-stream habitat and fish community structure in Piedmont watershed of the Chattahoochee River system. Ecology of Freshwater Fish 8, 237-246.

US Army Corps of Engineers (1981) Sacramento River and tributaries bank protection and erosion control investigation California, US Army Corps of Engineers.

Florsheim, J.L., Mount, J.F. and Chin, A. (2008) Bank erosion as a desirable attribute of rivers. BioScience 58(6), 519-529.

Garland, R.D., Tiffan, K.F., Rondoft, D.W. and Clark, L.O. (2002) Comparison of subyearling fall chinook salmon’s use of riprap revetments and unaltered habitats in Lake Wallula of the Colombia River. North American Journal of Fisheries Management 22, 1283-1289.

Jackson, T.A. (1992) Microhabitat utilization by juvenile chinook salmon *(Oncorhynchus tshawtscha)* in relation to stream discharges in the lower American River of California, Oregon State University.

US Fish and Wildlife Service (2004) Impacts of riprapping to aquatic organisms and river functioning, lower Sacramento River, California, US Fish and Wildlife Service.

Schmetterling, D.A., Clancy, C.G. and Brandt, T.M. (2001) Effects of Riprap Bank Reinforcement on Stream Salmonids in the Western United States. Fisheries 26(7), 6-13.

Chapman, D.W. and Knudsen, E. (1980) Channelization and Livestock Impacts on Salmonid Habitat and Biomass in Western Washington. Transactions of the American Fisheries Society 109(4), 357-363.

The Bay Institute (1998) From the Sierra to the sea: the ecological history of the San Francisco Bay-Delta watershed, The Bay Institute,.

Cramer, S.P., Demko, D., Fleming, C., Loera, T. and Neeley, D. (1992) Effects of pumping by Glenn-Colusa Irrigation District on juvenile chinook migrating down the Sacramento River, Submitted to: Glenn-Colusa Irrigation District.

Cramer, S.P. and Demko, D. (1993) Evaluation of juvenile Chinook entrainment at six unscreened water diversions along the Sacramento River by Reclamation District 108, Prepared for: Downey, Brand, Seymour & Rohwer Attorneys.

Hanson, C.H. (2001) Contributions to the Biology of Central Valley Salmonids. Brown, L.R. (ed), pp. 331-341, California Department of Fish and Game, Sacramento, California.

Kimmerer, W.J. (2008) Losses of Sacramento River chinook salmon and Delta Smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 6(2).

McNabb, C.D., Liston, C.R. and Borthwick, S.M. (2003) Passage of Juvenile Chinook Salmon and other Fish Species through Archimedes Lifts and a Hidrostal Pump at Red Bluff, California. Transactions of the American Fisheries Society 132(2), 326-334.

Mussen, T.D., Cocherell, D., Hockett, Z., Ercan, A., Bandeh, H., Kavvas, M.L., Cech, J.J. and Fangue, N.A. (2012) Assessing Juvenile Chinook Salmon Behavior and Entrainment Risk near Unscreened Water Diversions: Large Flume Simulations. Transactions of the American Fisheries Society 142(1), 130-142.

ICF Jones & Stokes (2008) Literature search and data analysis of fish loss at unscreened diversions in California’s Central Valley, Prepared for: US Fish and WIldlife Service.

Vogel, D. (2013) Evaluation of fish entrainment in 12 unscreened Sacramento River diversions, Prepared for: CVPIA Anadromous Fish Screen Program (US Fish and Wildlife Service and US Bureau of Reclamation) and Ecosystem Restoration Program (California Department of Fish and Wildlife, US Fish and Wildlife Service, and NOAA Fisheries).

Sabal, M., Hayes, S., Merz, J. and Setka, J. (2016) Habitat Alterations and a Nonnative Predator, the Striped Bass, Increase Native Chinook Salmon Mortality in the Central Valley, California. North American Journal of Fisheries Management 36(2), 309-320.

Jeffres, C.A., Opperman, J.J. and Moyle, P.B. (2008) Ephemeral floodplain habitats provide best growth conditions for juvenile Chinook salmon in a California river. Environmental Biology of Fishes 83(4), 449-458.
Limm, M.P. and Marchetti, M.P. (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.
Sommer, T.R., Nobriga, M.L., Harrell, W.C., Batham, W. and Kimmerer, W.J. (2001) Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58(2), 325-333.
Decker, A.S., Lightly, Marion J, Ladwig, Aleria A. (2002) The contribution of two constructed side-channels to coho salmon smolt production in the Englishman river, Canadian Technical Report of Fisheries and Aquatic Sciences.
Morley, S.A., Garcia, P.S., Bennett, T.R. and Roni, P. (2005) Juvenile salmonid (Oncorhynchusspp.) use of constructed and natural side channels in Pacific Northwest rivers. Canadian Journal of Fisheries and Aquatic Sciences 62(12), 2811-2821.
Adam Henderson, S.o.C., Department of Water Resources (2013) Habitats- existing conditions and tracking

Shaded Riverine Aquatic Cover (SRA).
USFWS (1992) Shaded riverine aquatic cover of the Sacramento River system: classification as resource category 1 under the FWS mitigation policy, US Department of the Interior.
CDFW (1978) A sprawning gravel survey of the Cottonwood Creek basin, Prepared under interagency agreement between the US Corps of Engineers and the California Department of Fish and Game.
Harvey, C. (1997) Historical review of anadromous fishereis in Deek Creek.
Murray, C.B. and Rosenau, M.L. (1989) Rearing of Juvenile Chinook Salmon in Nonnatal Tributaries of the Lower Fraser River, British Columbia. Transactions of the American Fisheries Society 118(3), 284-289.
Walther, R.C. (2009) Spatial and temporal ecology of fish larvae in seasonal and perennial tributaries of the Sacramento River, California, California State University, Chico.
Maslin, P.E., Lennox, M. and Kindopp, J. (1998) Intermittent streams as rearing habitat for Sacramento River Chinook Salmon *(Oncorhynchus tshawytscha)*, US Fish and Wildlife Service.
Baker, P.F., Speed, T.P. and Ligon, F.K. (1995) Estimating the influence of temperature on the survival of chinook salmon smolts(Oncorhynchus tshawytscha) migrating through the Sacramento- San Joaquin River Delta of California. Canadian Journal of Fisheries and Aquatic Sciences 52(4), 855-863.
Lehman, B., Huff, D.D., Hayes, S.A. and Lindley, S.T. (2017) Relationships between Chinook Salmon Swimming Performance and Water Quality in the San Joaquin River, California. Transactions of the American Fisheries Society 146(2), 349-358.
USFWS, S., Energy Planning and Instream Flow Branch (2005) Flow-habitat relationships for Chinook Salmon rearing in the Sacramento River between Keswick Dam and Battle Creek.
Young, P.S., Cech, J.J., Jr. and Thompson, L.C. (2011) Hydropower-related pulsed-flow impacts on stream fishes: a brief review, conceptual model, knowledge gaps, and research needs. Reviews in Fish Biology and Fisheries 21(4), 713-731.
Zeug, S.C., Sellheim, K., Watry, C., Wikert, J.D. and Merz, J. (2014) Response of juvenile Chinook salmon to managed flow: lessons learned from a population at the southern extent of their range in North America. Fisheries Management and Ecology 21(2), 155-168.
Kjelson, M.A. and Brandes, P.L. (1989) Proceedings of the National Workshop on the effects of habitat alteration on salmonid stocks. Levings, C.D., Holtby, L.B. and Henderson, M.A. (eds), pp. 100-115, Canadian Special Publication of Fisheries and Aquatic Sciences.
Michel, C.J., Ammann, A.J., Lindley, S.T., Sandstrom, P.T., Chapman, E.D., Thomas, M.J., Singer, G.P., Klimley, A.P. and MacFarlane, R.B. (2015) Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences 72(11), 1749-1759.
Tiffan, K.F., Kock, T.J., Haskell, C.A., Connor, W.P. and Steinhorst, R.K. (2009) Water Velocity, Turbulence, and Migration Rate of Subyearling Fall Chinook Salmon in the Free-Flowing and Impounded Snake River. Transactions of the American Fisheries Society 138(2), 373-384.
Lonzarich, D.G. and Quinn, T.P. (1995) Experimental evidence for the effect of depth and structure on the distribution, growth and survival of stream fishes. Canadian Journal of Fisheries and Aquatic Sciences 73, 2223-2230.