Spring-run Workshop Factsheet

Life history variation in Central Valley spring-run Chinook

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Population diversity has emerged as an important mechanism for resilience in changing environments (Hilborn et al. 2003). Biological diversity stabilizes ecosystem services (e.g. the portfolio effect). In salmon, the link between increased spatial variation in habitat use and decreased interannual variation in production is apparent for both juvenile (Thorson et al. 2014) and adult (Schindler et al. 2010) life stages. There are many indicators of life history diversity including genetic diversity (Gustafson et al. 2007), patterns in the timing of estuarine or ocean entry (Beechie et al. 2006), and fish size and occurrence (Miller et al. 2010, Sturrock et al. 2015). Further, these life history metrics can be linked to habitat and hydrology. For example, wetland restoration expanded juvenile life history variation by allowing greater expression of estuarine resident behaviors (Bottom et al. 2005). Sturrock et al. (2019) showed that the expression and successful return of juvenile migratory phenotypes to the Stanislaus River were correlated with hydrologic regime. Data collected in the Yolo Bypass (seasonal floodplain-tidal slough) revealed that habitats and hydrology which enhanced habitat complexity supported aspects of life history diversity for juvenile salmon (Goertler et al. 2017). Here we will be reviewing Central Valley spring-run Chinook salmon (*Oncorhynchus tshawytscha;* CVSC) life history diversity, with an emphasis on the juvenile life stage and relevant tools and emerging studies which advance the identification of life history variants.

CVSC historically comprised 19 independent populations (McElhany et al. 2000). Currently, four independent populations remain – Battle, Mill, Deer and Butte Creeks. CVSC were listed as state and federally threatened in 1999. Approximately 28% of their historic spawning and holding habitat remains accessible (Yoshiyama et al. 2001). CVSC were extirpated from tributaries in the San Joaquin River Basin, which represented a large portion of the historic range and abundance (Fisher 1994). The Battle Creek population was extirpated from its historical habitat and started repopulating in the 1990's (Johnson and Lindley 2016). The ESU also includes smaller dependent populations, that are unlikely to have persisted without immigration from other streams (e.g. they are sink populations or part of a metapopulation). Clear, Big Chico, Cottonwood, and Antelope Creeks and some San Joaquin River tributaries, have seen signs of spring-run repopulation (Johnson and Lindley 2016), likely opportunistic or consistent straying. The Feather River Hatchery population is also considered part of the ESU (Figure 1).

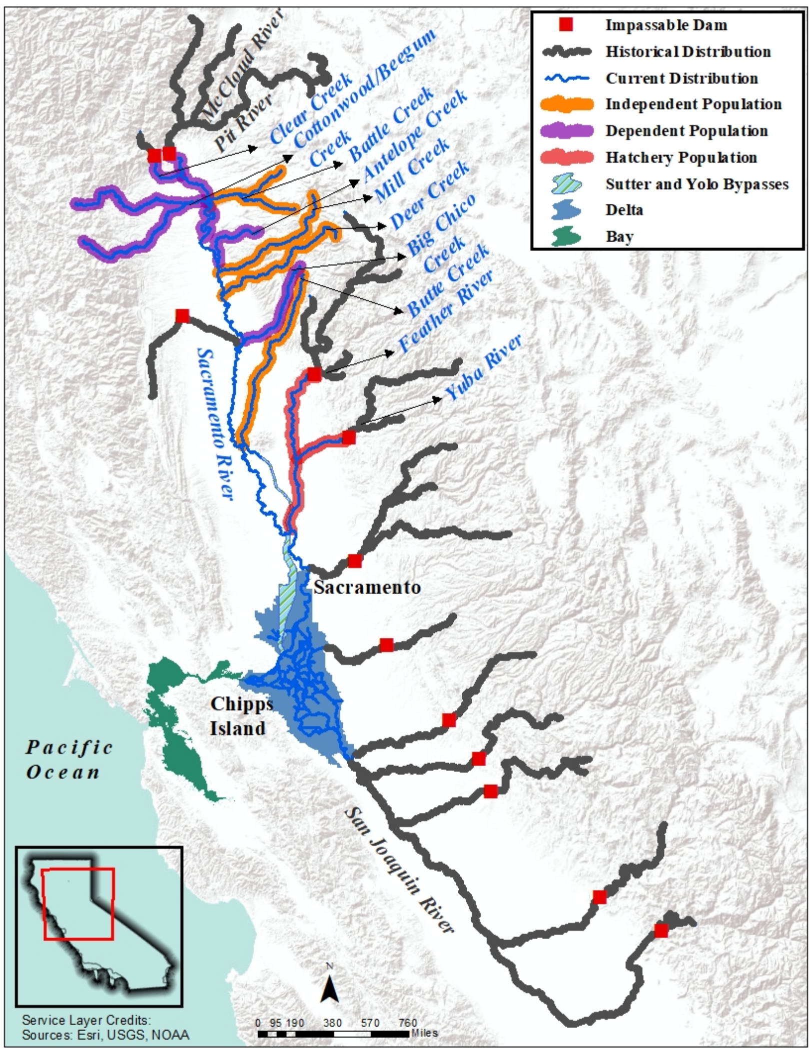

Figure 1: current CVSC populations and historical distribution.

CVSC adults migrate, hold or spawn in the Sacramento River basin from February through November. Fry emerge from November through April and juveniles rear year-round. Juvenile out-migration occurs in all but the warmest summer and early fall months (Table 1). Juvenile CVSC exhibit a range of life history variants (Figure 2). Juveniles may outmigrate as YOY (fry and subyearling) or yearlings and rear in the Sacramento River and its tributaries, Sutter and Yolo bypasses, and the San Francisco Estuary (Delta and bays). Juveniles spend from 3 to 15 months in freshwater before emigrating to the ocean (Cordoleani et al. In review).

Table 1: natural CVSC life history timing. Light grey boxes show the entire timing window for each life stage event, while the darker grey boxes show peak timing. YOY = young-of-the-year, corresponds to juveniles that migrate to the ocean within their first year. Yearling juveniles oversummer in freshwater before entering the ocean the following winter and spring (Cordoleani et al. In review).

Life Stage Event	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Adult spawning migration												
Adult holding												
Spawning												
Incubation												
Fry emergence												
Juvenile rearing												
YOY outmigration												
Yearling outmigration												

For the purposes of this workshop, participants will be asked to contribute to a discussion of how to incorporate the complex life history strategies of CVSC into the calculation of a Sacramento River juvenile production estimate. Within the context of portfolio effect induced buffering, the juvenile life history variant which contributes most to adult returns may vary by year or prevailing environmental conditions in the freshwater, estuary or ocean and may not be the dominate life history variant exiting the Sacramento River. Although complex, quantifying the contribution on disparate life histories on production is relevant to the recovery and management of CVSC.

Potential Questions for the Development of a Juvenile Production Estimate (JPE):

1. Can juvenile life history diversity be incorporated into the spring-run JPE?
2. What are key uncertainties in spring-run life history that are relevant to JPE development, and what tools are appropriate to address these uncertainties?
3. How can run identification tools better integrate multiple aspects of life history diversity or be more inclusive of a broad range of juvenile life history variants (Figure 2)? Can several identification tools be used in combination to address uncertainties when describing juvenile life history diversity?
4. There are multiple regulatory documents impacting spring-run (2019 NMFS BO, 2016 Feather River NMFS BO, 2020 ITP, and others). How will requirements of each regulatory document impact life history diversity and the potential need to reevaluate the JPE once restoration occurs?

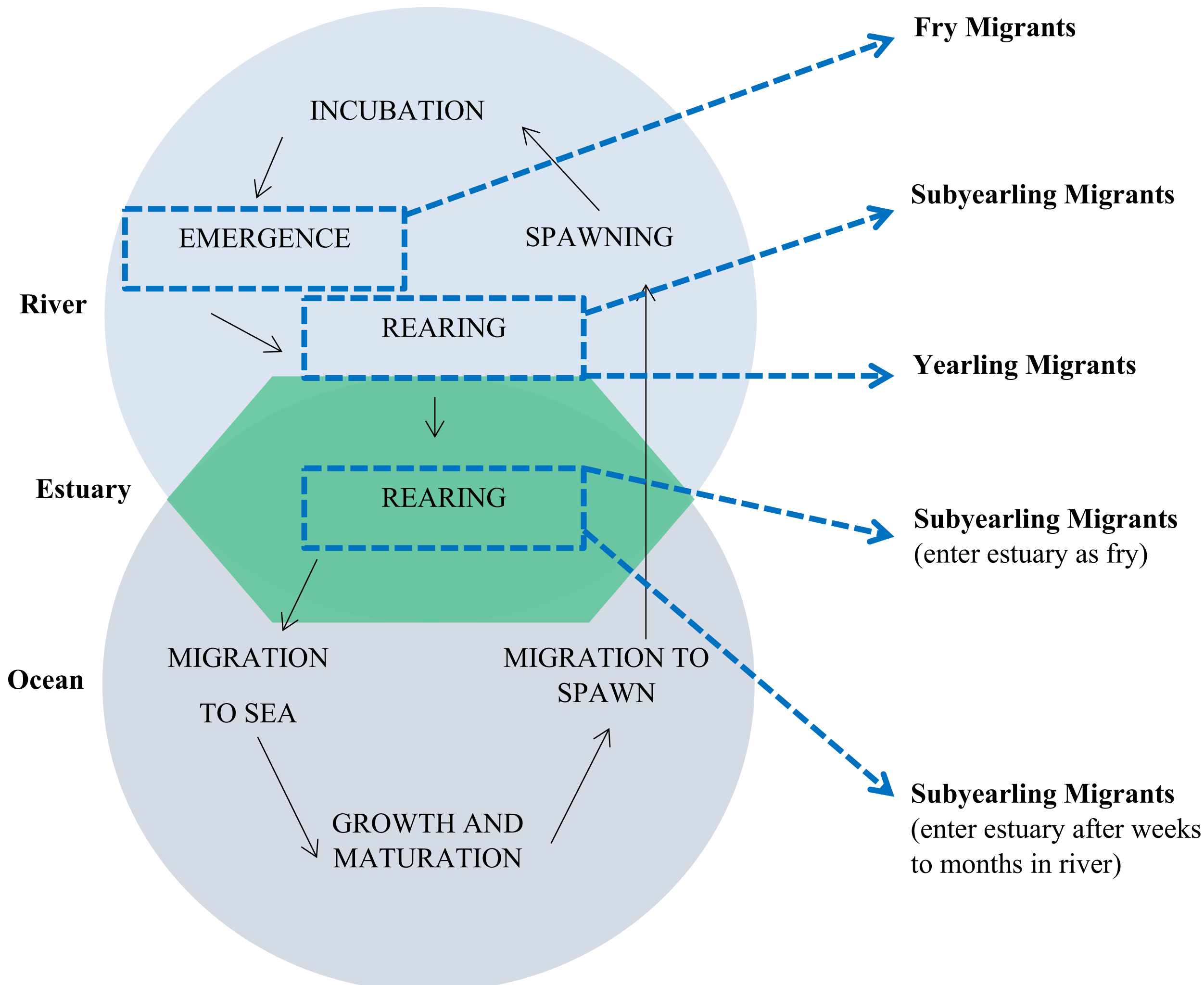

Figure 2: conceptual depiction of Central Valley Chinook salmon juvenile life history variation described by Williams 2006 & 2012. The entire salmon life cycle is represented, however, differences among the timing of juvenile phases (fluvial rearing, tidal rearing and migration to sea) are emphasized (adapted from IEP Technical Report 91 & Bottom et al. 2009).

Traditionally, juvenile life history diversity has been difficult to integrate into real-time salmon management. Commonly, juvenile spring-run life history diversity is described by the size and timing of juvenile Chinook salmon captured at rotary screw traps. For example, Figure 3 shows the length and capture day of juvenile Chinook salmon collected in the Butte Creek rotary screw trap between 1995 and 2004. In addition to variation in size and timing, trapping data can be used to describe presence in a location within the landscape and differentiate YOY from yearlings. However, juvenile Chinook captured in rotary screw traps are assumed to be migrating and run of origin is difficult to determine without genetic confirmation and complete fall-run hatchery marking (see “Identifying spring-run” factsheet for more information). Data from Figure 3 show a clear bimodal distribution in size of fish occupying Butte Creek, especially from Nov-March, and had been assumed to be yearlings and YOY progeny from Butte Creek spawners. However, work by Phillis et al. (2018), shows winter run juveniles use non-natal streams and tributaries as stop-over rearing habitat during outmigration, which brings into question the possibility of non-natal rearing for other runs and tributaries. Catch data alone does not fully describe the transitions used to define all life history variants present within the spring-run juvenile population (Figure 2). Catch data does not identify population of origin, confirm run identity of spring-run, describe residence time across habitats and life-stages, distinguish individual variation in migration behavior or estimate apparent or individual growth rates.

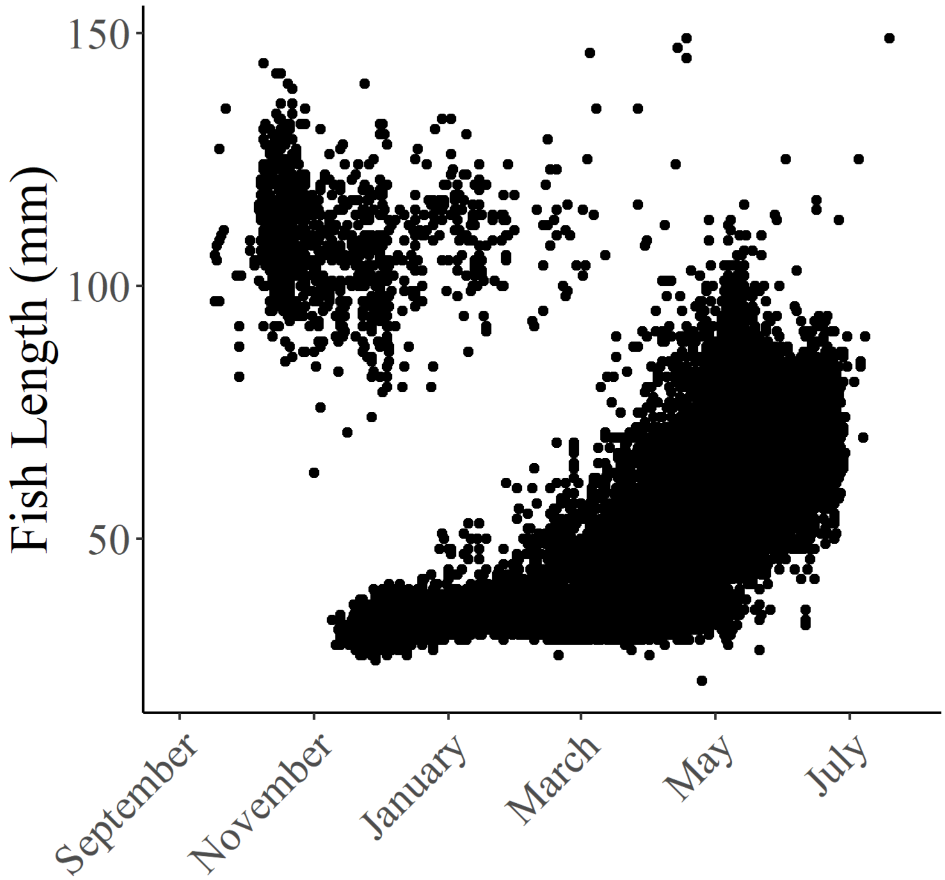

Figure 3: length and capture day of juvenile Chinook salmon collected in the Butte Creek rotary screw trap between 1995 and 2004.

Here we will discuss several monitoring advancements that provide these additional metrics of juvenile life history diversity in CVSC: otolith microchemistry, acoustic telemetry and coded wire tagging. We also provide examples, with CVSC data from studies currently in progress (Cordoleani et al. In prep, Goertler et al. In prep, Notch et al. In prep) in the effort to inform discussions on how these data could be integrated into proposed spring-run juvenile production estimates (JPE) that addresses life history variation. See "Monitoring of the Central Valley spring-run Chinook" factsheet Table 1 & 2 for more information on where and when these types of data are collected.

Otolith Isotopes

Otoliths are ear stones which lay down daily rings similar to rings on a tree and can be used to determine age, growth, stress and habitat use. The chemical analysis of otoliths recovered from adult CVSC enables an examination of the entire life history of successful spring-run returns. Strontium isotope ratios are an excellent geographic marker in the California Central Valley, because they vary across the watershed, and those variations are recorded in the layers of the otolith (Ingram and Weber 1999, Barnett-Johnson et al. 2008). Otolith strontium isotope analyses can thus be used to reconstruct movement and life-history patterns of individual salmon across habitats and life stages (Johnson et al. 2016, Phillis et al. 2018, Sturrock et al. 2019).

For example, the Figure 4 shows the results from a study of adult spring-run otoliths collected between 2003 and 2018 during annual snorkel (Deer Creek, N=59), redd (Mill Creek, N=60) and carcass (Butte Creek, N=286) surveys (Cordoleani et al. In prep). Specific 87Sr/86Sr threshold values, from a Central Valley isoscape database (Barnett-Johnson et al 2008, Sturrock et al. 2015, Phillis et al. 2018), were used to identify CVSC juvenile movements from one rearing location to another (i.e, natal tributary, Sacramento River, Sacramento-San Joaquin Delta). Cordoleani et al. In prep, observed that Mill and Deer Creek CVSC adult survivors exhibited three distinct life-history types during their juvenile rearing phase - identified as “early”, “intermediate” and “late” migrants. See Figure 4 of the size (A.) and time (B.) at which the individual CVSC adult survivors exited their natal tributaries as juveniles. Conversely, juvenile rearing and outmigration for Butte Creek CVSC adult survivors corresponded to a single intermediate migrant type. Early, intermediate, and late migrants correspond to the fry, subyearling and yearling migrants in the conceptual depiction of juvenile life history variation (Figure 2), respectively. Although rearing and migration strategies based on size and timing can be observed in trapping data, otolith microchemistry analysis provides additional information on the relative importance of each of these life history types in the adult population and illuminates directional selection effects. Further, variation in juvenile outmigration diversity between spring-run tributaries adds a layer of spatial complexity that may be linked to variation in environmental conditions across the landscape (Beechie et al. 2006).

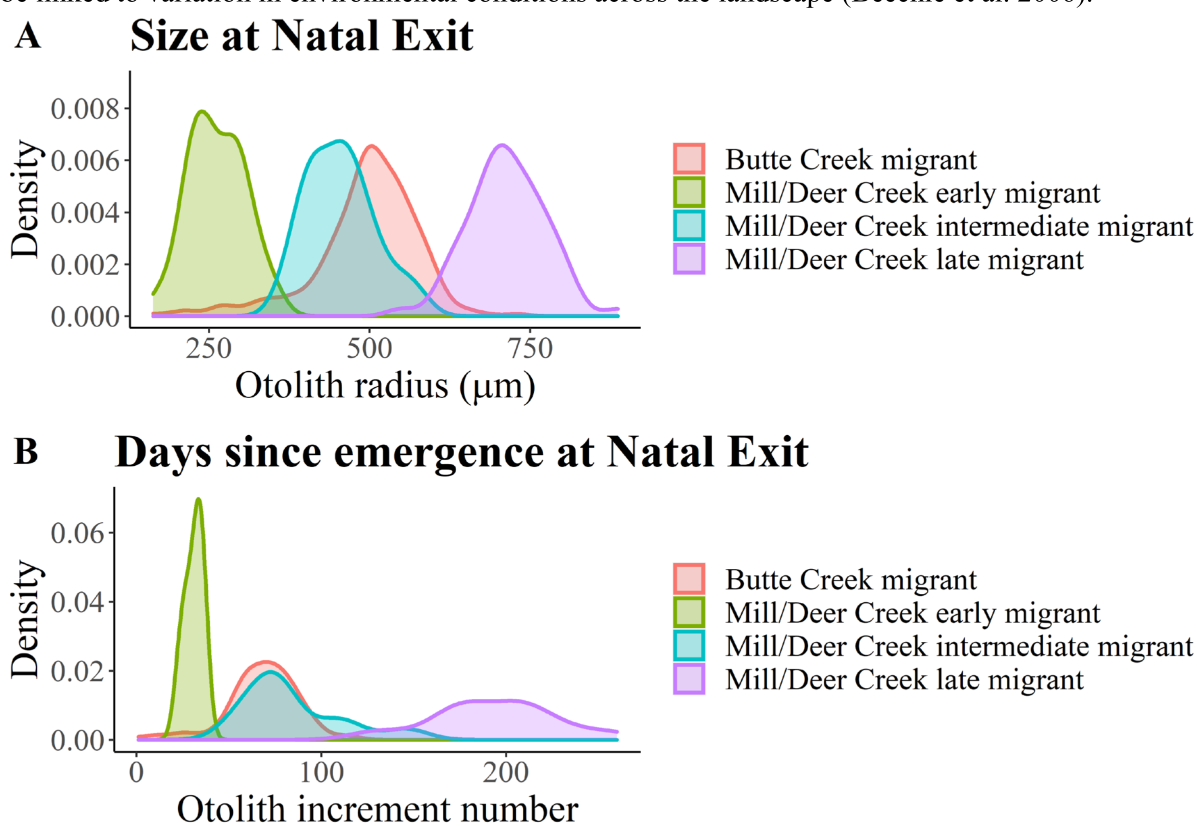

Figure 4: A. Otolith radius, which is a proxy for fish size, distributions at natal exit of fish from Butte, Mill and Deer Creeks. B. Otolith increment number, or days since emergence (a proxy for fish age), distributions at natal exit for fish from Butte, Mill and Deer Creeks. Color describes juvenile outmigranting strategies from Cordoleani et al. In prep.

Acoustic Telemetry

Another high-resolution tool to examine movement rates is acoustic telemetry, which uses miniature transmitters to track the timing, duration, and presence of individuals across landscapes. A synthesis of telemetry studies from the Central Valley has shown variation in migration timing and route, with some evidence for portfolio effect induced buffering (Goertler et al. In prep). Acoustically tagged individuals from Cordoleani et al. 2018, Notch et al. 2020, (wild Butte (n =194), Mill and Deer Creek (n=147)) and Singer et al. 2020 (Feather River Hatchery (n=750)) show the individual variation present within a single life history type (subyearling migrants which primarily rear in river, Figure 5). Across these studies migration began between April 7th (Feather River Hatchery) and April 17th (Mill Creek), and all fish detection histories end (presumably, completed their migration or perished) by June 2nd. Wild Butte Creek spring-run outmigrated to the San Francisco Estuary through the Sacramento River and its sloughs, while Feather River spring-run also outmigrated through the Central Delta (Goertler et al. In prep). Acoustic tagging studies generally target the largest sized individuals and juvenile CVSC in Figure 5 ranged from 73 to 135 and 78 to 106 millimeters in fork length, for wild and hatchery fish respectively.

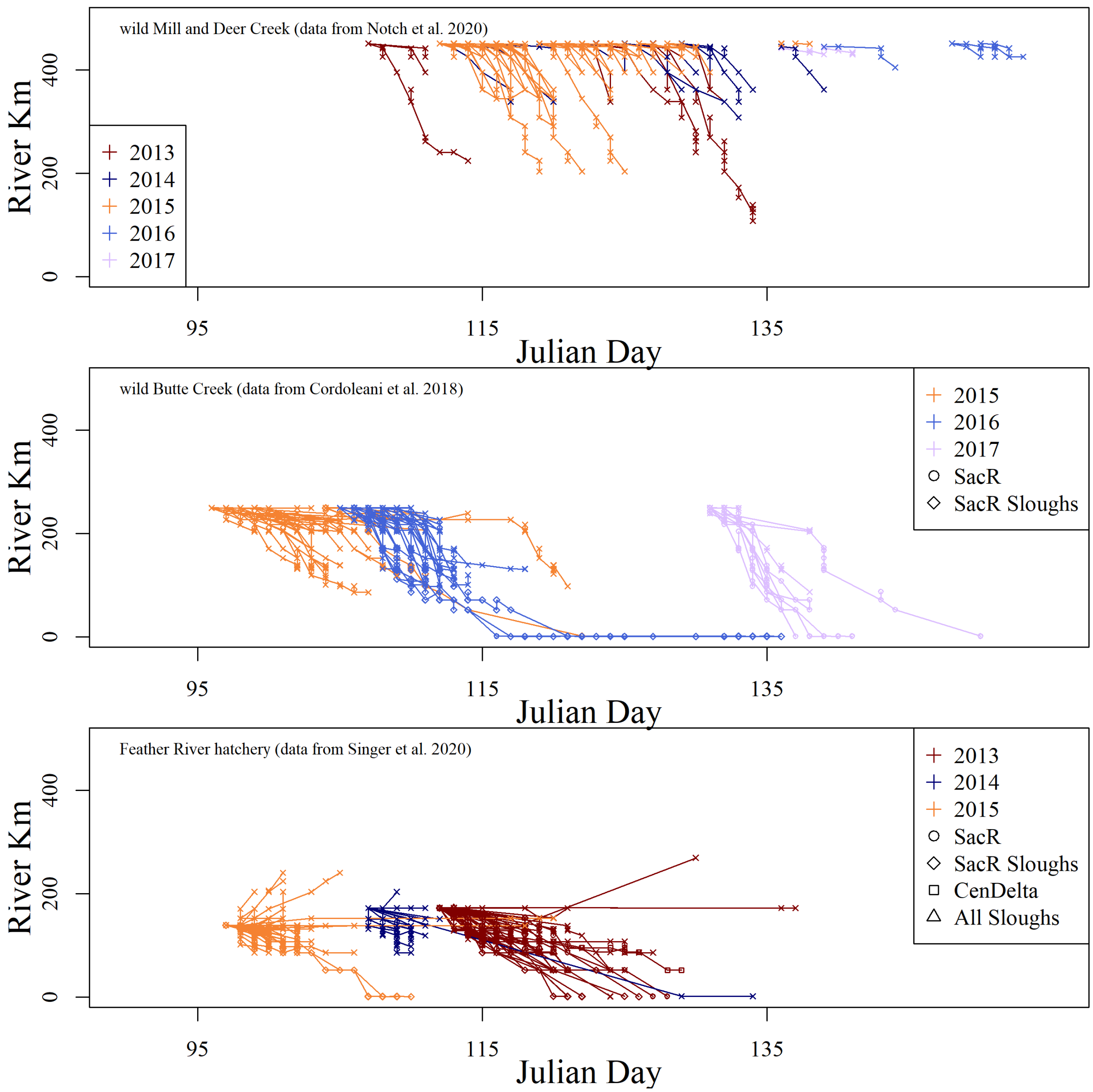

Figure 5: individual movement described by acoustic telemetry detections across space (river Km) and time (Julian day), year is color and routing is shape for those fish detected in the estuary (routing analysis: Goertler et al. In prep https://deltascience.shinyapps.io/CHNTelemetrySynth/). All fish have been genetically confirmed to be CVSC spring-run by the NOAA SWFSC genetics laboratory. Routes are Sacramento River (SacR) and its sloughs (SacR Sloughs), the Central Delta (CenDelta) and Sacramento River sloughs in combination with Central Delta sloughs (All Sloughs). If fish were not detected in the estuary the shape is x.

Coded Wire Tags

Coded wire tags (CWT) have been used to study the residence time, movement and survival of salmon for many decades (Nandor et al. 2010). Small fish can be tagged by hand or with an automated tagging trailer, and large sample sizes can be obtained as the cost of CWT's are relatively low. Another advantage of CWTs is their longevity, CWTs can be recovered from adult salmon to describe ocean distribution, reconstruct spawner age structure and evaluate the impacts of ocean harvest (Satterthwaite et al. 2018).

The California Department of Fish and Wildlife coded wire tagged juvenile Chinook salmon near the spawning grounds in Butte Creek and re-captured those individuals downstream in the Sutter Bypass from 1996 to 2008 (Ward et al. 2004). This study provided the first glimpse at two juvenile rearing strategies exhibited in lower Butte Creek and the Sutter Bypass – fish that migrate quickly through the Butte Creek watershed (11 days ± 5.6 days), and fish that rear for extended periods of time (72 days ± 13.5 days). Recaptured juveniles were more likely to rear (83%) than outmigrate quickly (17%), with rearing taking place upstream of the Sutter Bypass in the Butte Sink wetland area. In addition to residence time, apparent growth rates can be estimated with CWTs. Individual growth rates are not available because multiple individuals and, in some cases, multiple release groups across consecutive days are tagged with the same CWT number. In this study, apparent growth rates were estimated between 0.62mm/day for rearing fish, and 0.11mm/day for fry outmigrating quickly (Notch et al. In prep).

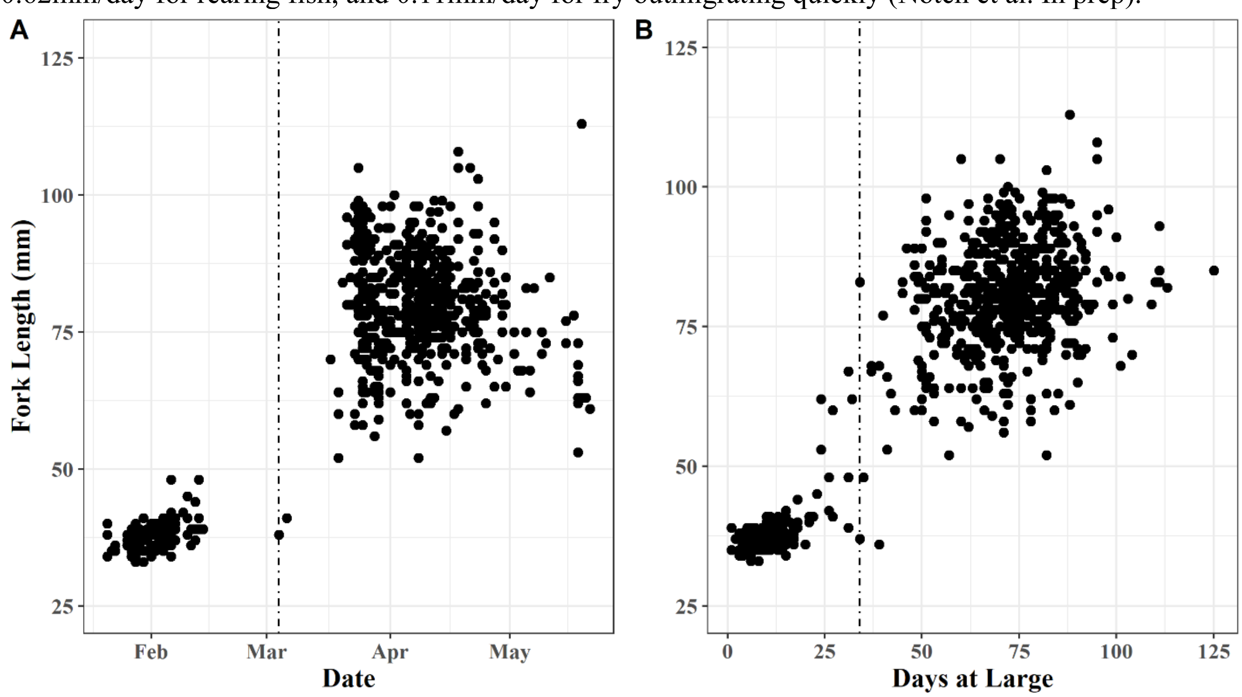

Figure 6: (A.) fork length (mm) at recapture date and (B.) fork length (mm) compared with "days at large" or residence time (days between release in the Butte Creek spawning grounds and recapture in Sutter Bypass) of coded wire tagged juvenile Chinook salmon. The dotted line delineates life history types (quick downstream migration or prolonged rearing).

This data shows that juvenile spring-run outmigrating from Butte Creek exhibit a similar rearing strategy, which can also be seen in the otolith isotope analysis in later years (Cordoleani et al. In prep). In combination with the acoustic telemetry result and catch data from the Butte Creek trap we can distinguish fry migrants from subyearling migrants that rear in Butte Creek and the Sutter Bypass as well as yearlings. The only life history variants that remain difficult to identify are subyearlings which rear in the lower rivers and estuary. This complexity is important for the maintenance of resilient salmon populations, yet further work is needed to understand the mechanisms that promote and support this diversity. Despite this progress in the quantification of different aspects of life history variation, there is a need to expand our toolbox, particularly with respect to the collection and integration of these types of data into our understanding of how management actions can function to support the role of life history diversity in recovering CVSC.

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