Estimating spawner-recruit relationships for Sacramento River Fall Chinook based on natural-area escapement and the Sacramento Index adjusted by proportion natural-origin escapement estimates

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NON PEER-REVIEWED DRAFT, FOR DISCUSSION PURPOSES ONLY

Interest has been expressed in fitting a spawner-recruit relationship for SRFC based on natural area spawners, with recruits measured as natural-origin pre-fishing ocean abundance derived from a cohort reconstruction.

However, cohort reconstructions for SRFC have not been completed. I wondered if as a crude proxy, we could estimate natural-origin recruits as the product of the Sacramento Index (SI, O'Farrell et al. 2013, an index of pre-fishing ocean abundance of the composite hatchery plus natural SRFC stock, with some limitations) and the fraction of SRFC escapement estimated to be of natural-origin in CDFW's annual coded-wire tag recovery reports (e.g., Letvin et al. 2021, as compiled in Satterthwaite 2023 and updated with the addition of Dean and Lindley 2023). We would assume that spawners from a particular year *y* produce recruits observed predominantly in the SI for year *y*+3.

This measure of recruitment has several limitations. Even for the composite stock, the SI omits natural mortality, maturation spread over multiple age classes, and most sources of non-landed fishing mortality; it also has limitations in its estimates of landed fishing mortality. This reduces its ability to reflect the production from a specific cohort, and introduces bias that can vary with the harvest rate (i.e. all else being equal, the SI will be higher for a cohort experiencing a high harvest rate, because some fish counted in the harvest might not have shown up in the escapement if left unharvested since they might have died of natural causes or not returned to spawn that year[1]).

On top of the limitations of the SI, the proportion of escapement that is natural-origin is difficult to estimate precisely and is generally low, such that small errors can be consequential proportionally. The composition of the escapement may not match the composition of the ocean harvest (e.g. if hatchery- versus natural-origin fish have different maturation schedules or vary in behaviors that expose them to fishing) and the assumption that recruitment occurs solely at age-3 (i.e., indexing recruitment as the SI 3 years after spawning) may be weaker for natural-origin fish. The SRFC escapement composition estimates are based on all age classes including jacks, and may differ from the composition of adults alone.

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[1] Conversely, however, a bias could be introduced in the opposite direction by the SI calculation not accounting for release or dropoff mortality that would tend to accompany retained catch. However the dropoff mortality rate is small compared to the assumed annual rate of natural mortality, and mortality associated with sublegal releases may be low in most sectors for age-3 and older SRFC due to high proportions of fish being legal-sized.

With these caveats in mind, I assembled natural-area adult SRFC escapement estimates, SI estimates, and estimates of the proportion of the escapement that was of natural origin for parent spawning years 2007-2015 and return years 2010-2018. 2007 was the first parent spawning year included because 2010 is the first year with an escapement composition estimate available for the corresponding return year. For the first set of analyses, 2015 is the last parent spawning year included because I wanted to be able to use a previously established flow covariate (Munsch et al. 2020) and data from the specific gage used for that paper is not available in the same format as before. This makes it difficult to extend that index to additional years that were not included in the original paper. Shifting to a different gage allows including spawning years 2016 and 2017 (see Addendum 2), but I cannot extend beyond that until new CWT recovery reports provide escapement composition estimates for return years after 2020[2]. The flow index is based on December of year *y* through May of year *y*+1.

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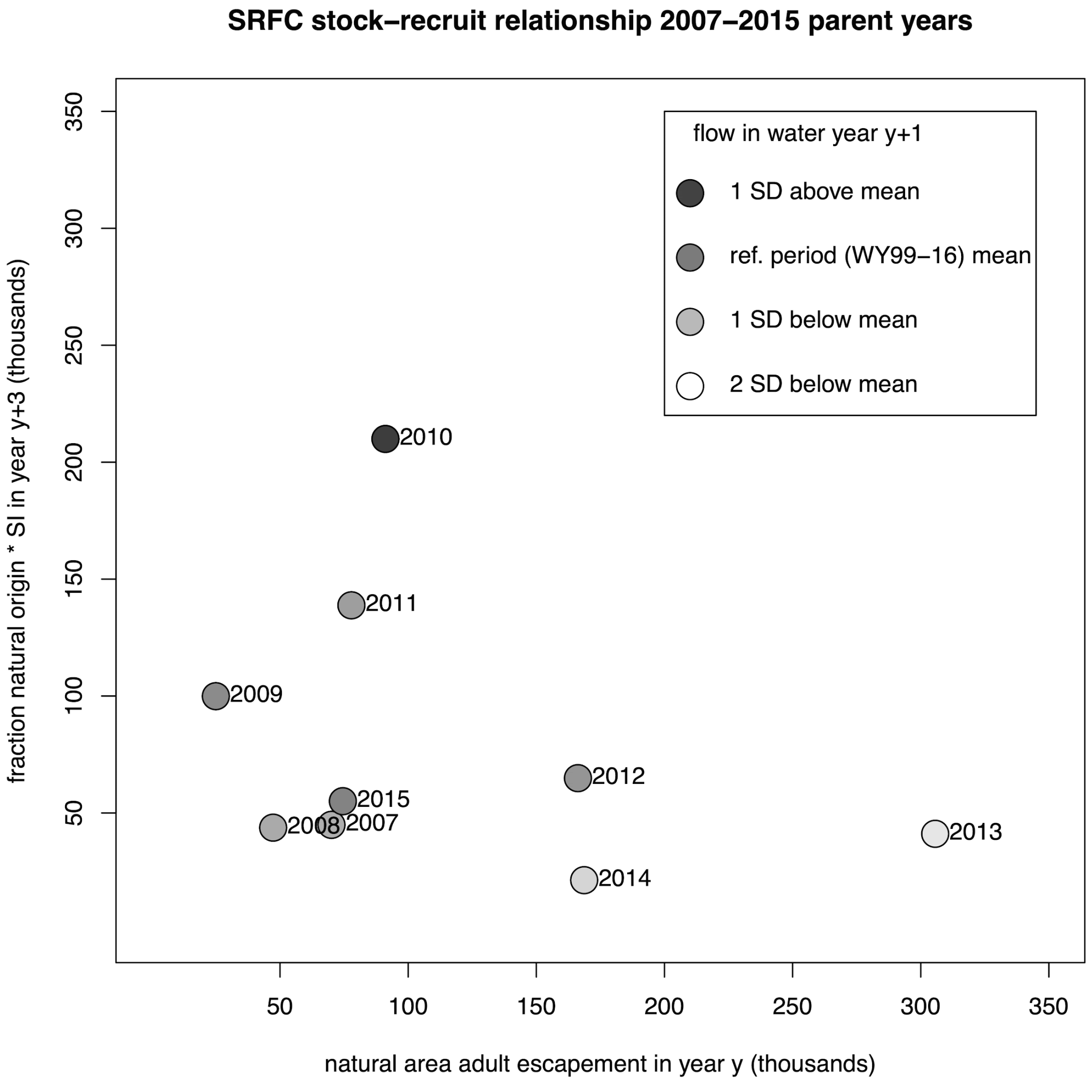
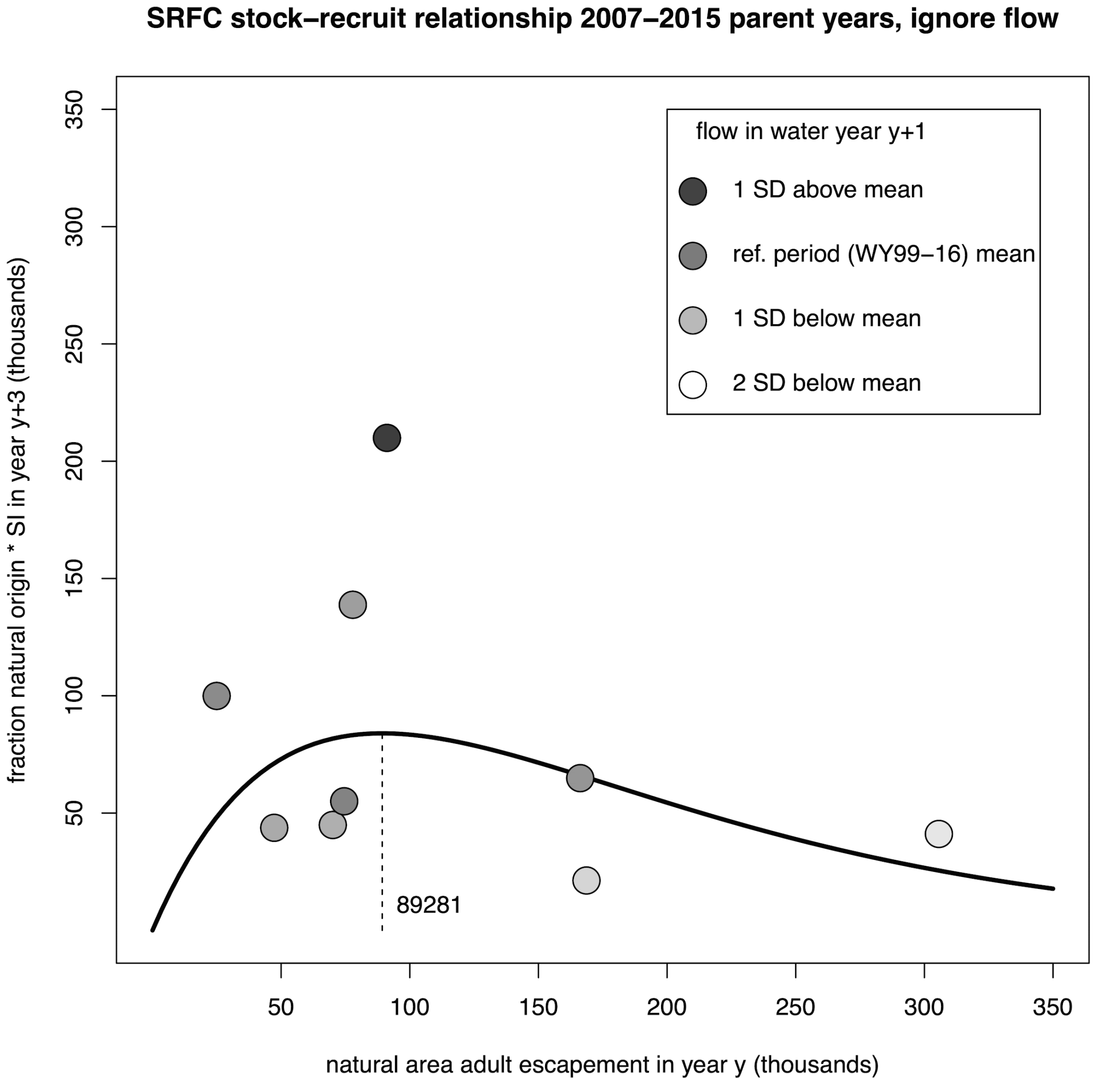
[2] And note that the gap in CWT sampling of 2020 ocean fisheries may compromise cohort reconstructions for brood years exposed to fisheries then, and releases of unmarked fry may compromise the ability to estimate natural-origin escapement or reconstruct natural-origin cohorts in the future.

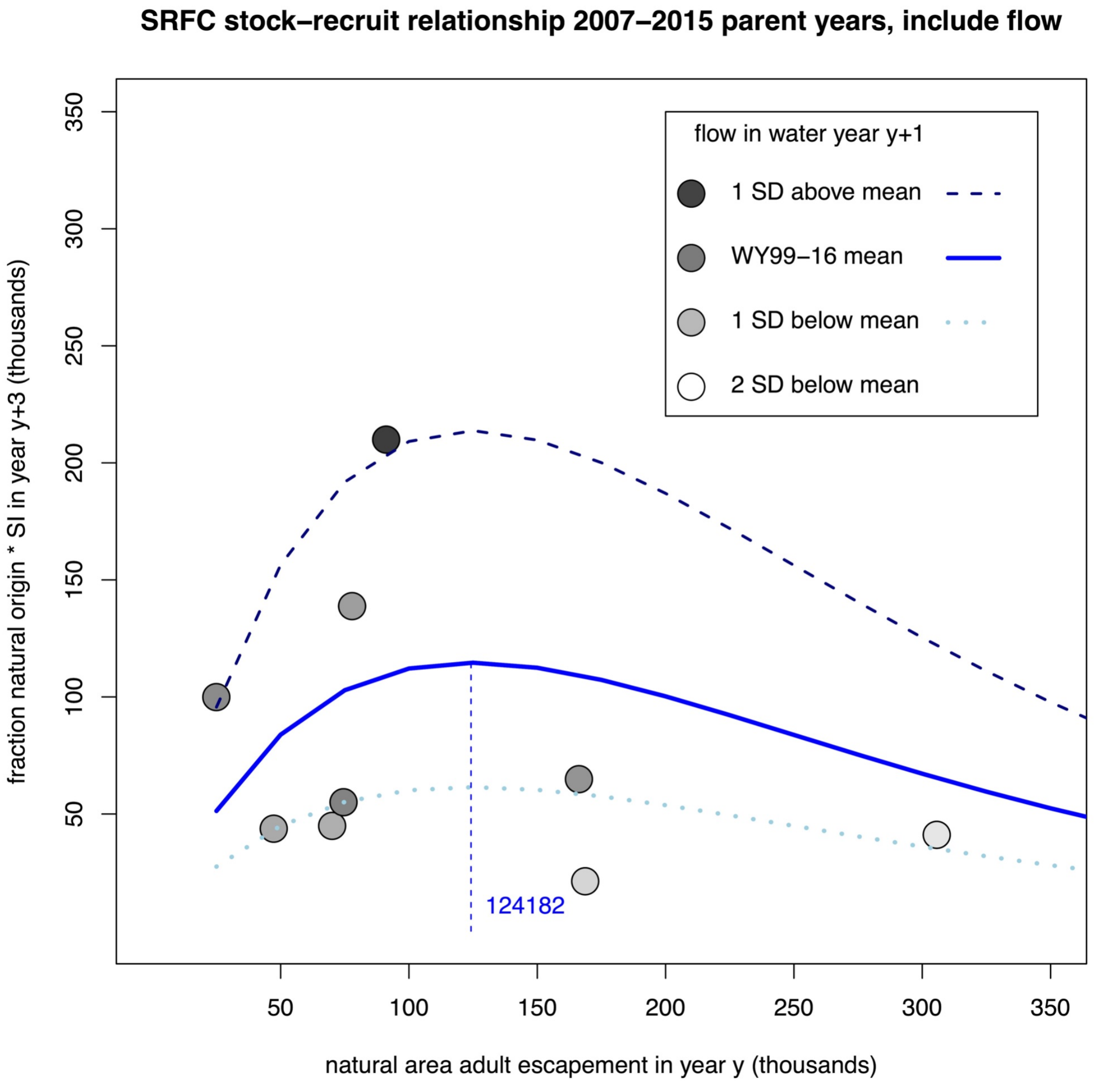
Before fitting any models, it is informative to inspect the input “data”. Note that an unfortunate constraint of this dataset (which would be shared by a cohort reconstruction limited to cohorts after the Constant Fractional Marking program began) is a general lack of data at high spawning abundance or high flow (the flow z-scores are based on the longer reference period used in Munsch et al. 2020 [water years 1999-2016], thus the majority [8/9] of flow scores are negative). In addition to the lack of temporal coverage, the observed combinations of spawners and flows are unbalanced - for example, the only observation at high spawning abundance was at the lowest flow in the dataset, and the highest flow in the dataset was at less than a third of the maximum escapement.



Neglecting flow, a simple Ricker model estimates maximum production at a natural-area escapement of approximately 89,000 adult SRFC. This corresponds surprisingly well to the natural area escapement expected for 122,000 total (hatchery plus natural area) adult spawners using the 2012-2021 median of 69% of adult SRFC spawners spawning in natural areas (Satterthwaite 2022). However, it is important to keep in mind that a combination of forecasting and implementation error means that a target escapement higher than 122,000 during the preseason planning process is needed to have a ≥50% probability of achieving escapement that high in practice (Satterthwaite 2023).


SRFC stock–recruit relationship 2007–2015 parent years, ignore flow

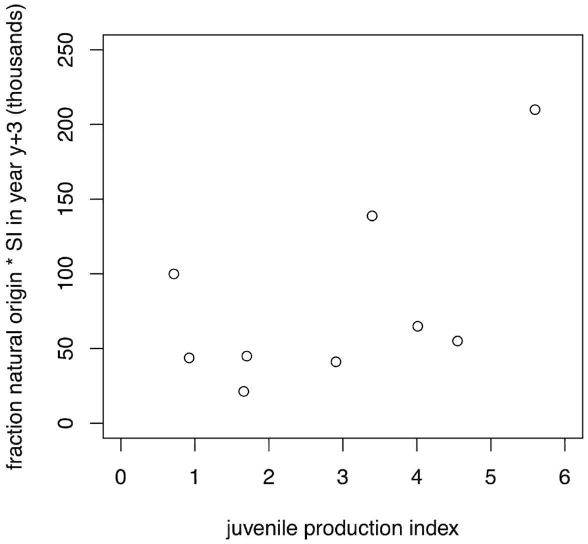
Accounting for flow suggests that natural production is maximized at about 124,000 natural area adult spawners. This corresponds surprisingly well to the natural area escapement expected for 180,000 total (hatchery plus natural area) adult spawners using the 2012-2021 median of 69% of adult SRFC spawners spawning in natural areas (Satterthwaite 2022). However, it is important to keep in mind that a combination of forecasting and implementation error means that a target escapement higher than 180,000 during the preseason planning process is needed to have a ≥50% probability of achieving escapement that high in practice (Satterthwaite 2023). It should also be noted that this model involves fitting three parameters from only nine data points, and there is a moderate degree of correlation (r=-0.55) between spawners and flow within the dataset. A common rule of thumb is to not run regression models including multiple covariates with |r|>0.7, but the cutoff is somewhat arbitrary.


SRFC stock–recruit relationship 2007–2015 parent years, include flow

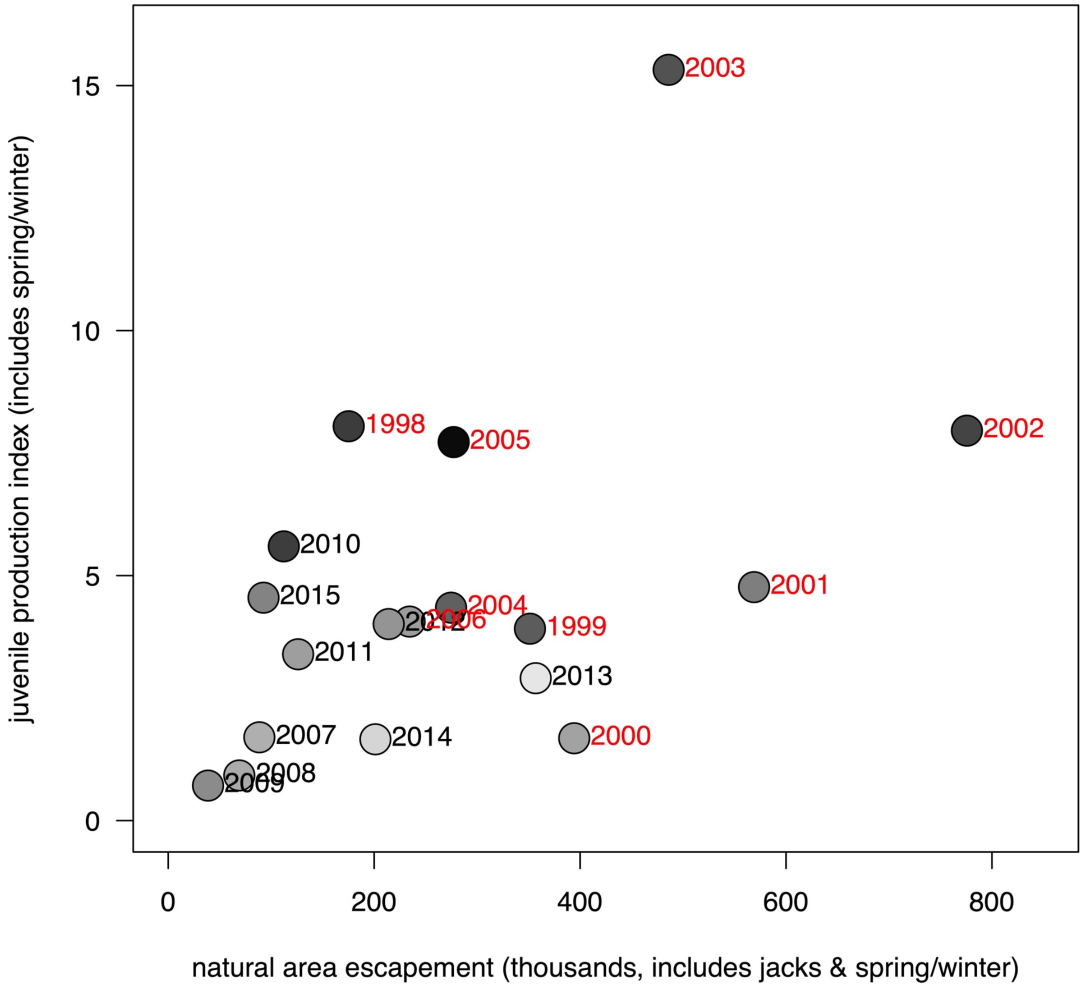
It is also important to again note the limitations in the SI as an index of recruitment for a specific cohort, the limitations in applying composition estimates from the escapement to the SI, and the lack of data at high spawner abundance and high flow. In addition, uncertainty in natural area spawning escapement is not accounted for, and this can introduce a bias into fitted spawner-recruit relationships (Adkison 2022).

Note also that there could be an interest in the natural-area escapement expected to maximize natural-origin yield as opposed to natural-origin production. However, it is unclear how to interpret the yield calculations coming out of a stock-recruit relationship fitted to natural-origin production as a function of natural-area escapement when the majority of natural-area escapement is often of hatchery-origin. There may not be a strong link between the amount of natural-origin ocean abundance escaping from fishing and the expected natural-area escapement, but the MSY calculation assumes it is natural-origin recruitment escaping fishing that drives natural-area production.

Another potential use of a SRFC cohort reconstruction would be to test for density dependence after the juvenile stage used as the measure of recruits in Munsch et al. (2020). If the juvenile index predicts ocean abundance well, and in a non-saturating way, this might be interpreted as evidence for a lack of compensatory or over-compensatory density dependence after the juvenile stage, and the expectation that the same conditions that maximize juvenile production would also maximize pre-fishing ocean abundance. This could increase confidence in analyses making use of the full range of years explored in Munsch et al. (2020), which included more years of high spawning escapement and more years of high flow. The juvenile index from Munsch et al. (2020) only weakly predicted (r=0.57) the recruitment index based on the SI and proportion escapement of natural-origin for common years. However, there was no clear sign of the saturating relationship that would be expected if there was strong density-dependence after the juvenile stage. Given the low correlation and uncertainties associated with the recruitment index and with the potential operation of density-dependence, it is unclear whether the juvenile index or the SI multiplied by the fraction of escapement estimated to be natural-origin is a better indicator of recruitment (although the juvenile index is at least clearly linked to a single cohort).



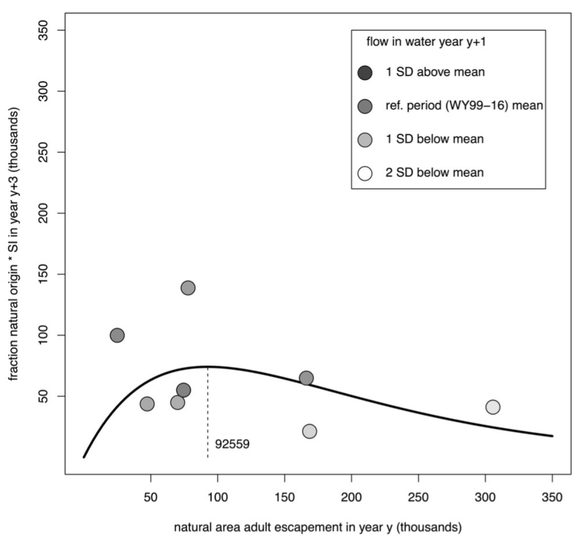
The natural-area escapement maximizing natural production according to these analyses is substantially lower than the level derived from other studies covering a longer time period (PFMC 2019, Munsch et al. 2020, Satterthwaite 2022, Satterthwaite 2023). Although the representativeness of older data may be limited, limiting the data analyzed to spawning years 2007 and later removes data from many years of relatively high spawning abundance and/or high flow, as shown in this plot of the annual juvenile production index versus spawners and flows reported in Munsch et al (2020), with years highlighted in red not included in this analysis:

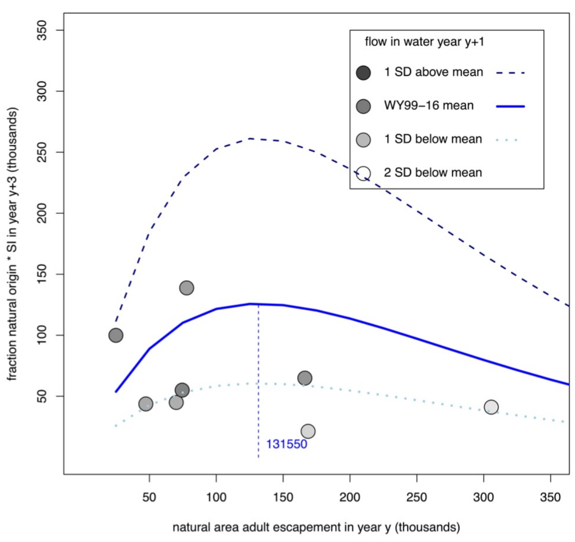


Addendum 1 - Effects of “Outlier” Years

Within the set of years analyzed here, brood years 2010 and/or 2013 could be considered outliers -- 2010 because of much higher flow than other years analyzed, 2013 because of much higher escapement. Dropping 2010 leads to a 4% increase in the spawning escapement expected to maximize natural production in the model without a flow covariate and a 6% increase in the model with a flow covariate. Dropping 2013 decreases the spawning escapement expected to maximize natural production by 33% in the model without a flow covariate, or by 43% with the flow covariate. Dropping both 2010 and 2013 leads to results similar to dropping 2013 alone.

Thus, the model appears highly sensitive to the very limited data at high escapement levels, and it seems inadvisable to pursue this approach without more observations at high escapement.


SRFC stock–recruit relationship 2007–2015 parent years, ignore flow [drop 2010]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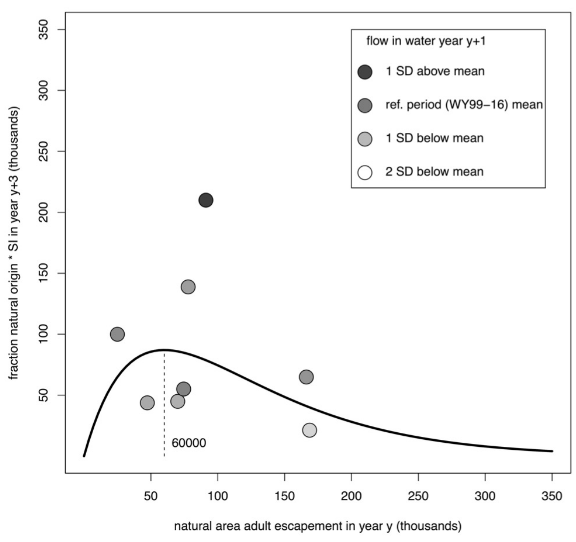
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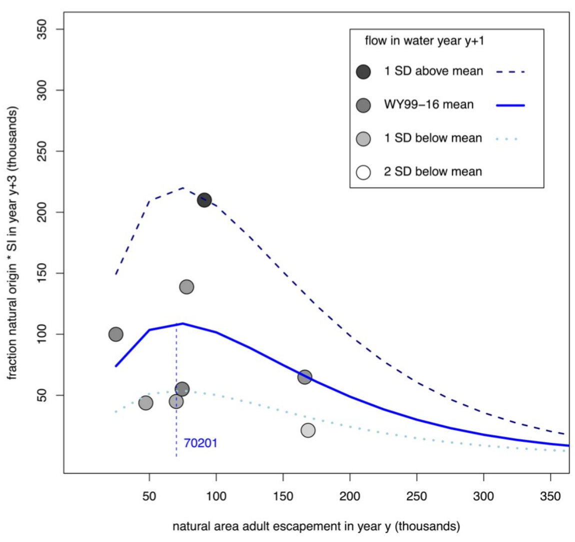
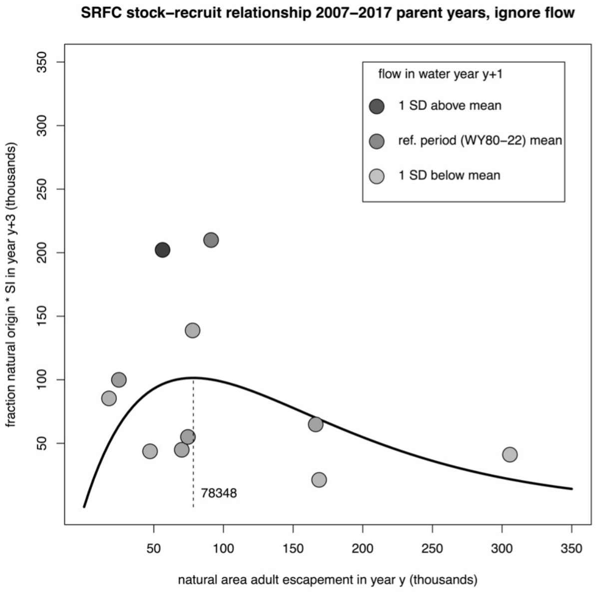
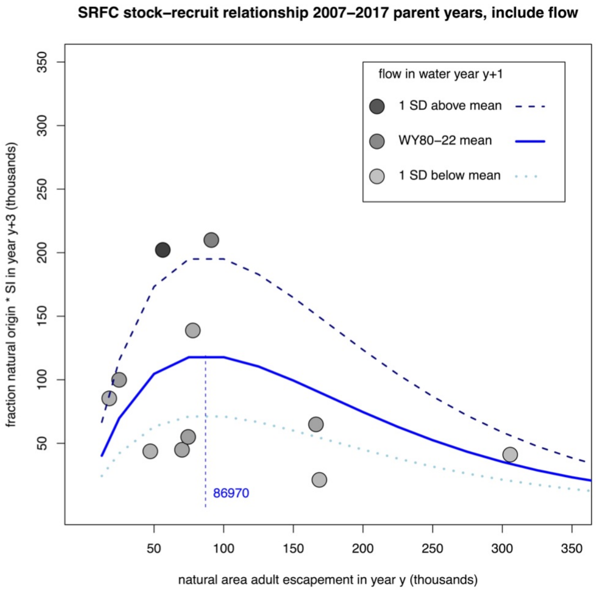

SRFC stock–recruit relationship 2007–2015 parent years, include flow [drop 2013]

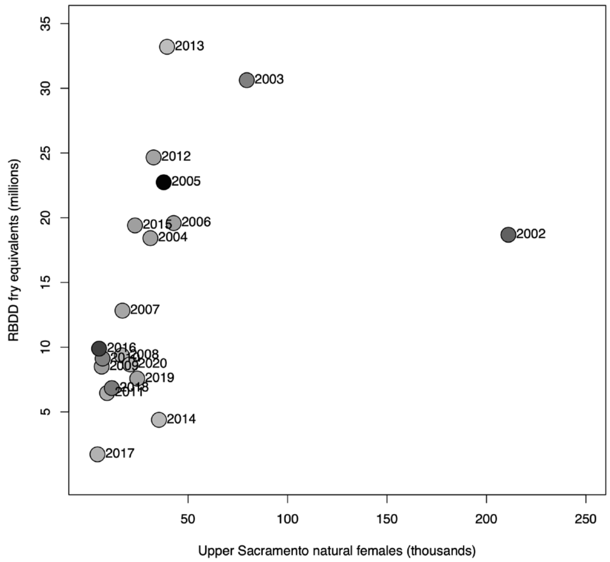
Addendum 2 - Effects of Including Brood Year 2016 and 2017

Results are broadly similar when including brood years 2016 and 2017 by shifting the flow metric used to gage 11377100 near Red Bluff, although a somewhat lower escapement is expected to maximize production, especially when considering a flow covariate. The reference period for z-scoring flow for these analyses is water years 1980-2022.

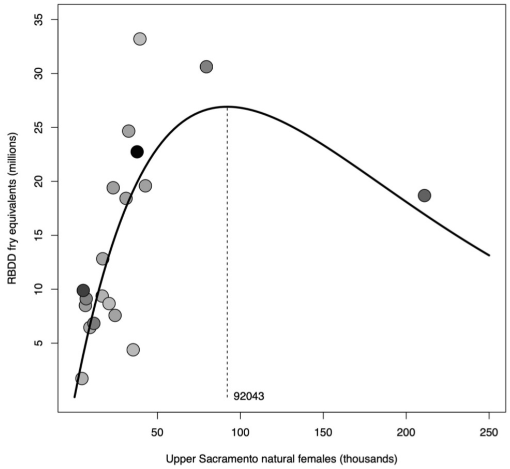




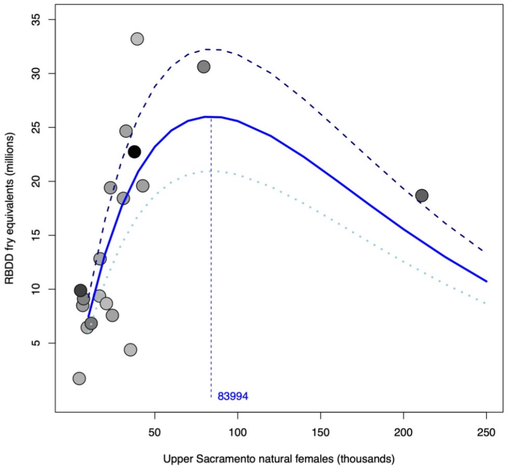
I was also interested to see how using this flow metric influenced stock-recruit curves for the Upper Sacramento (PFMC 2019, Satterthwaite 2023) as well. Effects of incorporating flow in the Upper Sacramento stock-recruit relationships were fairly minor, though the inclusion versus exclusion of brood year 2002 had a larger effect.



Upper Sacramento stock−recruit relationship 2002−2020 run years, ignore flow



Upper Sacramento stock−recruit relationship 2002−2020 run years, include flow



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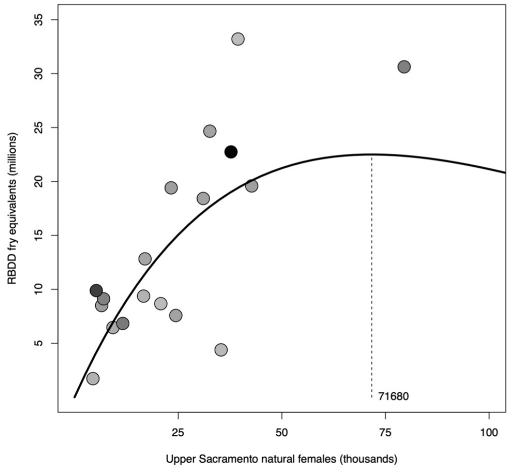
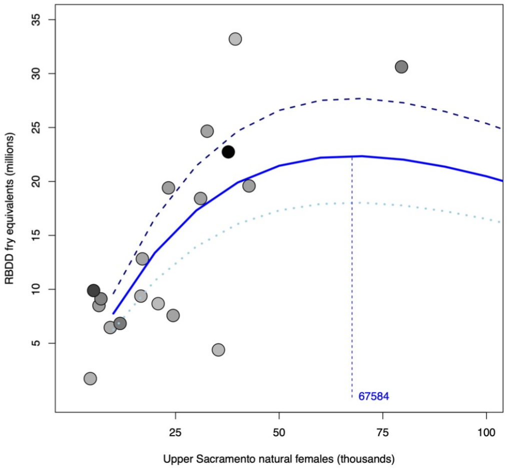


Upper Sacramento stock−recruit relationship 2003−2020 run years, include flow



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