Temperature-Dependent Mortality (TDM) of Winter-Run Chinook Salmon

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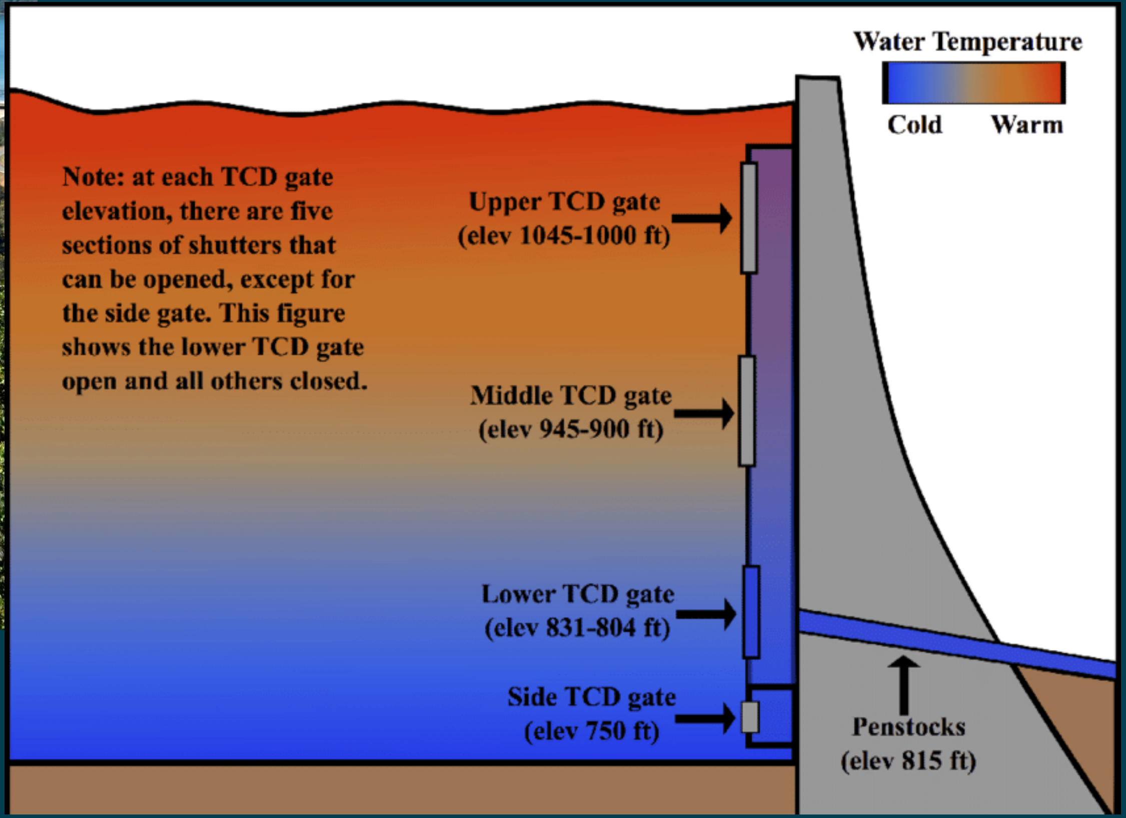
Science and *Modeling Divisions* are Collaborators

Sacramento River winter-run Chinook salmon (SRWRC)

- Endangered ESU in the Sacramento River
- Unique life history
  - Winter migration, summer spawning (May-July)
- Loss of access to historical habitat upstream of Shasta Dam
- Early life stages (eggs, fry) are vulnerable to effects of high temperature

Obtained from Anderson et al. 2022

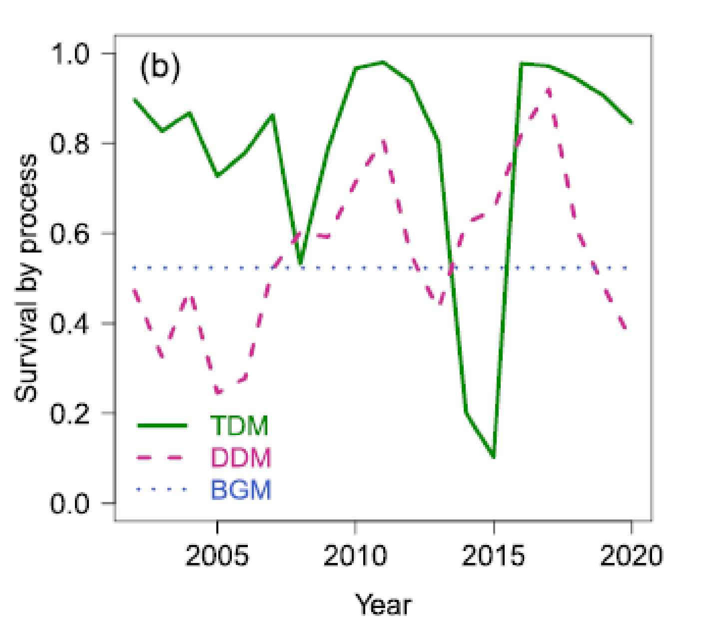
Sacramento River temperature management



Obtained from Daniels et al. 2018

Translating temperatures into biological effects

- Two studies inform recent modeling of temperature effects on SRWRC
  - Martin et al. 2017; Anderson et al. 2022
- $ETF = TDM * DDM * BGM$
  - *ETF* = egg-to-fry survival
  - *TDM* = temperature-dependent mortality, based on:
    - T_{crit}: threshold temperature
    - B_t: slope of temperature effects
  - *DDM* = density-dependent mortality, based on:
    - K: carrying capacity
  - *BGM* = constant background survival



Obtained from Anderson et al. 2022

TDM in the 2019 Biological Assessment

Assumed no biological (spawning) uncertainty

Fixed, assumed redd locations over space…

Table X. Spatial distribution of simulated redds

River Reach	River Mile	Average percentages (2007-2014)
Keswick to A.C.I.D. Dam.	298	46.4%
A.C.I.D. Dam to Highway 44 Bridge	296	46.1%
Highway 44 Br. to Airport Rd. Br.	284	6.7%
Airport Rd. Br. to Balls Ferry Br.	275	0.3%
Balls Ferry Br. to Battle Creek.	271	0.2%
Battle Creek to Jellys Ferry Br.	266	0.2%
Jellys Ferry Br. to Bend Bridge	257	0.1%
Bend Bridge to Red Bluff Diversion Dam	242	0.0%

…and time

Table X. Temporal distribution of simulated redds

Dates (m/d)	Average percentages (2007-2014)
5/15	5.4%
6/1	5.9%
6/9	7.8%
6/16	13.3%
6/24	16.0%
7/1	15.9%
7/9	14.2%
7/16	10.4%
7/24	6.7%
8/1	3.1%
8/16	1.4%

TDM in the 2019 Biological Assessment

Variability in TDM characterized over water years (WYs) only

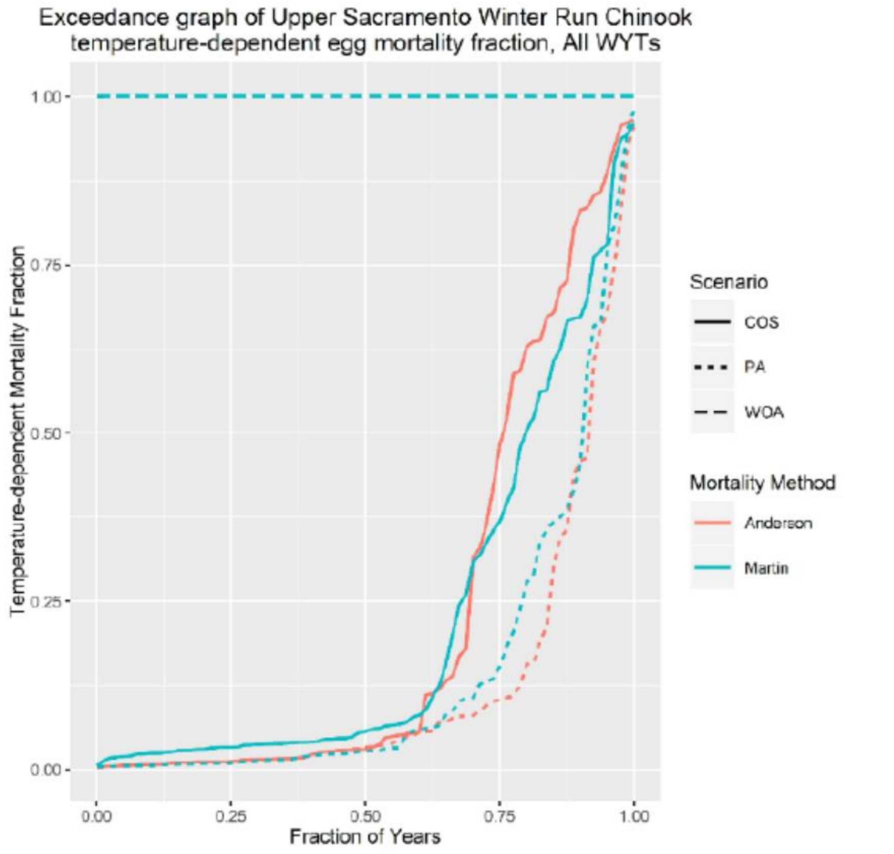


Figure 5.6-21. Exceedance curves of Upper Sacramento River Winter-run Chinook Salmon Temperature-Dependent Egg to Fry Mortality for All Water Year Types

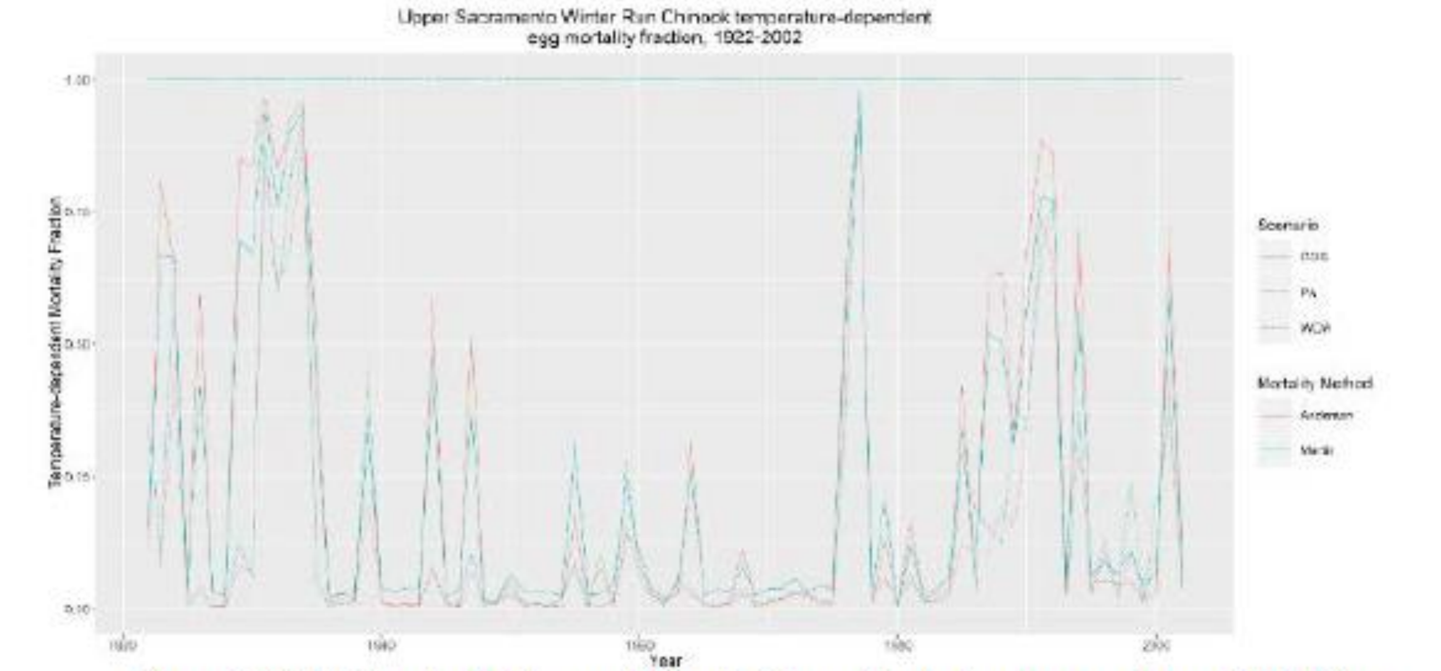


Figure 5.6-23. Estimated Winter-run Chinook Salmon Egg to Fry Average Annual Mortalities (average of Martin and Anderson mortality estimates) and HEC 5Q Estimates of June through September Monthly Average Water Temperatures at Keswick from 1922 to 2002.

Some challenges associated with TDM models

- Documented issues in model convergence
  - Potential overfitting due to data availability
- No integrated estimates of uncertainty for TDM
  - Models are fit to estimates of ETF, not TDM
  - Survival of egg and fry stages is confounded
- Temperature is the only evaluated environmental covariate

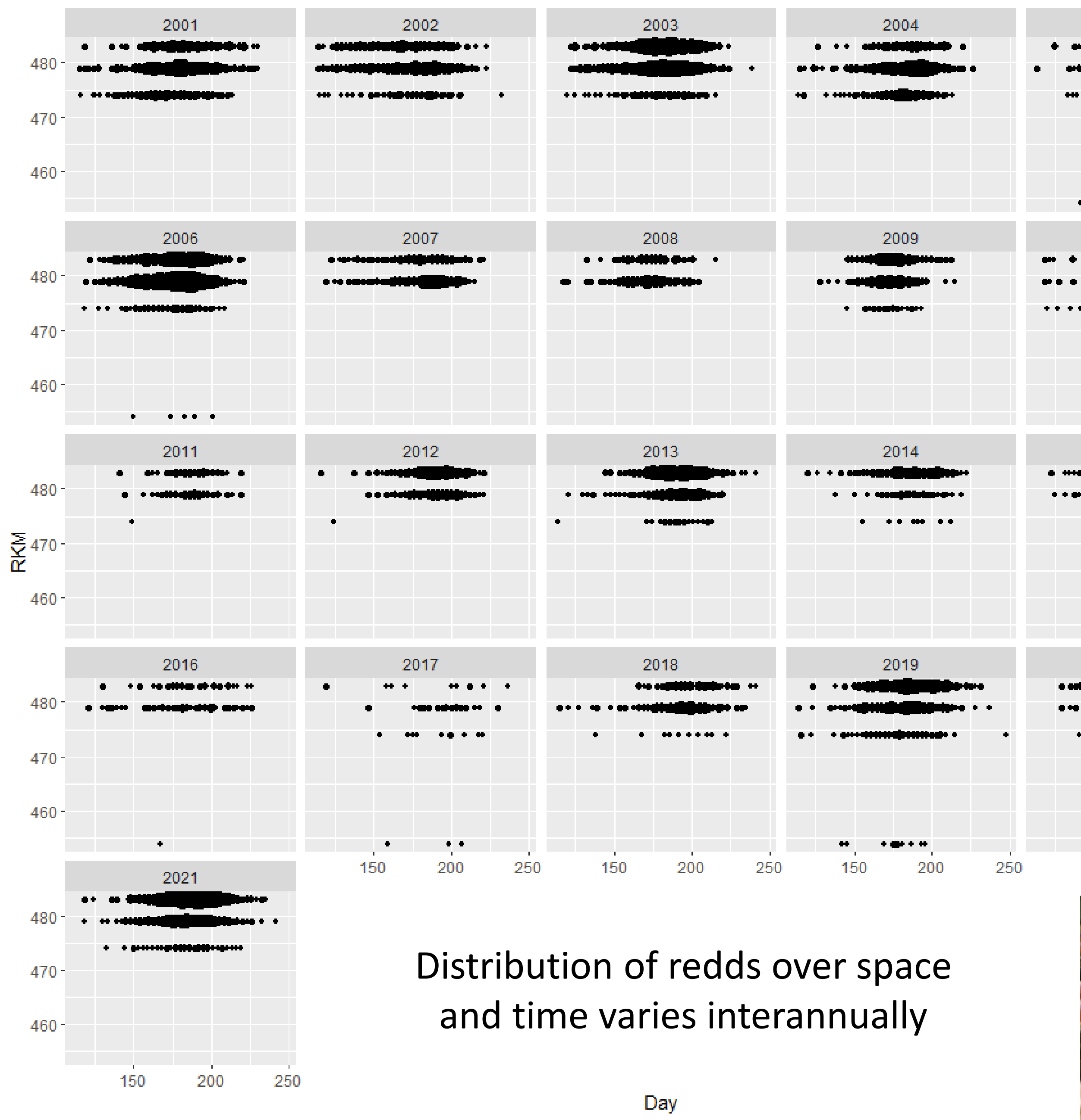
- We can address some of these issues with modeling!

Motivating questions

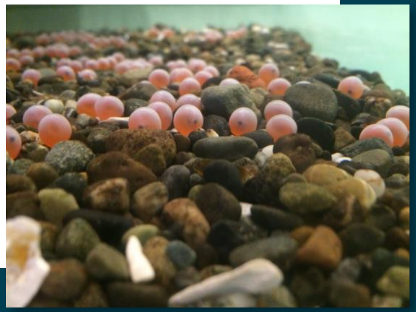
- How can we better utilize existing TDM frameworks to translate modeled temperatures in the Upper Sacramento River (e.g., from HEC-5Q) into expected biological effects on SRWRC?
  - Can we incorporate biological uncertainty?
  - Can we incorporate model uncertainty?

Accounting for biological uncertainty: Unknown redd distribution

Run TDM model for each WY for each annual distribution



Distribution of redds over space and time varies interannually

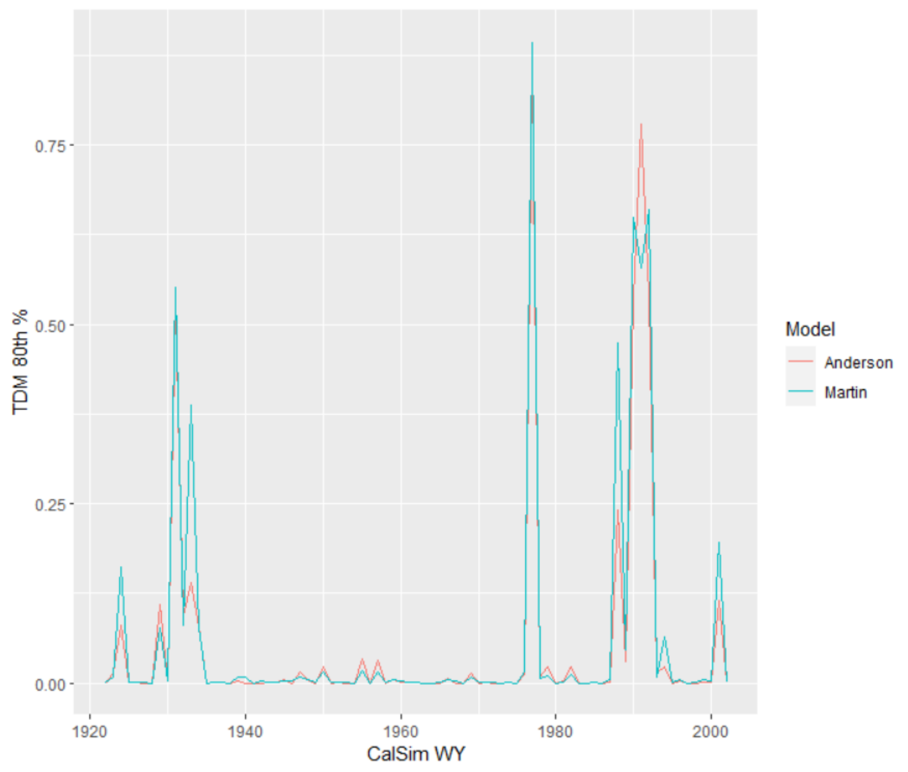


Data obtained from SacPAS

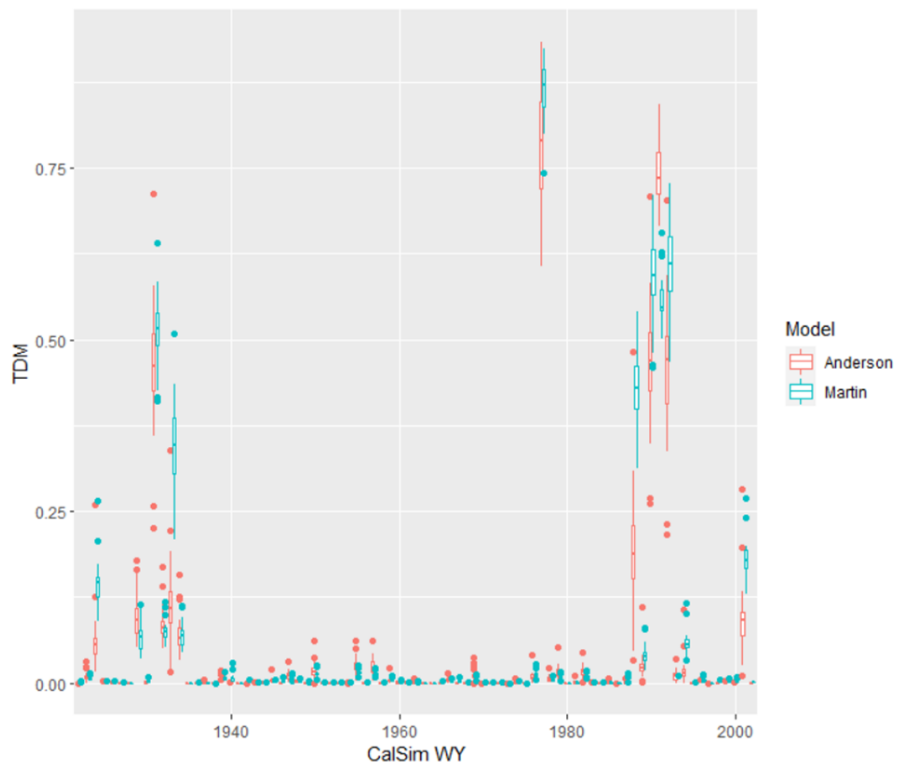
[SacPAS Fish Model v.2.7.4: SacPAS Central Valley Prediction and Assessment of Salmon (washington.edu)]

Accounting for biological uncertainty: Summarizing variability

Collapse variability into a single TDM estimate for each WY (80th Percentile)



Capture variability across TDM estimates for each WY



Draft TDM estimates generated by Drew Loney (USBR) from example HEC-5Q data – subject to change

Accounting for model uncertainty: Refitting TDM model with Bayesian methods

Probability of data *B* given outcome *A* (model likelihood)

Probability of outcome *A* (prior)

Probability of outcome *A* given data *B* (posterior)

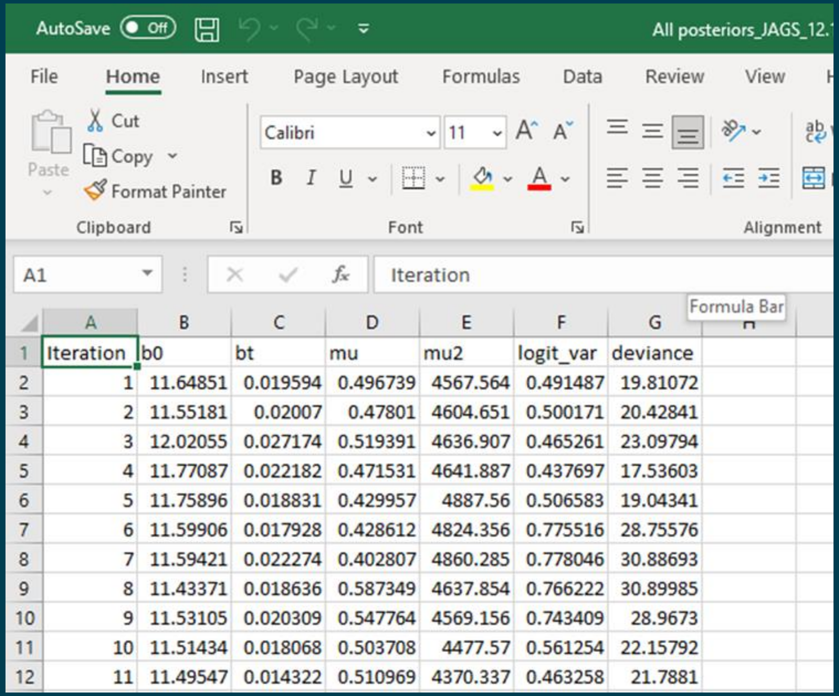
$$P(A \mid B) = \frac{P(B \mid A)P(A)}{P(B)}$$

Probability of data *B* (constant)

- Bayesian modeling, typically using Markov Chain Monte Carlo (MCMC) methods, allows you to obtain:
  - Posterior estimates of parameters, with corresponding likelihood
  - Direct probability interpretations of results (*see frequentist approaches*)

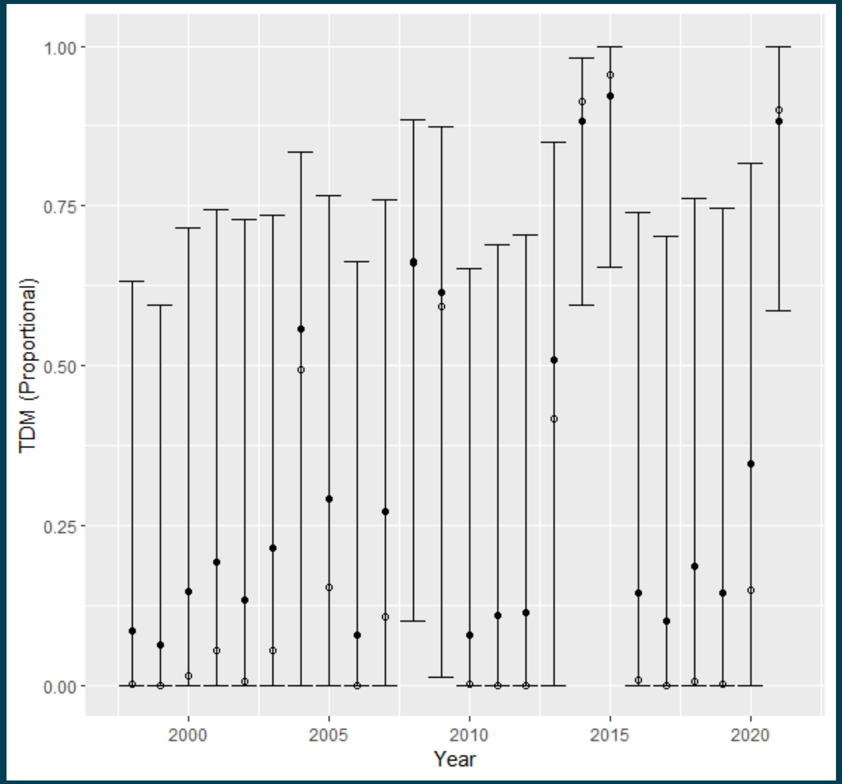
Accounting for model uncertainty: Refitting Martin et al. (2017) in jags

- Observed difficulties in model convergence
- Similar expected parameter values
- Obtained posterior parameter estimates



Iteration	b0	bt	mu	mu2	logit_var	deviance
1	11.64851	0.019594	0.496739	4567.564	0.491487	19.81072
2	11.55181	0.02007	0.47801	4604.651	0.500171	20.42841
3	12.02055	0.027174	0.519391	4636.907	0.465261	23.09794
4	11.77087	0.022182	0.471531	4641.887	0.437697	17.53603
5	11.75896	0.018831	0.429957	4887.56	0.506583	19.04341
6	11.59906	0.017928	0.428612	4824.356	0.775516	28.75576
7	11.59421	0.022274	0.402807	4860.285	0.778046	30.88693
8	11.43371	0.018636	0.587349	4637.854	0.766222	30.89985
9	11.53105	0.020309	0.547764	4569.156	0.743409	28.9673
10	11.51434	0.018068	0.503708	4477.57	0.561254	22.15792
11	11.49547	0.014322	0.510969	4370.337	0.463258	21.7881

Characterize TDM in the Upper Sacramento River, Above Clear Creek (CCR)

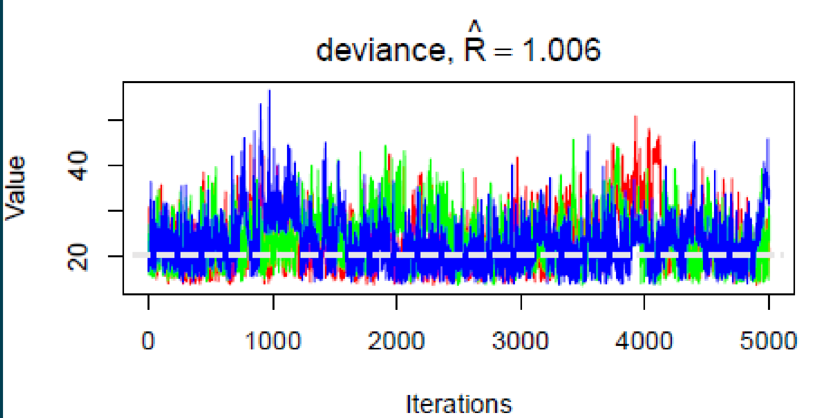


Accounting for model uncertainty: Dealing with parameter covariance

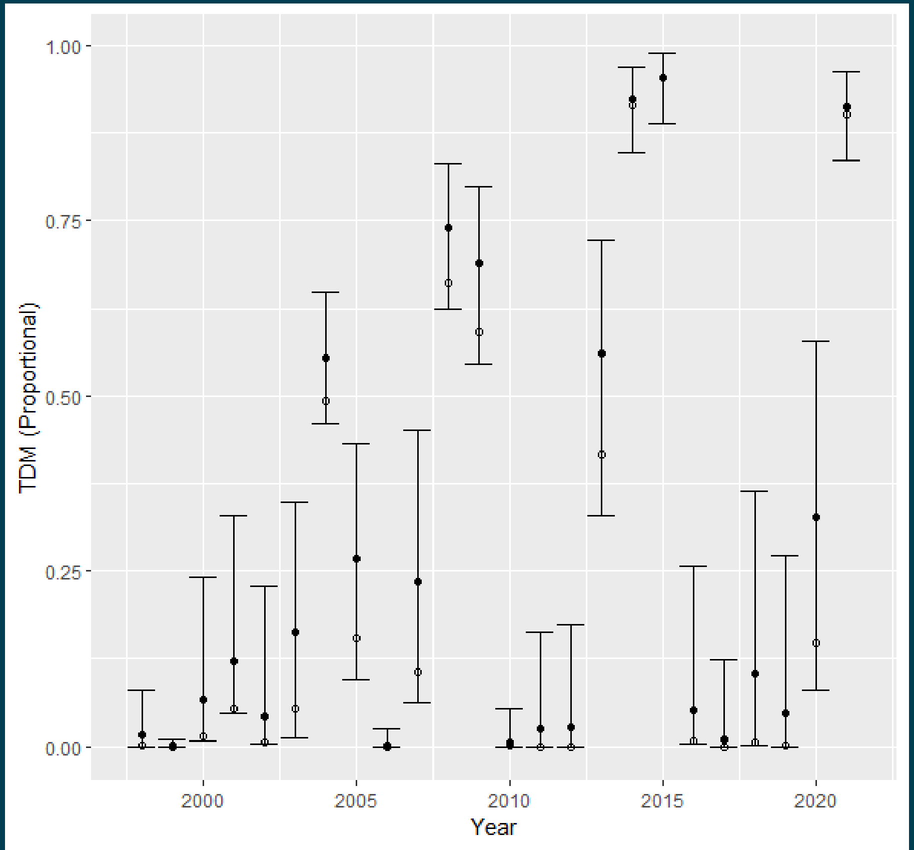
Pearson's correlation matrix

	T_{crit}	b_t	S_0	K
T_{crit}	1	0.030	**-0.647**	-0.172
b_t		1	-0.003	-0.010
S_0			1	-0.093
K				1

Filter out low likelihood values

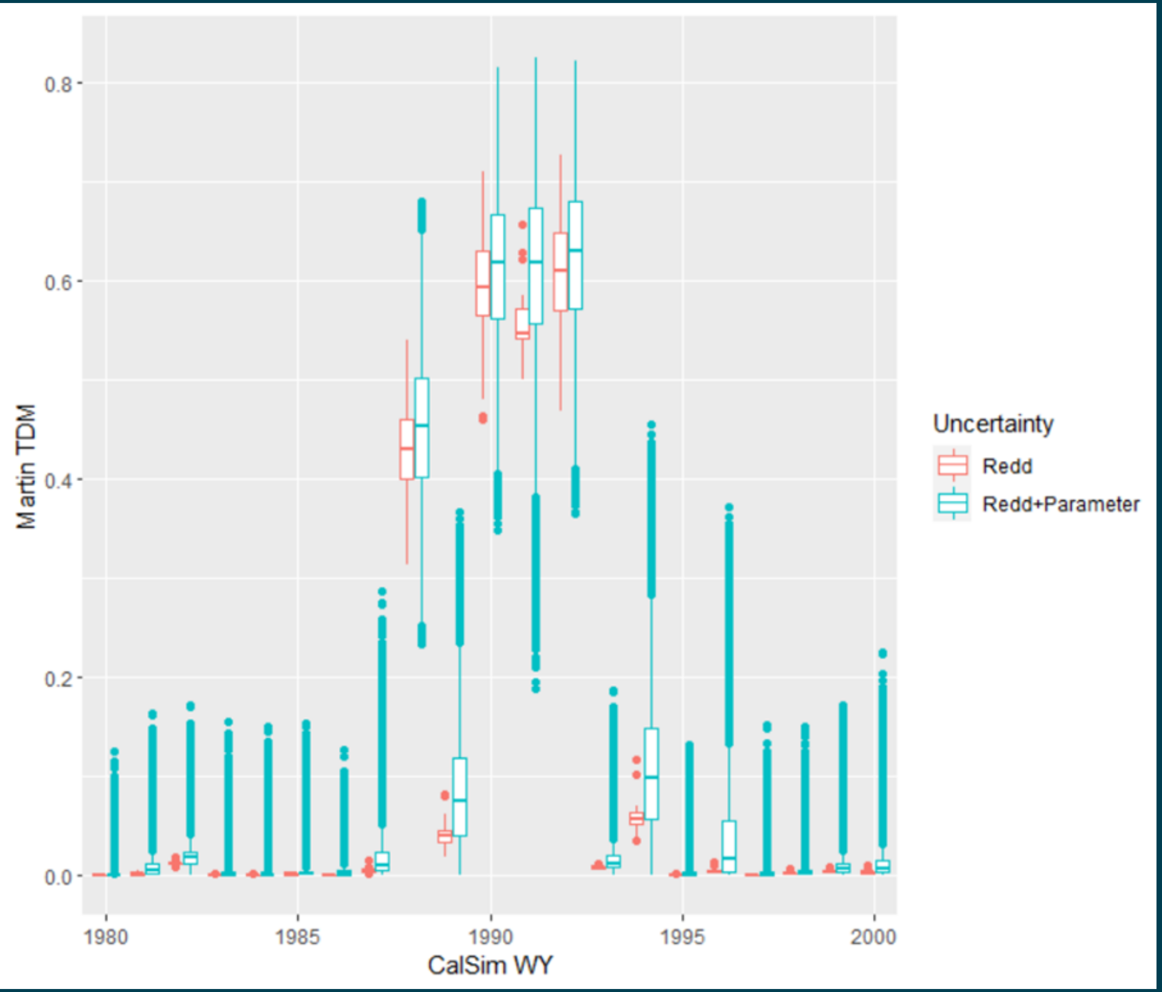


Re-characterize TDM in the Upper Sacramento River, Above Clear Creek (CCR)



Accounting for both biological and model uncertainty

Propose summarizing/visualizing the combined uncertainty for a subset of TDM analyses



Draft TDM estimates generated by Drew Loney (USBR) from example HEC-5Q data – subject to change

Analysis conclusions and limitations

- We can characterize both biological and model-based uncertainty in estimates of TDM, as a way of framing confidence in forecasts
- However…
  - We've only conducted model fitting for stage-independent TDM
  - We can't use integrated estimates of model variance from model fitting
  - The parameter filtering cut-off value (deviance=20) is somewhat arbitrary

Next steps: Address data gaps

- Study egg incubation survival in the Upper Sacramento River
  - Artificial redds and/or streamside remote site incubators
- Study fry survival in the field in the Upper Sacramento River
  - PIT or acoustic telemetry tagging studies
- Preliminary study plans have been drafted to address these needs
  - Explore effects of multiple environmental conditions for both

Thanks for Listening!