SacPAS Fish Model

W. Nicholas Beer and Jennifer L. Gosselin

SacPAS
CENTRAL VALLEY PREDICTION AND ASSESSMENT OF SALMON

COLUMBIA BASIN RESEARCH

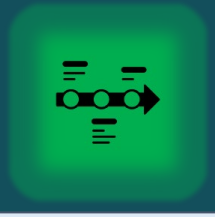
UNIVERSITY of WASHINGTON



Outline

- **SacPAS Fish Model Framework and Decision Support**

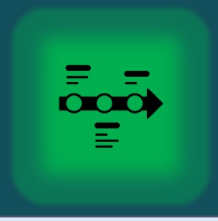




Outline

- **SacPAS Fish Model Framework and Decision Support**





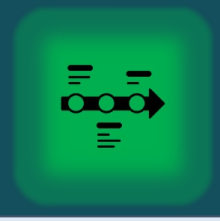
- **SacPAS Models**
  - Egg-to-Fry Survival (v4.0)
  - Migration & Survival
  - Delta Survival



Outline

- **SacPAS Fish Model Framework and Decision Support**

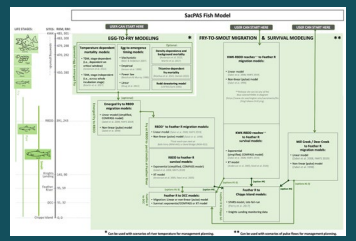




- **SacPAS Models**
  - Egg-to-Fry Survival (v4.0)
  - Migration & Survival
  - Delta Survival



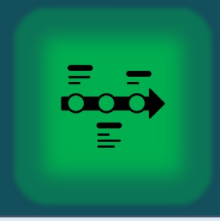
- **User Interface & Resources**
  - User Interface
  - SacPAS Fish Model manual



Outline

- **SacPAS Fish Model Framework and Decision Support**





- **SacPAS Models**
  - Egg-to-Fry Survival (v4.0)
  - Migration & Survival
  - Delta Survival

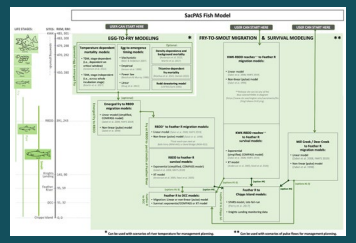




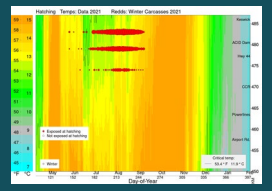


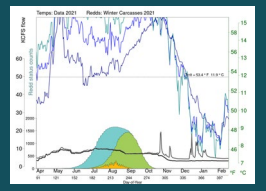


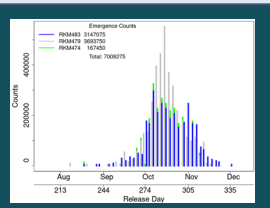
- **User Interface & Resources**
  - User Interface
  - SacPAS Fish Model manual

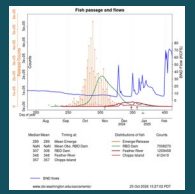


- **Examples**









SacPAS Fish Model Framework



Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.

SacPAS Fish Model Framework



Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.
- Life-history stages are characterized independently.

SacPAS Fish Model Framework



Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.
- Life-history stages are characterized independently.
- Prioritize published models relevant to the life-stage processes when available.

SacPAS Fish Model Framework



Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.
- Life-history stages are characterized independently.
- Prioritize published models relevant to the life-stage processes when available.
- Update with new information regularly.

SacPAS Fish Model Framework



Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.
- Life-history stages are characterized independently.
- Prioritize published models relevant to the life-stage processes when available.
- Update with new information regularly.
- Support scenario modes for key data inputs.

SacPAS Fish Model Framework

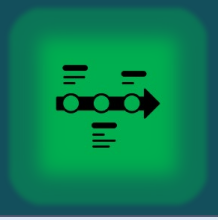


Framework Design:

- Link life-history stages with daisy-chain of results as inputs through framework.
- Life-history stages are characterized independently.
- Prioritize published models relevant to the life-stage processes when available.
- Update with new information regularly.
- Support scenario modes for key data inputs.
- Enable scripting for easy access to results.

SacPAS Fish Model Framework and Decision Support

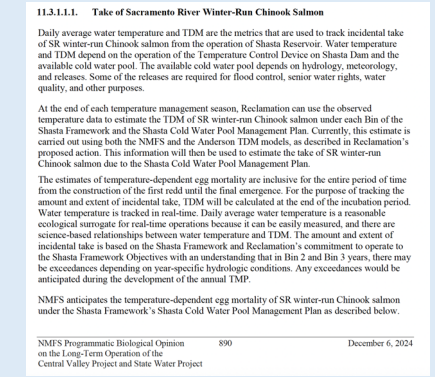




- Estimate temperature-dependent mortality in winter-run Chinook Salmon
  - Relates to scenarios of temperature-control water release
- Estimate juvenile survival
  - Relates to pulse flow scenarios

SacPAS Fish Model Framework and Decision Support

- ESA Section 7(a)(2) Programmatic Biological Opinion for the Reinitiation of Consultation on the Long-Term Operation of the Central Valley Project and State Water Project



11.3.1.1.1. Take of Sacramento River Winter-Run Chinook Salmon

Daily average water temperature and TDM are the metrics that are used to track incidental take of SR winter-run Chinook salmon from the operation of Shasta Reservoir. Water temperature and TDM depend on the operation of the Temperature Control Device on Shasta Dam and the available cold water pool. The available cold water pool depends on hydrology, meteorology, and releases. Some of the releases are required for flood control, senior water rights, water quality, and other purposes.

At the end of each temperature management season, Reclamation can use the observed temperature data to estimate the TDM of SR winter-run Chinook salmon under each Bin of the Shasta Framework and the Shasta Cold Water Pool Management Plan. Currently, this estimate is carried out using both the NMFS and the Anderson TDM models, as described in Reclamation's proposed action. This information will then be used to estimate the take of SR winter-run Chinook salmon due to the Shasta Cold Water Pool Management Plan.

The estimates of temperature-dependent egg mortality are inclusive for the entire period of time from the construction of the first redd until the final emergence. For the purpose of tracking the amount and extent of incidental take, TDM will be calculated at the end of the incubation period. Water temperature is tracked in real-time. Daily average water temperature is a reasonable ecological surrogate for real-time operations because it can be easily measured, and there are science-based relationships between water temperature and TDM. The amount and extent of incidental take is based on the Shasta Framework and Reclamation's commitment to operate to the Shasta Framework Objectives with an understanding that in Bin 2 and Bin 3 years, there may be exceedances depending on year-specific hydrologic conditions. Any exceedances would be anticipated during the development of the annual TMP.

NMFS anticipates the temperature-dependent egg mortality of SR winter-run Chinook salmon under the Shasta Framework's Shasta Cold Water Pool Management Plan as described below.

NMFS Programmatic Biological Opinion on the Long-Term Operation of the Central Valley Project and State Water Project 890 December 6, 2024

- Temperature Management Plan
https://www.waterboards.ca.gov/drought/sacramento_river/docs/2026/2026-final-srg-temp-wtr-mgmt-plan.pdf



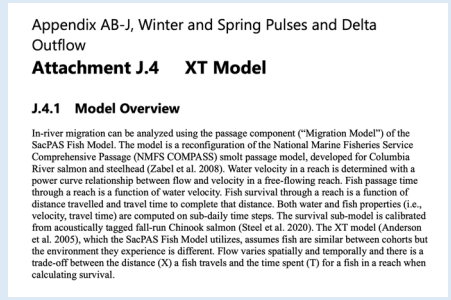
— BUREAU OF — RECLAMATION

2026 Sacramento River Temperature Management Plan

Executive Summary

This Temperature Management Plan (TMP or Plan) describes how the U.S. Bureau of Reclamation (Reclamation) proposes to operate Shasta Reservoir and the Temperature Control Device (TCD) on Shasta Dam for the 2026 temperature management season. The Plan utilizes data from various sources, including: Reclamation's May 90% exceedance forecast of Central Valley Project (CVP) operations, recent reservoir temperature profiles,

- XT Model in LTO of the CVP and SWP Environmental Impact Statement
https://www.usbr.gov/mp/nepa/includes/documentShow.php?Doc_ID=54710



Appendix AB-J, Winter and Spring Pulses and Delta Outflow

Attachment J.4 XT Model

J.4.1 Model Overview

In-river migration can be analyzed using the passage component ("Migration Model") of the SacPAS Fish Model. The model is a reconfiguration of the National Marine Fisheries Service Comprehensive Passage (NMFS COMPASS) smolt passage model, developed for Columbia River salmon and steelhead (Zabel et al. 2008). Water velocity in a reach is determined with a power curve relationship between flow and velocity in a free-flowing reach. Fish passage time through a reach is a function of water velocity. Fish survival through a reach is a function of distance travelled and travel time to complete that distance. Both water and fish properties (i.e., velocity, travel time) are computed on sub-daily time steps. The survival sub-model is calibrated from acoustically tagged fall-run Chinook salmon (Steel et al. 2020). The XT model (Anderson et al. 2005), which the SacPAS Fish Model utilizes, assumes fish are similar between cohorts but the environment they experience is different. Flow varies spatially and temporally and there is a trade-off between the distance (X) a fish travels and the time spent (T) for a fish in a reach when calculating survival.

SacPAS Models





SacPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Notes & References

SacPAS Fish Model v 4.0

Sacramento River Chinook salmon

EGG-TO-FRY MODELING

Basic settings | Intermediate settings | Full settings

Basic: simple selection of historical year for river temperature and redd data inputs
Intermediate: additional options for temperature, salmon runs, and survival model; Egg-to-Fry model outputs can be inputs to Migration and Survival modeling
Full: all input options available, including thiamine-dependent fry mortality and redd dewatering

MIGRATION AND SURVIVAL MODELING

Basic settings | Full settings

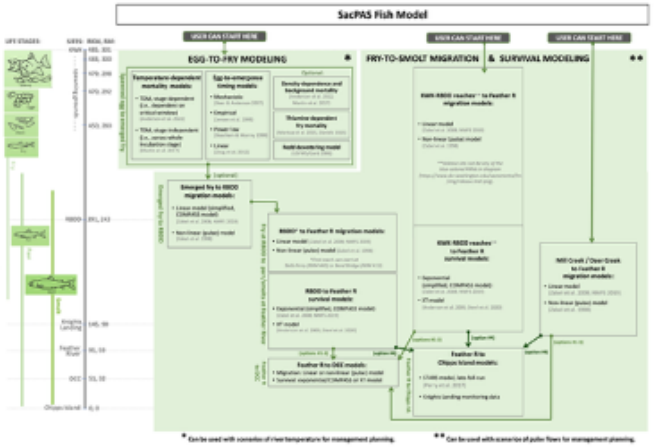
Basic: simple input console with river flow and fish release; the rest has default model configurations
Full: all model configurations expanded in the online interface

BACKGROUND

The SacPAS Fish Model includes Egg-to-Fry Modeling and Migration and Survival Modeling. It offers a web interface to multiple, interconnected models for Sacramento River Chinook salmon (see diagram). Predictions of salmon responses (hindcasts and hypothetical scenarios) are possible with the use of historical data, real-time data, and user-specified data (e.g., alternative scenarios). Egg-to-Fry Modeling is the first tool under the SacPAS Fish Model. The online tool includes various temperature-dependent mortality models, egg-to-emergence timing models, density-dependent models, and a redd dewatering model. Migration and Survival Modeling is the second tool under the SacPAS Fish Model. This online tool includes several models that can include input data from the Egg-to-Fry Modeling tool, historical data, and user-specified data.

Notably, one of the primary stressors on Winter-Run Chinook Salmon in the Sacramento River is thermal stress during incubation. River managers allocate cool water releases from Shasta Reservoir to reduce this stress, but at the cost of limiting water releases at other times of the year. In the study, Anderson et al. 2022, the authors modeled the effect of thermal stress on egg incubation and concluded that in drought years, targeting cold water to the period of peak embryo hatching yields the highest survival for a minimum use of water. The model, available through Egg-to-Fry Modeling, allows resource managers and the public equal access to evaluate water operation plans and in real-time track the status of the endangered salmon in the Central Valley of California.

For more details see the manual, which includes sections on the modeling, a user's guide, and example results and interpretations.



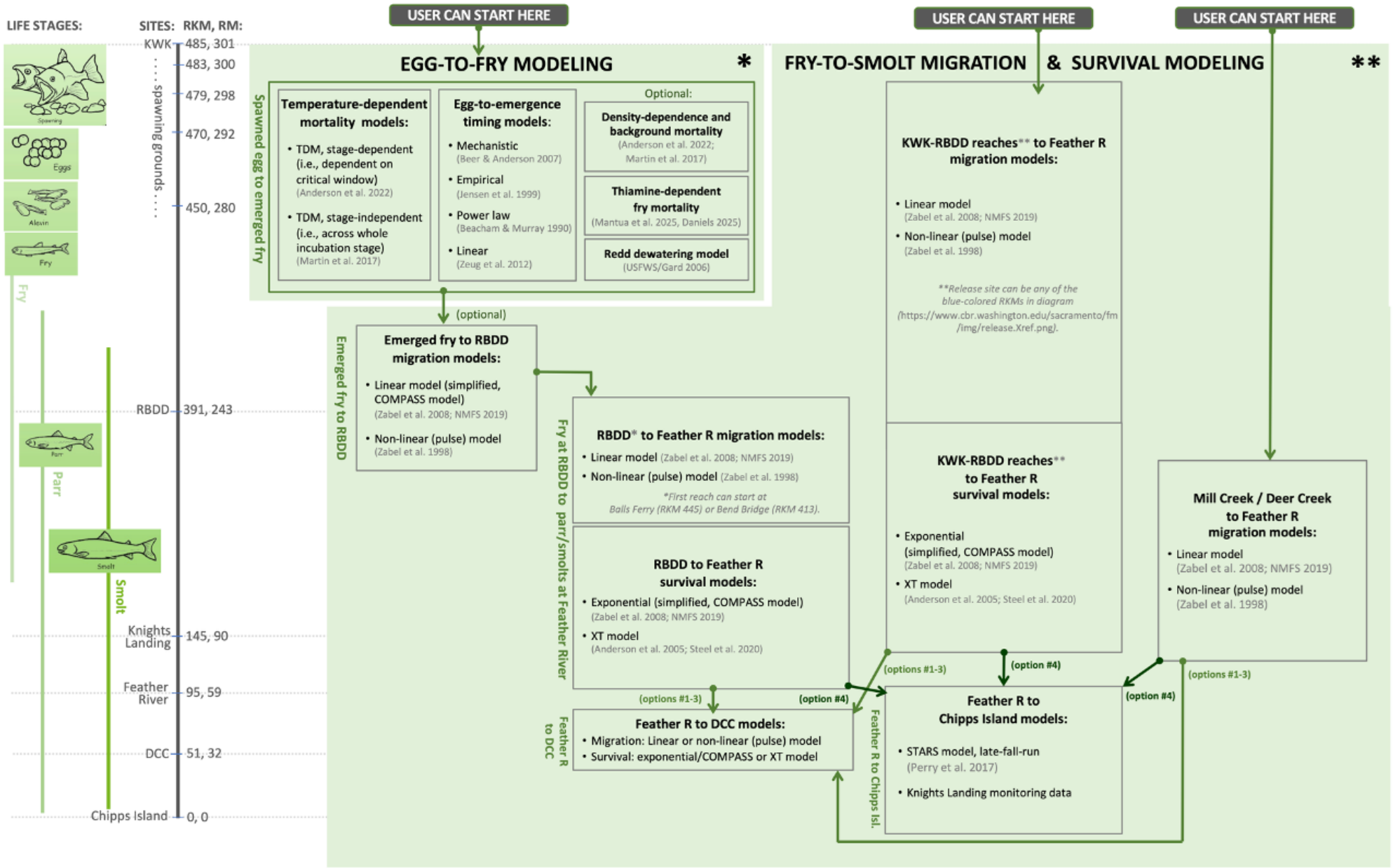
Maps & Diagrams
- Interactive map
- Diagrams

Methods, Notes & References
- SacPAS Fish Model manual
- Version Release History
- Data
- Notes

Citation

Columbia Basin Research, University of Washington. (2024). SacPAS Fish Model: Spawned egg to emerged fry, and juvenile migration and survival to the Delta. Available from www.cbr.washington.edu/sacramento/fishmodel.

SacPAS Fish Model



* Can be used with scenarios of river temperature for management planning.

** Can be used with scenarios of pulse flows for management planning.

SacPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Notes & References

SacPAS Fish Model: METHODS, NOTES & REFERENCES

MANUAL

Beer WN, Gosselin JL, Chen M, Kwok K, Nguyen HD, Iltis S, Carter M, and Anderson JJ. 2026-10-25. SacPAS Fish Model (Version 4.): Models, User's Guide, and Example Results & Interpretations. Prepared by Central Valley Prediction and Assessment of Salmon (SacPAS), Columbia Basin Research, School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. See SacPAS Fish Model manual.

VERSION RELEASE HISTORY

See Version Release History.

DATA

Data Disclaimer

Redd and carcass data are made available courtesy of the California Department of Fish and Wildlife (CDFW). The data are provisional and subsequent review may result in revisions to the data. The data were not collected following a study design for various egg growth and survival models. It is important to consider data limitations when used in modeling applications. For example, the aerial redd dataset is limited due to its susceptibility to turbid water and other environmental characteristics that can make viewing the redd locations difficult.

SacPAS Models: Egg-to-Fry Modeling



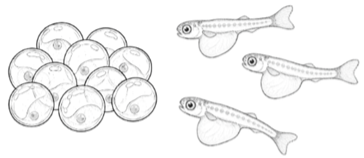
- **Simulates development and survival on a daily basis.**
- **Aggregates each cohort of redds that share spawning date and location.**
- **Outputs can be used as inputs to Migration and Survival Model.**

SacPAS Models: Egg-to-Fry Modeling



Egg-to-Fry Survival Model: four mortality processes

Egg & Alevin Mortality



Fry Mortality



DDM

High density of redds in the spawning habitat can result in superimposition of redds and consequently, egg mortality.

TDM

High water temperatures can cause egg and alevin mortality.

TDFM

Thiamine Deficiency Complex can cause fry mortality.

BGM

Mortality from processes not explicitly modeled, such as predation, competition, and juvenile stranding.

Modeled Egg-to-Fry Survival

SacPAS Models: Egg-to-Fry Modeling

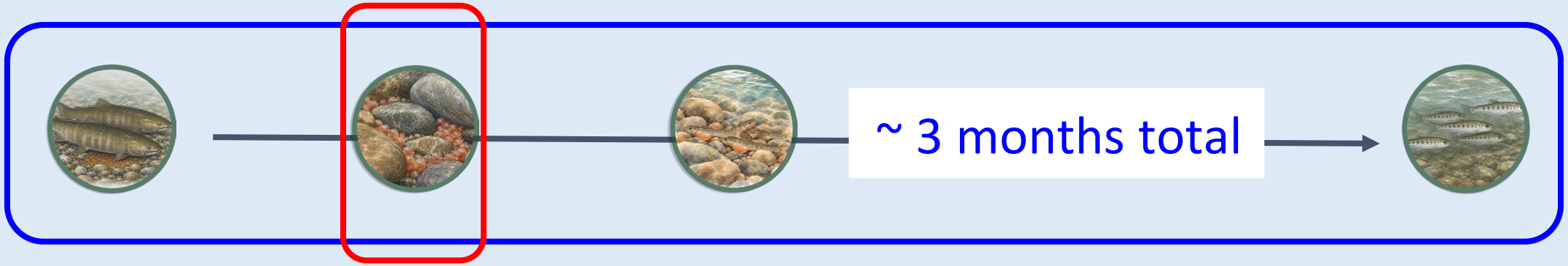


Stage-Dependent mortality (Anderson et al. 2022):

TDM occurs a few (~ 4) days prior to hatching when eggs are most thermally sensitive.

Stage-Independent mortality (Martin et al. 2017):

TDM occurs at any time during development between spawning and emergence.



SacPAS Models: Egg-to-Fry Modeling



Egg-to-Fry Survival (S_j)

reach i
year j
day y

Background survival

Thiamine-dependent fry mortality

Density-dependent survival

$$S_j = \frac{B(1-T_j)}{A_j} \sum_{i=1}^{A_j} U_{i,j} V_{i,j}$$

Number of redds

Temperature-dependent survival

$$U_i = \frac{1}{1 + \frac{A_j}{D}}$$

$$V_i = \exp\left(-b \sum_{y=0}^{y=Y} \max(T_{y,i} - T_{crit}, 0)\right)$$

SacPAS Models: Egg-to-Fry Modeling



Egg-to-Fry Survival (S_j)

reach i
year j
day y

Background survival

Thiamine-dependent fry mortality

Density-dependent survival

$$S_j = \frac{B(1 - T_j)}{A_j} \sum_{i=1}^{A_j} U_{i,j} V_{i,j}$$

$$U_i = \frac{1}{1 + \frac{A_j}{D}}$$

Temperature-dependent survival

$$V_i = \exp\left(-b \sum_{y=0}^{y=Y} \max(T_{y,i} - T_{crit}, 0)\right)$$

Number of redds

model coefficients

SacPAS Models: Egg-to-Fry Modeling



Egg-to-Fry Survival (S_j)

reach i
year j
day y

Background survival

Thiamine-dependent fry mortality

Density-dependent survival

$$S_j = \frac{B(1 - T_j)}{A_j} \sum_{i=1}^{A_j} U_{i,j} V_{i,j}$$

$$U_i = \frac{1}{1 + \frac{A_j}{D}}$$

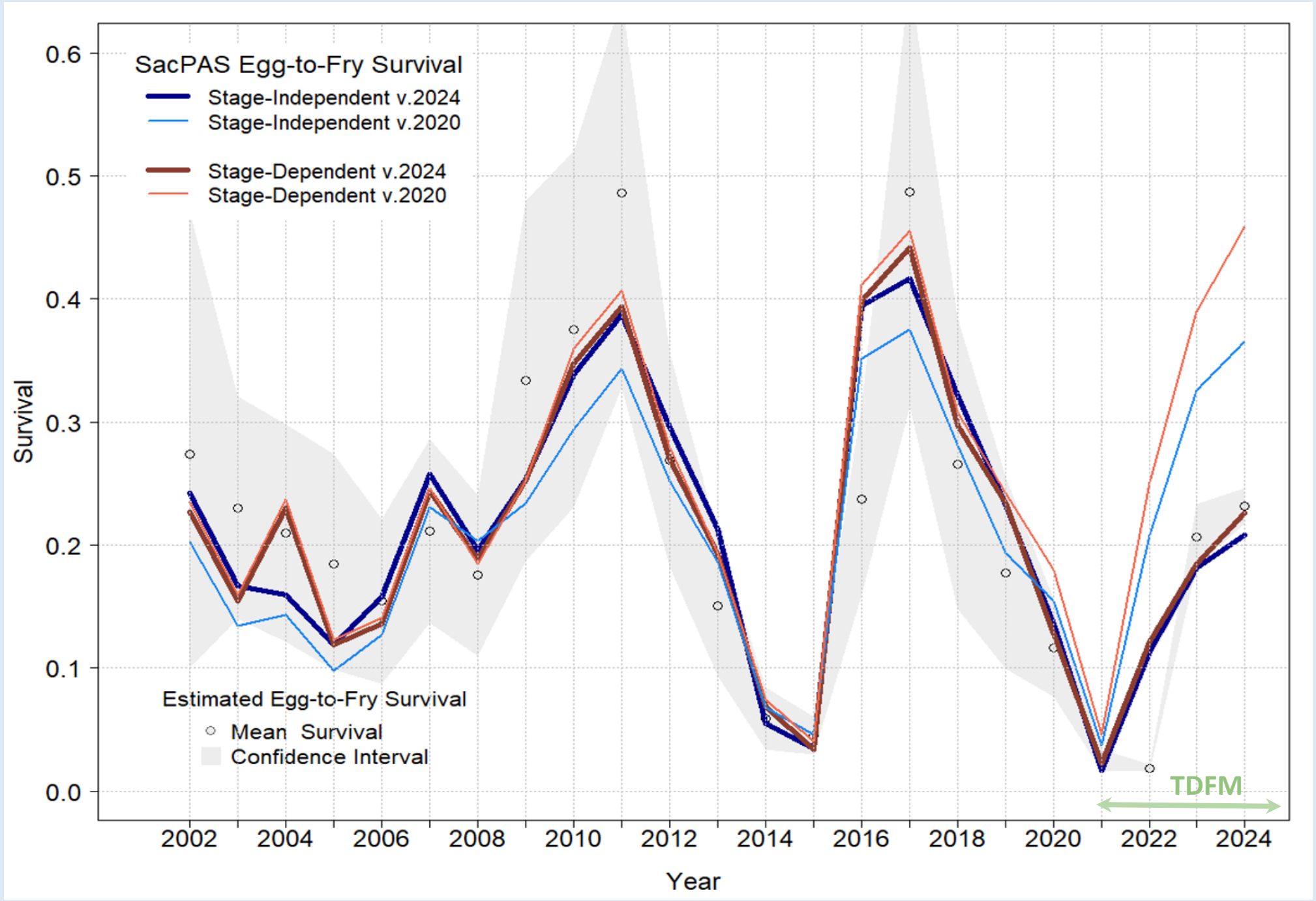
Temperature-dependent survival

$$V_i = \exp\left(-b \sum_{y=0}^{y=Y} \max(T_{y,i} - T_{crit}, 0)\right)$$

Number of redds

model coefficients

data or input estimates


SacPAS Egg-to-Fry Survival
Stage-Independent v.2024
Stage-Independent v.2020
Stage-Dependent v.2024
Stage-Dependent v.2020
Survival
0.0
0.1
0.2
0.3
0.4
0.5
0.6
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
Year
Estimated Egg-to-Fry Survival
Mean Survival
Confidence Interval
TDFM

SacPAS Models: Egg-to-Fry Modeling



Inputs

- Redd Distributions:
  - **Historical Data** from Winter, Spring, Fall, and Late-Fall Aerial & Carcass survey data
  - **Scenario distributions** specified by User

- Temperature profiles:
  - **Historical** timeseries
  - **Forecast** timeseries when available
  - **Scenarios** specified by user

- Modeling Choices:
  - **Mortality Sources**
  - **Development** Rates

SacPAS Models: Egg-to-Fry Modeling



Inputs

- Redd Distributions:
  - **Historical Data** from Winter, Spring, Fall, and Late-Fall Aerial & Carcass survey data
  - **Scenario distributions** specified by User

- Temperature profiles:
  - **Historical** timeseries
  - **Forecast** timeseries when available
  - **Scenarios** specified by user

- Modeling Choices:
  - **Mortality Sources**
  - **Development** Rates

Calibrated winter-run coefficients apply to **all** stocks.



SacPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Notes & References

SacPAS Fish Model v 4.0

Sacramento River Chinook salmon

Egg-to-Fry Modeling

Egg development, survival, and fry emergence

Make your selections:

Basic settings | Intermediate settings | Full settings

Simple selection of year for river temperature and redd data inputs for Winter-Run Chinook Salmon

---

Year

2020

Run | Reset

Citation

Columbia Basin Research, University of Washington. (2026). SacPAS Fish Model: Spawned egg to emerged fry, and juvenile migration and survival to the Delta. Available from www.cbr.washington.edu/sacramento/fishmodel.

SacPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Notes & References

SacPAS Fish Model v 4.0

Sacramento River Chinook salmon

Egg-to-Fry Modeling

Egg development, survival, and fry emergence

Make your selections:

Basic settings | Intermediate settings | Full settings

Additional options for temperature, salmon runs, and survival model;
Egg-to-Fry model outputs can be inputs to Migration and Survival modeling

---

River Temperature

- (●) **Historical:** 2020
- ( ) **Current year and forecast with NOAA temp from** NOAA CVTEMP:
  - NOAA_Leakage 25L3MTO_No_Pulse

Redds

- (●) **Historical:** Winter Carcass Survey — 2020
- ( ) **Forecast (winter-run):** 300 redds

Temperature-dependent Mortality

with critical thermal window during egg incubation prior to hatching

- (●) **Critical thermal window ON** (i.e., stage-dependent; days before hatching) (Anderson et al. 2022)
- ( ) **Critical thermal window OFF** (i.e., stage-independent; whole incubation stage) (Martin et al. 2017)

Run | Customize graphs | Reset

Send results to Migration Model

SACPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Note

SACPAS Fish Model v 4.0

Sacramento River Chinook salmon

Egg-to-Fry Modeling

Egg development, survival, and fry emergence

Make your selections:

Basic settings | Intermediate settings | Full settings

All input options available, including thiamine-dependent fry mortality and redd dewatering

---

River Temperature

- (●) **Historical:** 2020
- ( ) **Current year and forecast with NOAA temp from** NOAA CVTEMP:
  - NOAA_Leakage 25L3MTO_No_Pulse
- ( ) **Customized input or file:** Browse...

Units: (●) Celsius ( ) Fahrenheit Use Shiny tool to create temps.

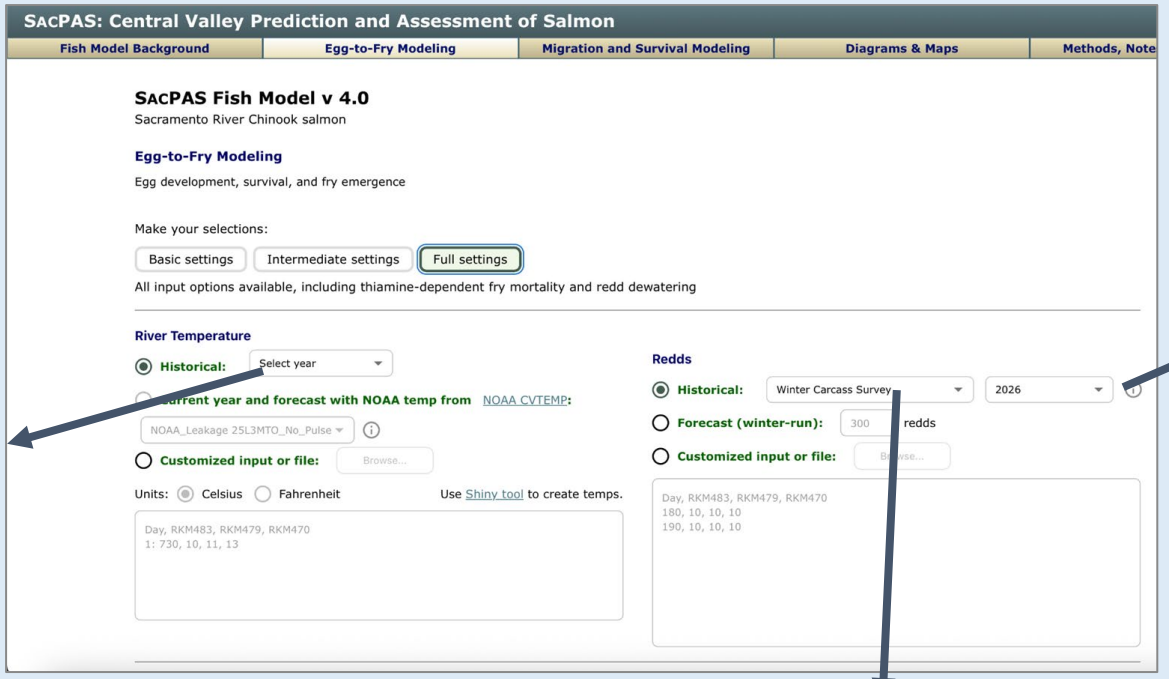
```
Day, RKM483, RKM479, RKM474
1: 730, 10, 11, 13
```

Redds

- (●) **Historical:** Winter Carcass Survey — 2020
- ( ) **Forecast (winter-run):** 300 redds
- ( ) **Customized input or file:** Browse...

```
Day, RKM483, RKM479, RKM474
180, 10, 10, 10
190, 10, 10, 10
```

13 years: 2013 - 2025
10 years: 2006 - 2015
10 years: 2016 - 2025
5 years: 2021 - 2025
Above Normal and Wet Years
Critical and Dry Years
Critical, Dry, and Below Normal Years
Wet years
Above Normal Years
Below Normal Years
Dry Years
Critical Years
2026
2025
2024
2023
2022
2021
2020



Winter Carcass Survey
Winter Aerial Survey
Spring Aerial Survey
Fall Aerial Survey
Late-Fall Aerial Survey
All Aerial Surveys

13 years: 2013 - 2025
10 years: 2006 - 2015
10 years: 2016 - 2025
5 years: 2021 - 2025
Above Normal and Wet Years
Critical and Dry Years
Critical, Dry, and Below Normal Years
Wet years
Above Normal Years
Below Normal Years
Dry Years
Critical Years
2026
2025
2024
2023
2022
2021
2020

Make your selections:

Basic settings | Intermediate settings | **Full settings**

All input options available, including thiamine-dependent fry mortality and redd dewatering

River Temperature

- (●) **Historical:** 2020
- ( ) **Current year and forecast with NOAA temp from** NOAA CVTEMP:
  - NOAA_Leakage 25L3MTO_No_Pulse
- ( ) **Customized input or file:** Browse...

Units: (●) Celsius ( ) Fahrenheit Use Shiny tool to create temps.

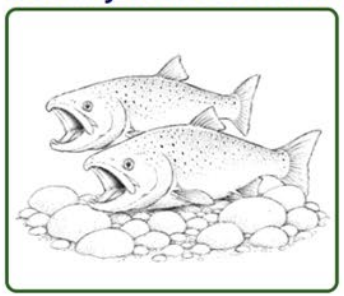
```
Day, RKM483, RKM479, RKM470
1: 730, 10, 11, 13
```

Redds

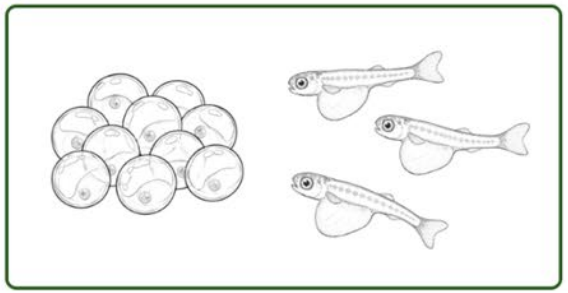
- (●) **Historical:** Winter Carcass Survey — 2020
- ( ) **Forecast (winter-run):** 300 redds
- ( ) **Customized input or file:** Browse...

```
Day, RKM483, RKM479, RKM470
180, 10, 10, 10
190, 10, 10, 10
```

Mortality effects: Redds to RBDD

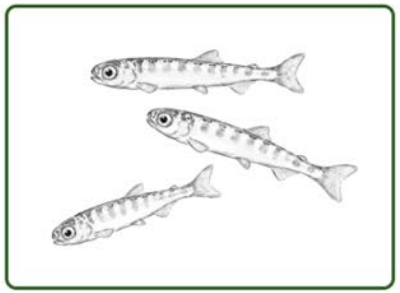


☑ **Density-dependent mortality**

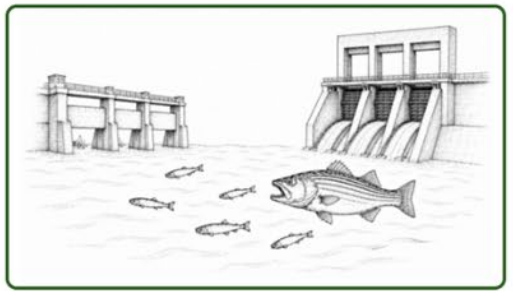


☐ **Redd dewatering**

☑ **Temperature-dependent mortality**



☑ **Thiamine-dependent Fry Mortality**



☑ **Background mortality**

Temperature-dependent Mortality

with critical thermal window during egg incubation prior to hatching

◉ **Critical thermal window ON** (i.e., stage-dependent; days before hatching) (Anderson et al. 2022)

End critical window: ◉ ATUs (°C days) 400

○ Compute hatching

TCrit: 11.9 °C

δ (days): 4 in critical window

bδ (rate): 0.5044 $°C^{-1}d^{-1}$

Background mortality and density-dependent mortality:

B (base rate): 0.4864 (background maximum survival)

Density effects per kilometer:

Carrying capacity: 84.9 per KM (averaged by reach)

○ **Critical thermal window OFF** (i.e., stage-independent; whole incubation stage) (Martin et al. 2017)

TCrit: 12.05 °C

bδ (rate): 0.02946 $°C^{-1}d^{-1}$

Background mortality and density-dependent mortality:

Base rate: 0.4404 (background maximum survival)

Density effects (Beverton-Holt):

Carrying capacity: 1226 redds total

Redd Dewatering Mortality (USFWS 2006a)

- (•) Observed KWK flows
- ( ) Customized input or file: [Browse...]

Units: (•) KCFS ( ) CFS

```
Day, KCFS
1: 730, 10
```

ACID Dam Configuration: (•) Boards out ( ) Boards in

Thiamine-dependent Fry Mortality (TDFM; Daniels, M. 2025)

Annual TDFM [0.36] ⓘ

Egg to Emergence Timing Model

- (•) Linear (Zeug et al. 2012): Target ATUs [958] degree C days
- ( ) Mechanistic (Beer and Anderson 1997): Egg mass [200] mg
- ( ) Empirical (Jensen et al. 1999)
- ( ) Power law: Days = e10.404 - 2.043*log(T°C + 7.575) (Beacham and Murray 1990)

[Run] [Customize graphs] [Reset]

☐ Get query string

Example results of Egg-to-Fry Survival outputs

Output Values

Display all

Summary Results

Redd Distribution

Pre-Hatching exposures (mean)

Pre-Hatching exposures (max)

All incubation exposure

Emergence timing

Hatch timing

Survivals to emergence

1580	Redds	12.7%	Total Survival	
Exposure to 11.9 degrees:		Survival	Mortality	
12.2%	Pre Hatch	0.996	0.004	TDM
100%	Pre Emergence	0.361	0.639	Spawner Density
		0.486	0.514	Background
Emergence Day:		1	0	Dewater *
270	Mean Day	0.73	0.27	TDFM
326	Last Day			

* Mortality switched 'off'.

Download image

Download csv file

Example results of Egg-to-Fry Survival outputs

Summary Results

Redd Distribution

Pre-Hatching exposures (mean)

Pre-Hatching exposures (max)

All incubation exposure

Emergence timing

Hatch timing

Survivals to emergence

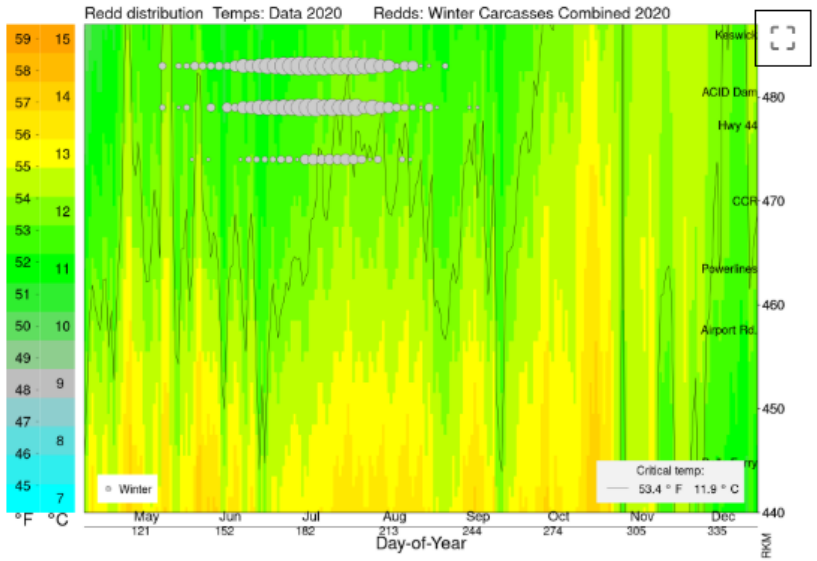
4.7% exposed to 11.9 °C prehatching

Mean Temp in 4 days pre-hatch by Reach

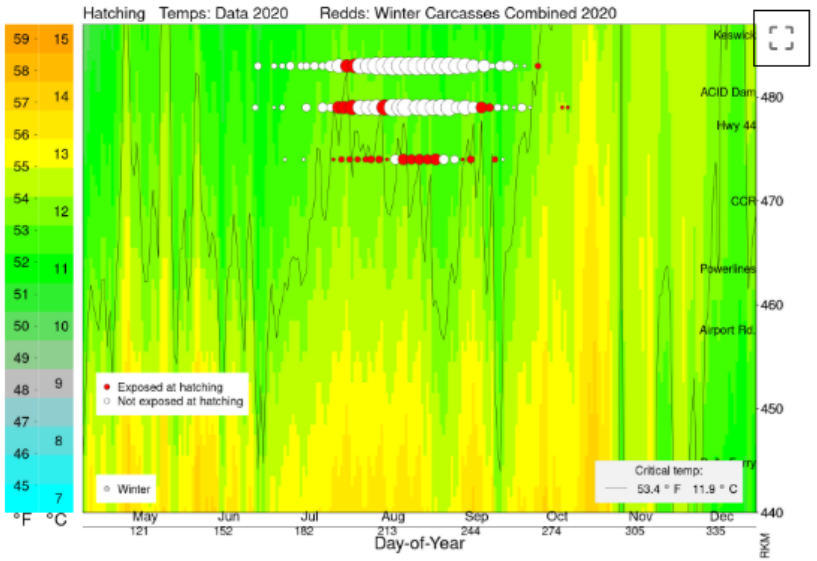
Redd day	129	135	138	140	141	144	146	147	150	153	156	158	159	161	162	164	165	167	168	170
Kes-ACID	11	11.1	11	-	11.2	11.3	-	11.3	11.5	11.6	11.6	-	11.7	-	11.8	-	11.7	-	11.7	-
ACID-Hwy44	11.3	11.2	11.1	-	-	-	-	11.4	-	11.7	11.7	-	11.8	-	11.9	-	11.9	-	11.8	-
Hwy44-ClrCk	-	-	-	11.4	-	-	11.6	-	-	-	-	11.9	-	12	-	12.1	-	11.9	-	11.9

Output Graphs

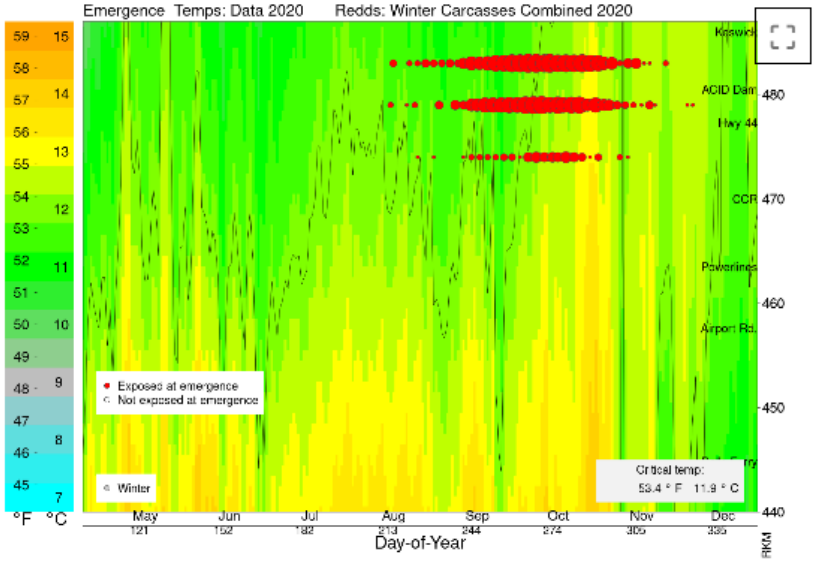
Static Plots | Interactive Plots | Animation



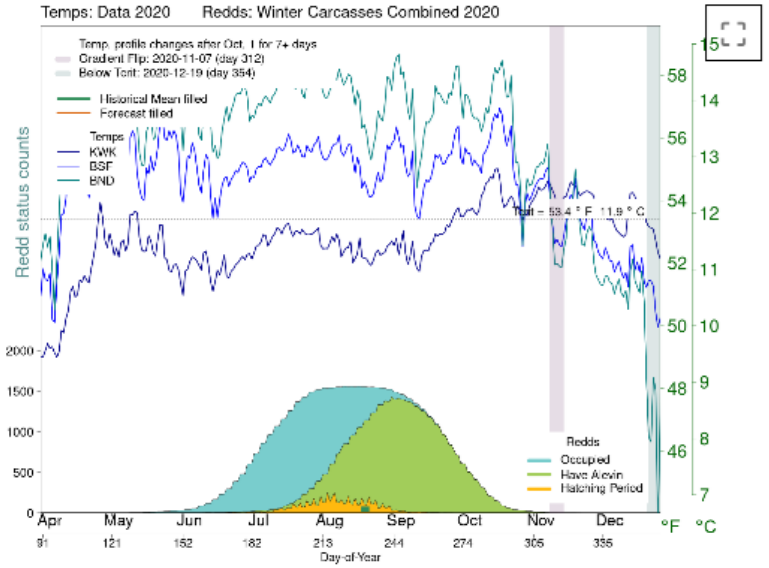
Download image



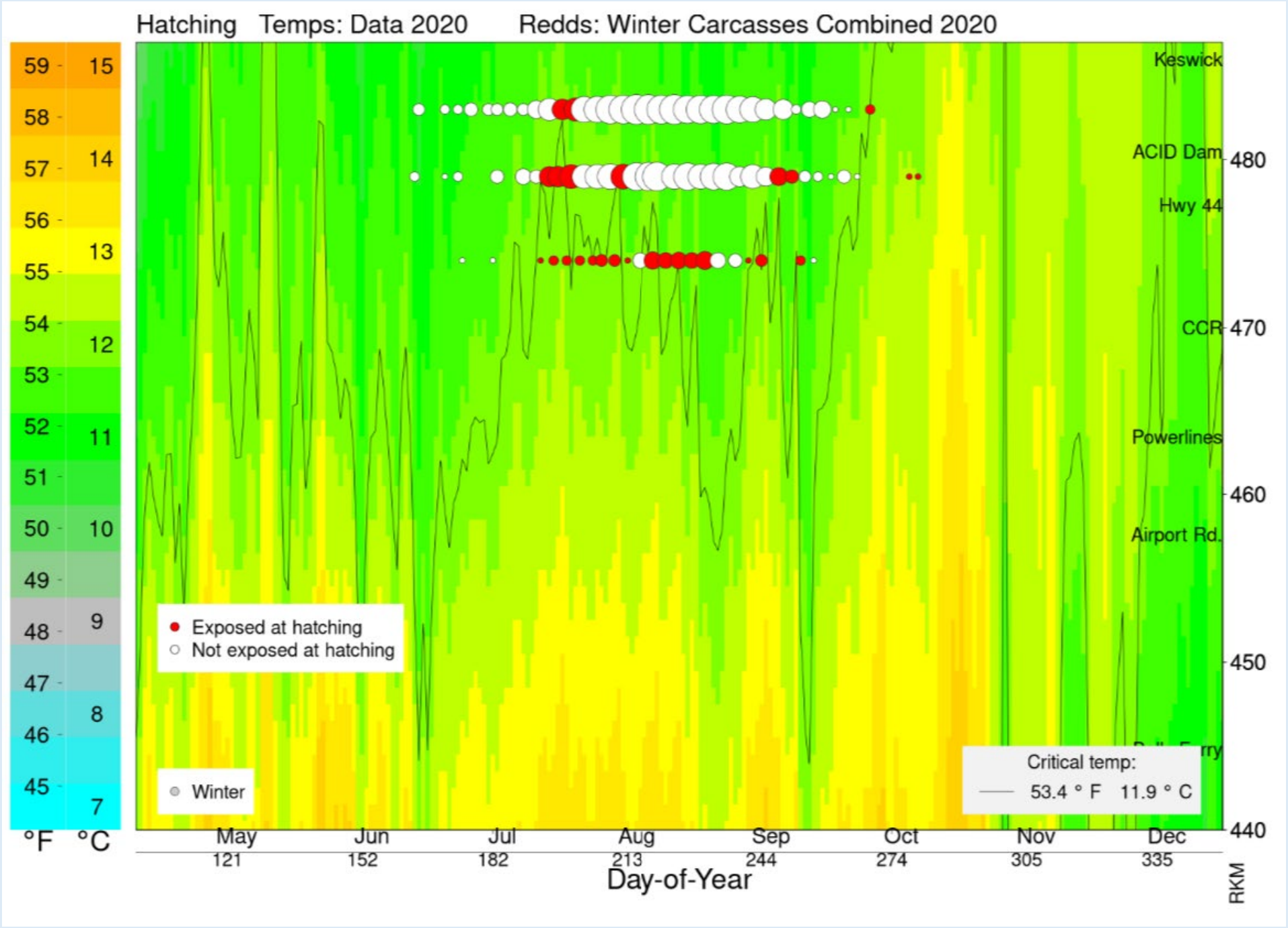
Download image

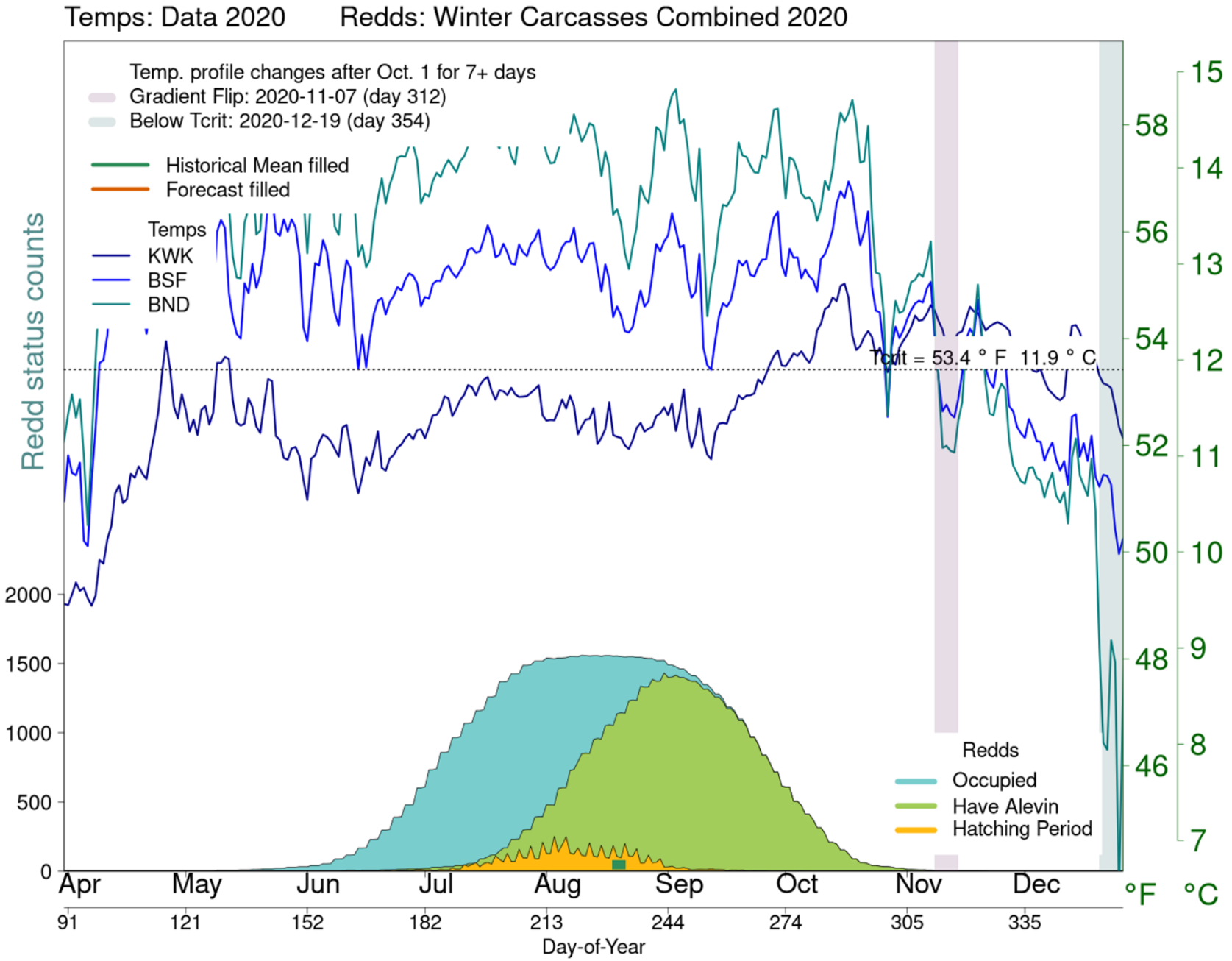


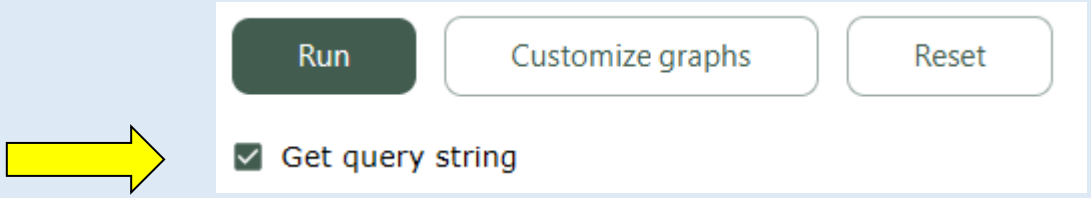
Download image



Download image


Hatching Temps: Data 2020
Redds: Winter Carcasses Combined 2020
°F
°C
59 15
58
57 14
56
55 13
54
53 12
52
51 11
50
49 10
48
47 9
46
45 8
7
Keswick
ACID Dam
Hwy 44
CCR
Powerlines
Airport Rd.
480
470
460
450
440
RKM
Exposed at hatching
Not exposed at hatching
Winter
Critical temp:
53.4 ° F 11.9 ° C
May 121
Jun 152
Jul 182
Aug 213
Sep 244
Oct 274
Nov 305
Dec 335
Day-of-Year


Temps: Data 2020
Redds: Winter Carcasses Combined 2020
Temp. profile changes after Oct. 1 for 7+ days
Gradient Flip: 2020-11-07 (day 312)
Below Tcrit: 2020-12-19 (day 354)
Historical Mean filled
Forecast filled
Temps
KWK
BSF
BND
Tcrit = 53.4 ° F 11.9 ° C
Redd status counts
2000
1500
1000
500
0
Redds
Occupied
Have Alevin
Hatching Period
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
91
121
152
182
213
244
274
305
335
Day-of-Year
58
56
54
52
50
48
46
°F
15
14
13
12
11
10
9
8
7
°C



Default, GUI-provided values are used for every parameter you did not alter.

Results Summary has several metrics:
https://www.cbr.washington.edu/sac-bin/fishmodel/getandplottemp.pl?temponly=off&TcritC=11.9&dirUseId=1793126432257&eggperredd=4991&mortality=emergemort&reddyear=2020&tdfmvalue=0.27&tempsource=dbtemp&tempyear=2020&raw=13

Grand Survival:
https://www.cbr.washington.edu/sac-bin/fishmodel/getandplottemp.pl?temponly=off&TcritC=11.9&dirUseId=1793126432257&eggperredd=4991&mortality=emergemort&reddyear=2020&tdfmvalue=0.27&tempsource=dbtemp&tempyear=2020&raw=1

Redd counts:
https://www.cbr.washington.edu/sac-bin/fishmodel/getandplottemp.pl?temponly=off&TcritC=11.9&dirUseId=1793126432257&eggperredd=4991&mortality=emergemort&reddyear=2020&tdfmvalue=0.27&tempsource=dbtemp&tempyear=2020&raw=2

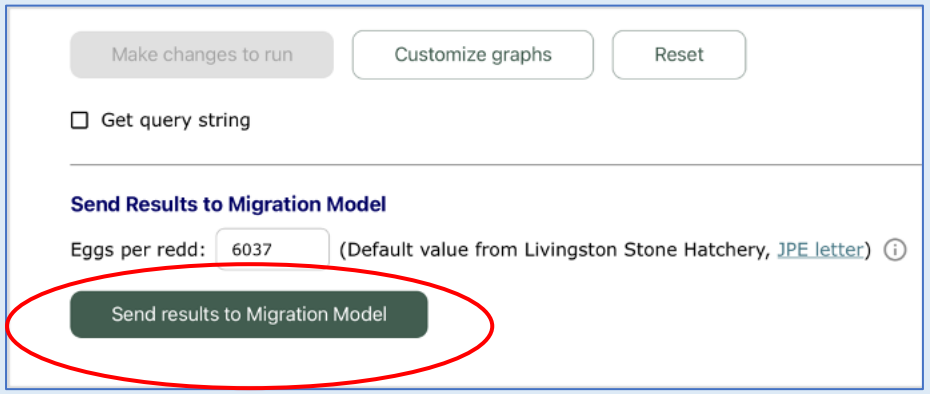
```
                    What,Value
              Redd source,Winter Carcasses Combined 2020
               Redd count,1580
                Redd year,2020
                Temp year,2020
                   TcritC,12.05
            Critical Days,4
     Prehatch Exposure %,0.3
    PreEmerge Exposure %,55.5
      Mean Emergence Day,269.2
      Last Emergence Day,326
     Incubation Survival,0.136
           TDM mortality,0.0322
 Spawner Density mortality,0.563
        Dewater mortality,0
    Background mortality,0.56
          TDFM mortality,0.27
          First Redd Day,129
          Mortality Type,emergemort
Temp. watch period in days,7
      Temp profile flips,2020-11-07
    Temp profile <TcritC,2020-11-29
```

What	Value
Redd source	Winter Carcasses Combined 2020
Redd count	1580
Redd year	2020
Temp year	2020
TcritC	12.05
Critical Days	4
Prehatch Exposure %	0.3
PreEmerge Exposure %	55.5
Mean Emergence Day	269.2
Last Emergence Day	326
Incubation Survival	0.136
TDM mortality	0.0322
Spawner Density mortality	0.563
Dewater mortality	0
Background mortality	0.56
TDFM mortality	0.27
First Redd Day	129
Mortality Type	emergemort
Temp. watch period in days	7
Temp profile flips	2020-11-07
Temp profile <TcritC	2020-11-29

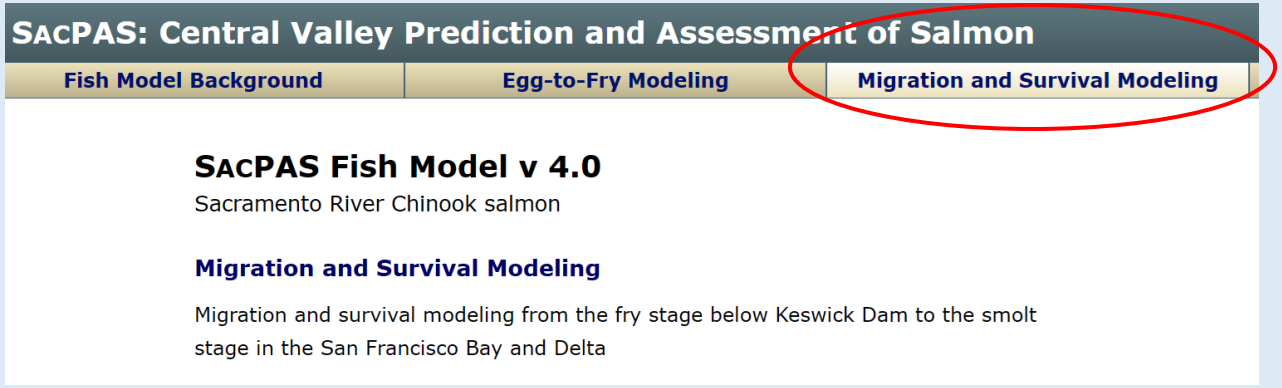
SacPAS Models: Migration and Survival



Using outputs from Egg-to-Fry model



Using RBDD passage or a scenario of timing and location

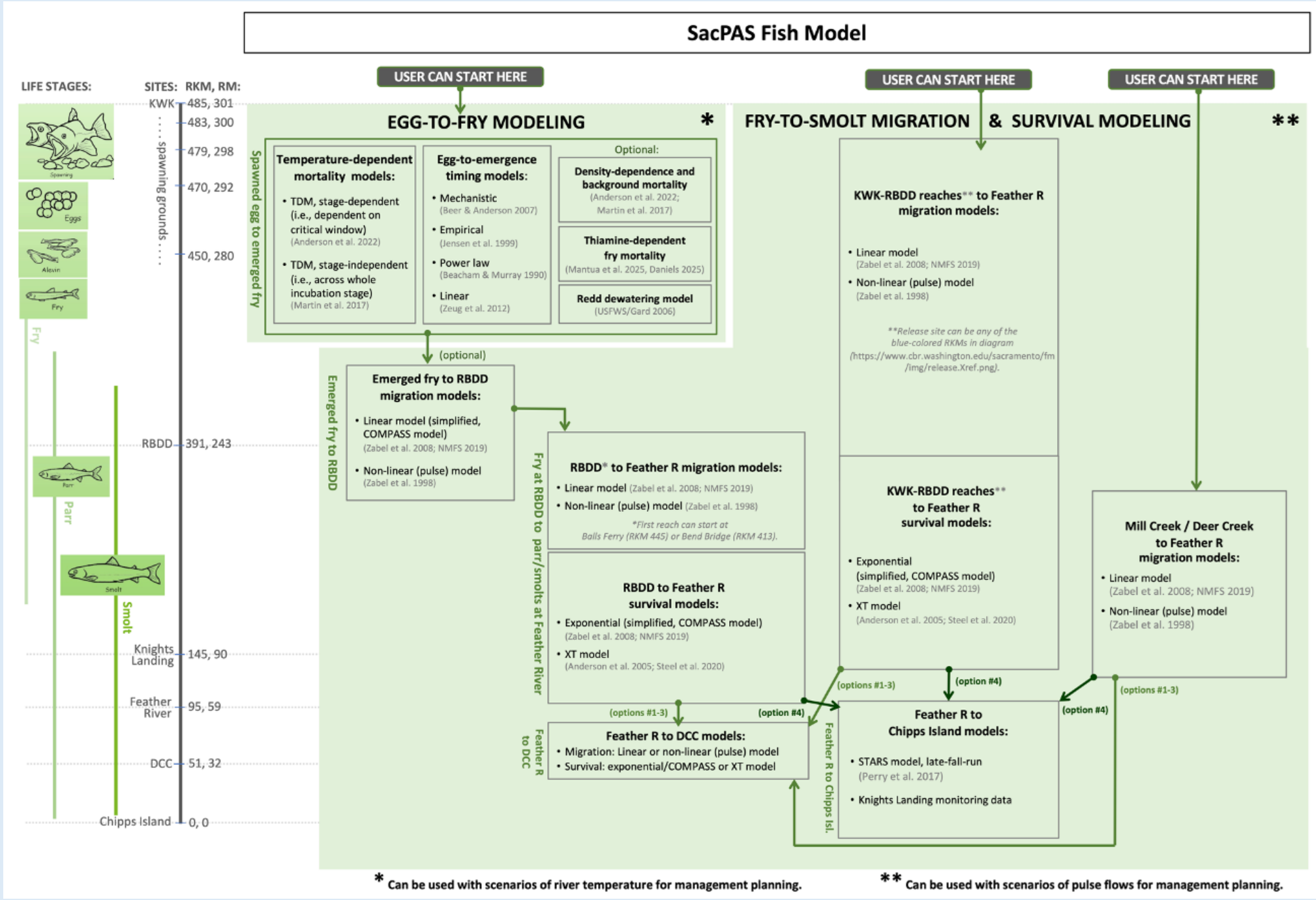


SacPAS Models: Migration and Survival



- **A Process Model using the COMPASS back-end.**
- **Simulates movement and survival on a daily basis through reaches of the Sacramento River.**
- **Outputs can be used as inputs to the STARS Model for the Delta.**

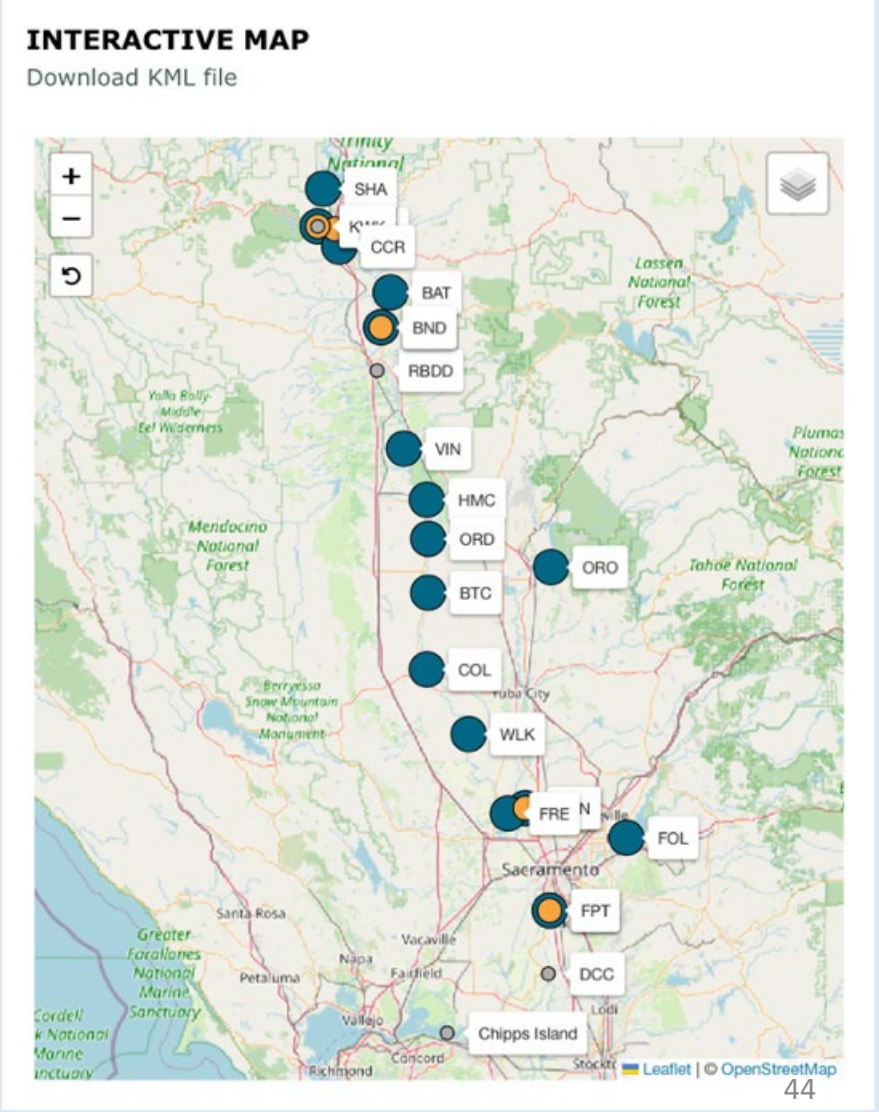
Survival, Travel time And Routing Simulation (Perry et al. 2018)


SacPAS Fish Model
LIFE STAGES:
SITES: RKM, RM:
KWK 485, 301
483, 300
479, 298
470, 292
450, 280
RBDD 391, 243
Knights Landing 145, 90
Feather River 95, 59
DCC 51, 32
Chipps Island 0, 0
spawning grounds
Spawning
Eggs
Alevin
Fry
Parr
Smolt
USER CAN START HERE
EGG-TO-FRY MODELING *
Spawned egg to emerged fry
Temperature-dependent mortality models:
• TDM, stage-dependent (i.e., dependent on critical window) (Anderson et al. 2022)
• TDM, stage-independent (i.e., across whole incubation stage) (Martin et al. 2017)
Egg-to-emergence timing models:
• Mechanistic (Beer & Anderson 2007)
• Empirical (Jensen et al. 1999)
• Power law (Beacham & Murray 1990)
• Linear (Zeug et al. 2012)
Optional:
Density-dependence and background mortality (Anderson et al. 2022; Martin et al. 2017)
Thiamine-dependent fry mortality (Mantua et al. 2025, Daniels 2025)
Redd dewatering model (USFWS/Gard 2006)
(optional)
Emerged fry to RBDD
Emerged fry to RBDD migration models:
• Linear model (simplified, COMPASS model) (Zabel et al. 2008; NMFS 2019)
• Non-linear (pulse) model (Zabel et al. 1998)
Fry at RBDD to parr/smolts at Feather River
RBDD* to Feather R migration models:
• Linear model (Zabel et al. 2008; NMFS 2019)
• Non-linear (pulse) model (Zabel et al. 1998)
*First reach can start at Balls Ferry (RKM 445) or Bend Bridge (RKM 413).
RBDD to Feather R survival models:
• Exponential (simplified, COMPASS model) (Zabel et al. 2008; NMFS 2019)
• XT model (Anderson et al. 2005; Steel et al. 2020)
(options #1-3)
(option #4)
Feather R to DCC
Feather R to DCC models:
• Migration: Linear or non-linear (pulse) model
• Survival: exponential/COMPASS or XT model
USER CAN START HERE
USER CAN START HERE
FRY-TO-SMOLT MIGRATION & SURVIVAL MODELING **
KWK-RBDD reaches** to Feather R migration models:
• Linear model (Zabel et al. 2008; NMFS 2019)
• Non-linear (pulse) model (Zabel et al. 1998)
**Release site can be any of the blue-colored RKMs in diagram (https://www.cbr.washington.edu/sacramento/fm/img/release.Xref.png).
KWK-RBDD reaches** to Feather R survival models:
• Exponential (simplified, COMPASS model) (Zabel et al. 2008; NMFS 2019)
• XT model (Anderson et al. 2005; Steel et al. 2020)
Mill Creek / Deer Creek to Feather R migration models:
• Linear model (Zabel et al. 2008; NMFS 2019)
• Non-linear (pulse) model (Zabel et al. 1998)
(options #1-3)
(option #4)
(options #1-3)
(option #4)
Feather R to Chipps Isl.
Feather R to Chipps Island models:
• STARS model, late-fall-run (Perry et al. 2017)
• Knights Landing monitoring data
* Can be used with scenarios of river temperature for management planning.
** Can be used with scenarios of pulse flows for management planning.

SacPAS Models: Migration and Survival



- Release Distributions:
  - **Output** from Egg-to-Fry model
  - **Historical Data** of RBDD passage (winter-run)
  - **Scenario distributions** specified by User
- Flow timeseries:
  - **Historical** timeseries at a point or within system
  - **Forecast** timeseries when available
  - **Scenarios** specified by user
- Modeling Choices:
  - **Survival**
  - **Migration** Rates



SACPAS: Central Valley Prediction and Assessment of Salmon

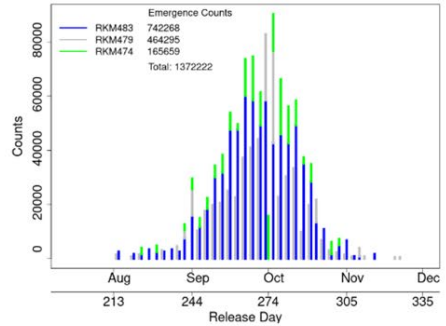
Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Me

SACPAS Fish Model v 4.0

Sacramento River Chinook salmon

Migration and Survival Modeling

Migration and survival modeling from the fry stage below Keswick Dam to the smolt stage in the San Francisco Bay and Delta



River Flow Inputs

- (●) **Historical system flows:** 2020 - 2021
- ( ) **Fixed site flows:** 2024 - 2025 at: BND
- ( ) **Customized input or file:** Browse...

Units: ( ) CFS (●) KCFS

```
Day, KCFS
1: 730, 15
```

- ( ) **Constant flows:** 2 KCFS

Fish Release Inputs

- ( ) **Passage estimates at Red Bluff Diversion Dam:** 2020
- (●) **Customized input or file:** Browse...

```
RKM,Day,Count
RKM483,215,2475
RKM483,221,1650
RKM483,224,1650
RKM483,227,3299
RKM483,230,2475
```

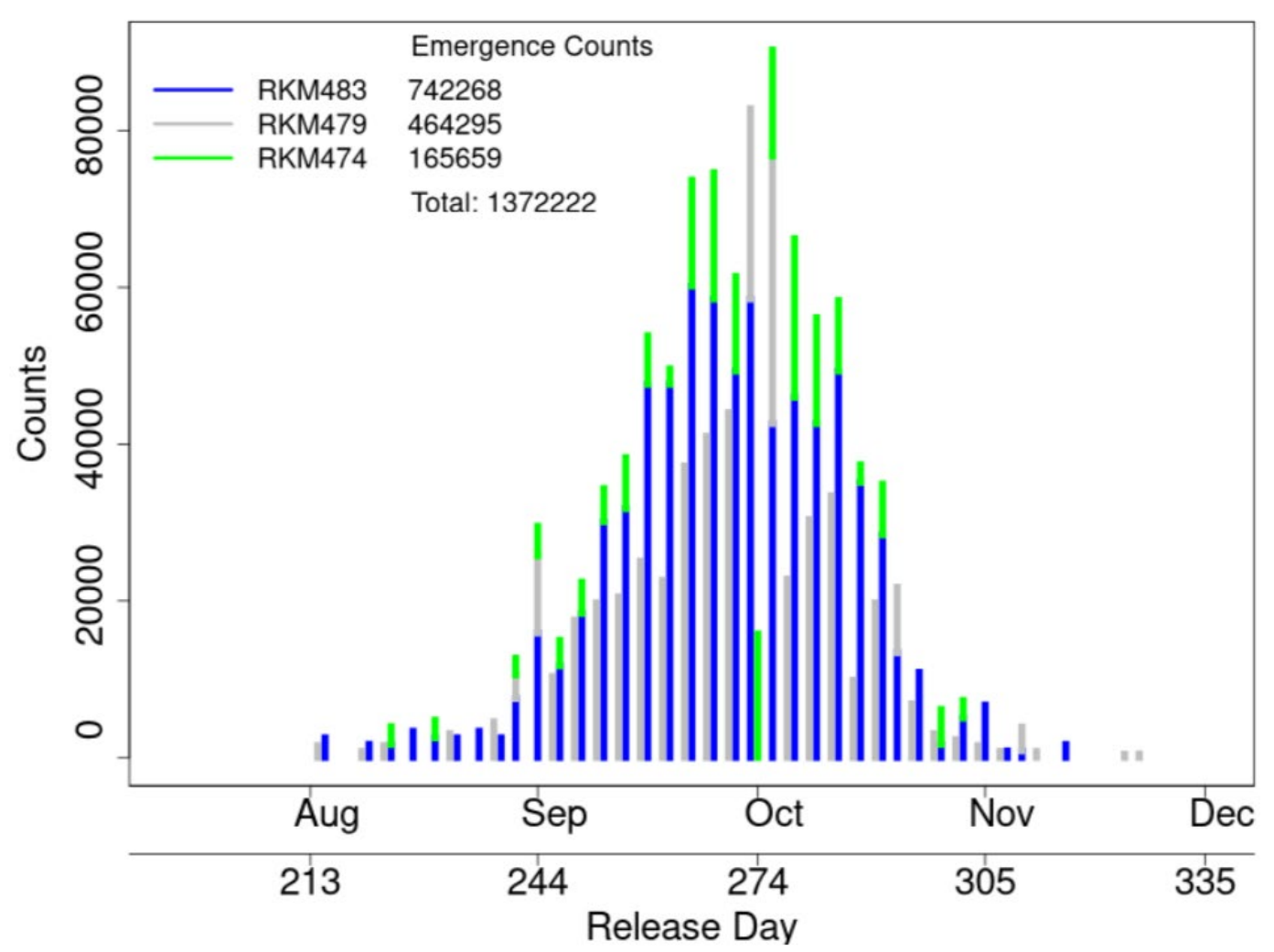
1580	Redds
Exposure to 11.9 degrees:	
12.2%	Pre Hatch
100%	Pre Emergence
Emergence Day:	
270	Mean Day
326	Last Day
12.7%	Total Survival

Surv.	Mort.	
0.996	0.004	TDM
0.361	0.639	Spawner Density
0.486	0.514	Background
1	0	Dewater
0.73	0.27	TDFM

* Mortality switched 'off'.

Additional Model Configurations

Run | Customize graphs | Reset



1580 Redds

Exposure to 11.9 degrees:

12.2% Pre Hatch

100% Pre Emergence

Emergence Day:

270 Mean Day

326 Last Day

12.7% Total Survival

Surv.	Mort.	
0.996	0.004	TDM
0.361	0.639	Spawner Density
0.486	0.514	Background
1	0	Dewater
0.73	0.27	TDFM

* Mortality switched 'off'.

SacPAS Models: Migration and Survival



SACPAS: Central Valley Prediction and Assessment of Salmon

Fish Model Background | Egg-to-Fry Modeling | Migration and Survival Modeling | Diagrams & Maps | Methods, Notes & References

SACPAS Fish Model v 4.0

Sacramento River Chinook salmon

Migration and Survival Modeling

Migration and survival modeling from the fry stage below Keswick Dam to the smolt stage in the San Francisco Bay and Delta

River Flow Inputs

- (●) **Historical system flows:** 2020 - 2021
- ( ) **Fixed site flows:** 2024 - 2025 at: BND
- ( ) **Customized input or file:** Browse...

Units: ( ) CFS (●) KCFS

Day, KCFS
1: 730, 15

- ( ) **Constant flows:** 2 KCFS

Fish Release Inputs

- (●) **Passage estimates at Red Bluff Diversion Dam:** 2020
- ( ) **Customized input or file:** Browse...

RKM,Day,Count
RKM483,270,1000

Additional Model Configurations

Run | Customize graphs | Reset

SacPAS Models: Migration and Survival



River Migration Modeling Configurations

◉ **Linear model**

Above Red Bluff Diversion Dam: Fish_Velocity (miles / day) = 1 + 0.05 x River_Velocity

Below Red Bluff Diversion Dam: Fish_Velocity (miles / day) = 1 + 0.07 x River_Velocity

○ **Non-linear model with flow and date threshold triggers**

Explore pulse-flow migration model parameters

Fish_Velocity (miles / day) = 1 + 0.5 x River_Velocity ÷ (1 + exp (- 0.8 x (Flow – 11 KCFS) – 0.04 x (day – 350))

Fish_Velocity variance: 50

cbr.washington.edu/shiny/MIGR.DISTRIB/

Exploratory fish migration rate model

COLUMBIA BASIN RESEARCH

Parameters below control the Fish velocity relationship to river velocity

alpha 0.85 **alpha2** 0.1

B0 0 **B1** 0.5

Velocity variance 50 **... and display range (%)** 80

Critical Flow (kcfs) 10.8

Example Flow (kcfs) 1 13 70

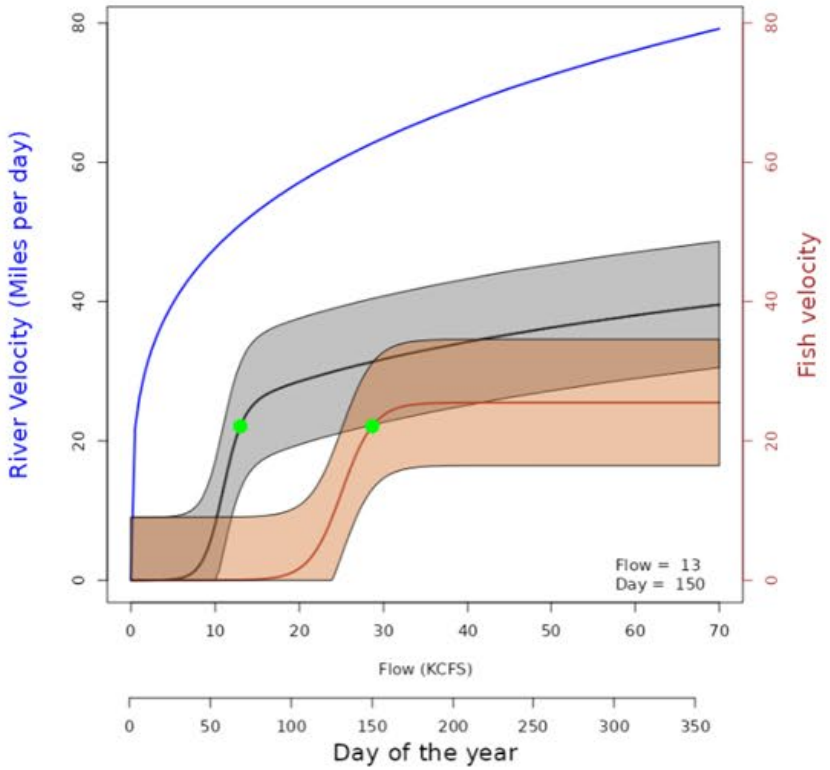
Critical Day of year 150

Example Day of year 1 150 365

Velocity of river is related to flow volume.

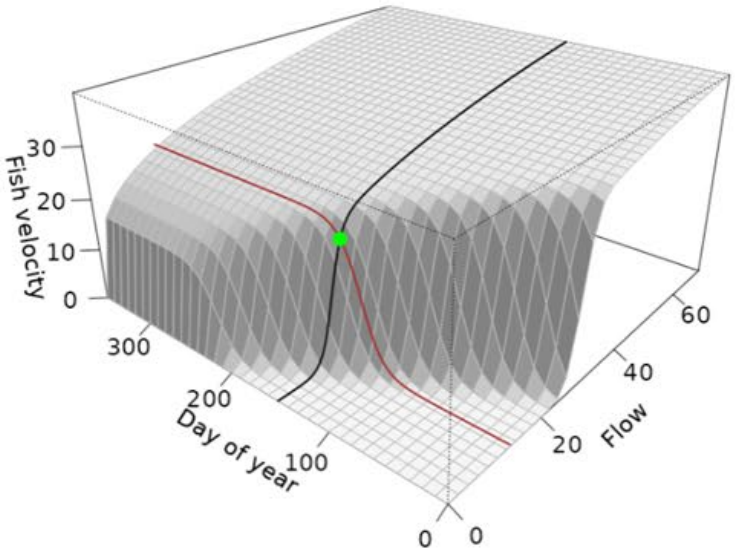
p0 (exponent) 0.2607 **p1** 1.598

Example migration rate model that initiates rapid migration at a critical flow and/or after a certain time in the year



River velocity (miles/day) = 1.598 *Flow^ 0.2607 * 16.34

Fish velocity = 0 + 0.5 x River_Velocity / (1+ exp(- 0.85 (Flow - 10.8) - 0.1 (Day - 150))



SacPAS Models: Migration and Survival



Survival Modeling Configurations

Explore survival model parameters

(●) **XT model (Anderson et al. 2006; Steel et al. 2020)**

xt0 intercept mean free-path length (1 / miles): 0.01012

xt1 flow-time scale parameter encounter speed (miles / day): 1.5227

( ) **Exponential model (simplified from Zabel et al. 2008)**

Distance (X) parameter: 0.0035

Time (T) parameter: 0.0325

Sacramento River Chinook Survival Rate Modeling

Modeling | Documents and Background

COLUMBIA BASIN RESEARCH

Flow range (kcfs)

0 — 20 — 50

Distance (miles)

0 — 44 — 100

Parameters for base survival model

pX	pT
0.0035	0.035

Parameters for XT survival model (in original Steel et al. 2020 units)

λ km	0.0065 1/KM 95.6956 Miles 0.0104 1/Miles
154	
ω cm/s	1.2351 Miles/Day 1.9876 KM/Day
2.3	

Velocity (miles per day) of river is related to flow volume (kcfs):

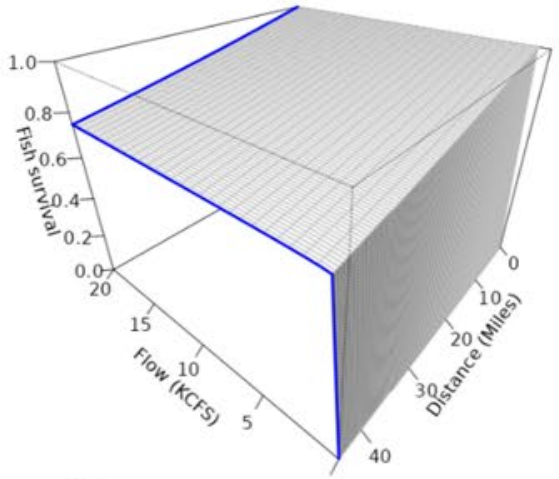
p1	p0 (exponent)
1.6	0.26

Fish Velocity proportion of River Velocity:

Speed Scalar	X-axis
0.5	Flow

Fish Velocity Variance: and use this range of the velocity distribution

Velocity variance	vVar effect band (%):
50	80



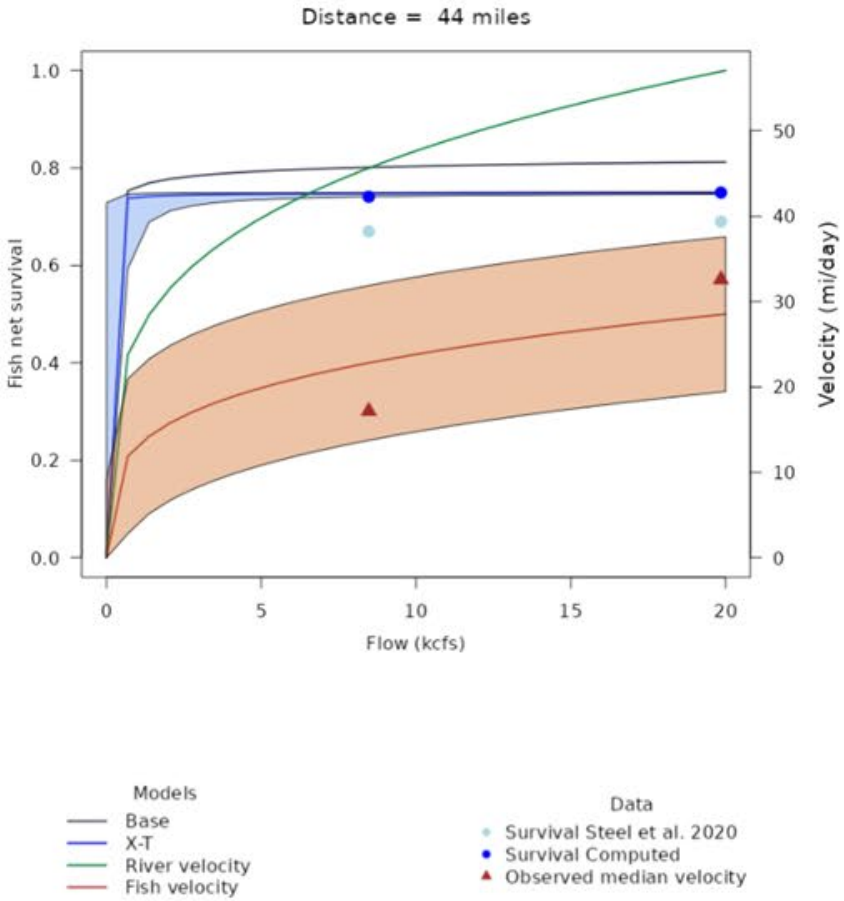
$$S = e^{-(p_X \cdot \text{distance} + p_T \cdot \text{time})}$$

$$S = e^{-\frac{1}{\lambda}\cdot\sqrt{\text{distance}^2 + \omega^2 \cdot \text{time}^2}}$$

where: $$\text{time} = \frac{\text{distance}}{\text{velocity}}$$

$$\text{velocity} = p_1 \cdot flow^{p_0} \cdot 16.34$$

Survival = exp(- (0.0035 x Distance + 0.035x Time))
Survival = exp(- 1/154 x sqrt(Distance^2 + 2.3x Time^2)))
River velocity (mi/day) = (1.6 x Flow^0.26) x 16.34 (mi/day)/(ft/sec)
Fish velocity (mi/day) = 0.5 x River velocity
Steel et al. (2020) data shown.



SacPAS Models: Delta Survival



Delta Migration Modeling Configurations

Ordered from simple to complex and realistic. See SacPAS Fish Model manual for more details.

- ○ **Continue migration model to DCC**
- ○ **Model DCC fish passage proportional to DCC flow**
  - ◉ Observed flow will match above years
  - ○ 10 year average; also default with user flow
  - ○ Customized input or file: Browse...

  Units: ○ CFS ◉ KCFS

  Day, KCFS
  1: 730, 15

- ○ **Simple model of DCC operations and effects**

  DCC Flow % when open: 25 %

- ◉ **STARS (Perry et al. 2018) model of Delta passage (recommended)**

  Both STARS and Simple use these controls:

  Daily catch trigger value: 3 at Feather River Confluence

  Days below trigger before re-opening: 3

  Days lag between trigger and action: 2

  Passage-To-Trigger ratio: 100

  Scheduled closure:

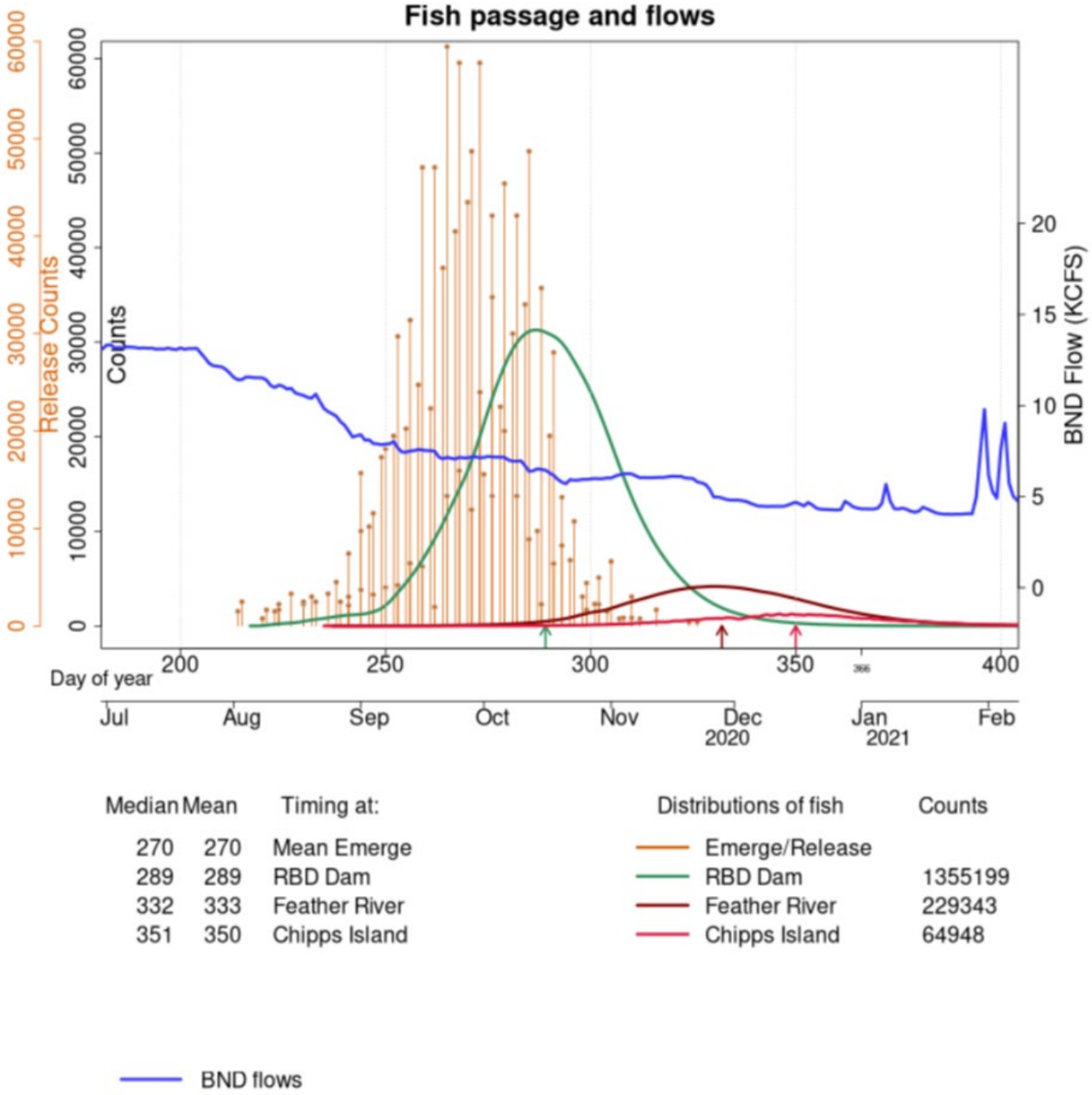
  1:140
  335:365

SacPAS Models: Delta Survival



STARS : Survival, Travel time And Routing Simulation (Perry et al. 2018)

- Inputs:
  - Migration and Survival model outputs
- Flow timeseries:
  - **Historical** timeseries from Migration and Survival Model
  - **Scenarios** specified by user
- Modeling Choices:
  - **DCC** gate status and controls



Passage Model Results

Stock:	Upload
Mean emergence:	269 (Day: 270)
Location(s):	RKM474 RKM479 RKM483
Flows:	2020 - 2021 retro

Release to RBD Dam

Mean arrival:	287 (18.2 Days)
Survival:	12.7% (previously computed)

RBD Dam to Feather River

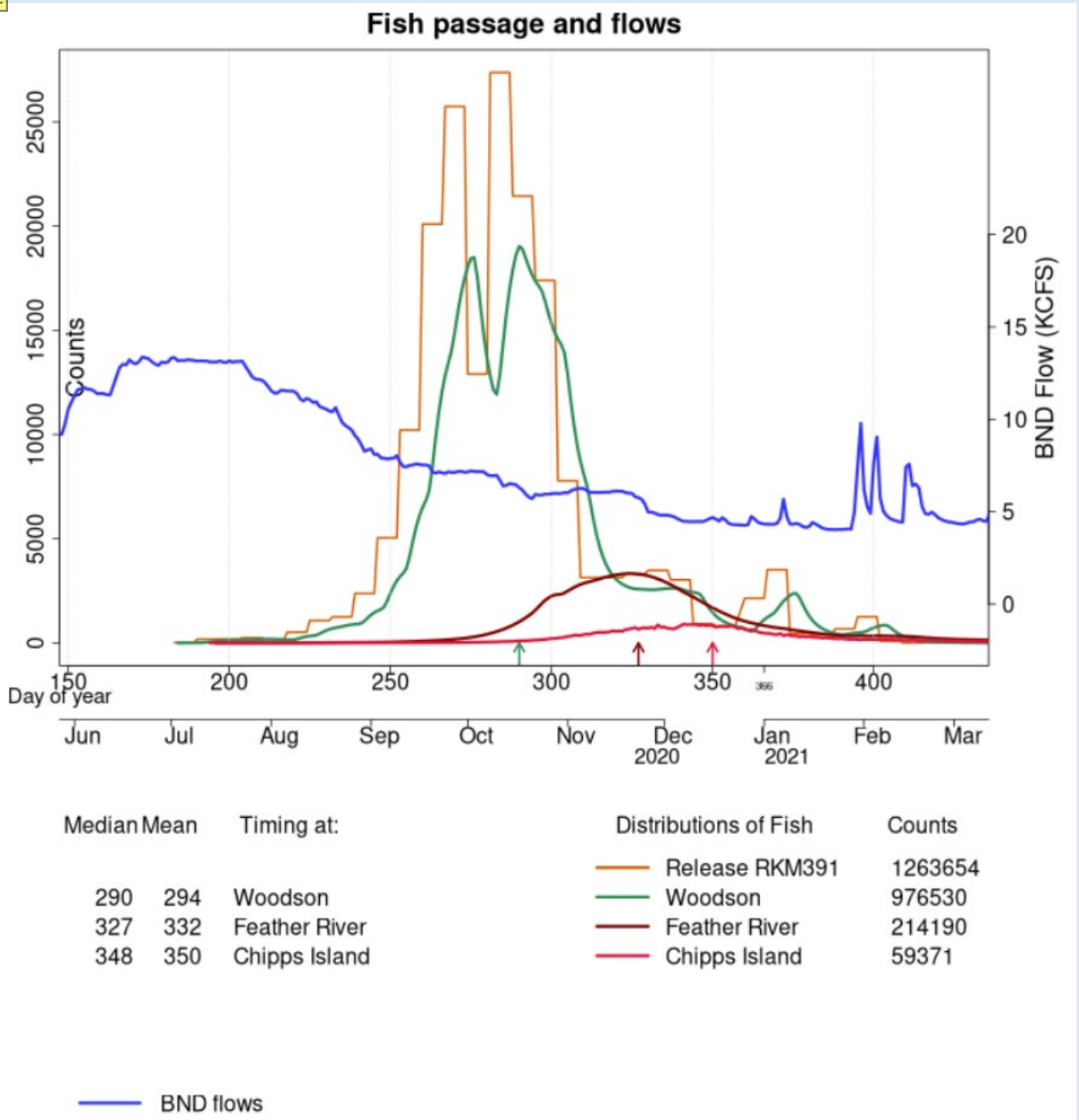
Mean arrival:	331 (44.1 Days)
Survival:	16.89%

Feather River to Chipps Island (Delta)

Mean arrival:	349 (17.6 Days)
Survival:	28%

Emergence location(s) to Chipps Island

In-River Travel Time:	79.9 Days
Survival including egg stage:	4.72%



Passage Model Results

Stock:	Winter_Chinook
Mean release:	286 (Day: 287)
Location(s):	RKM391
Flows:	2020 - 2021 retro

RBD Dam to Woodson

Mean arrival:	292
Survival:	77.3%

RBD Dam to Feather River

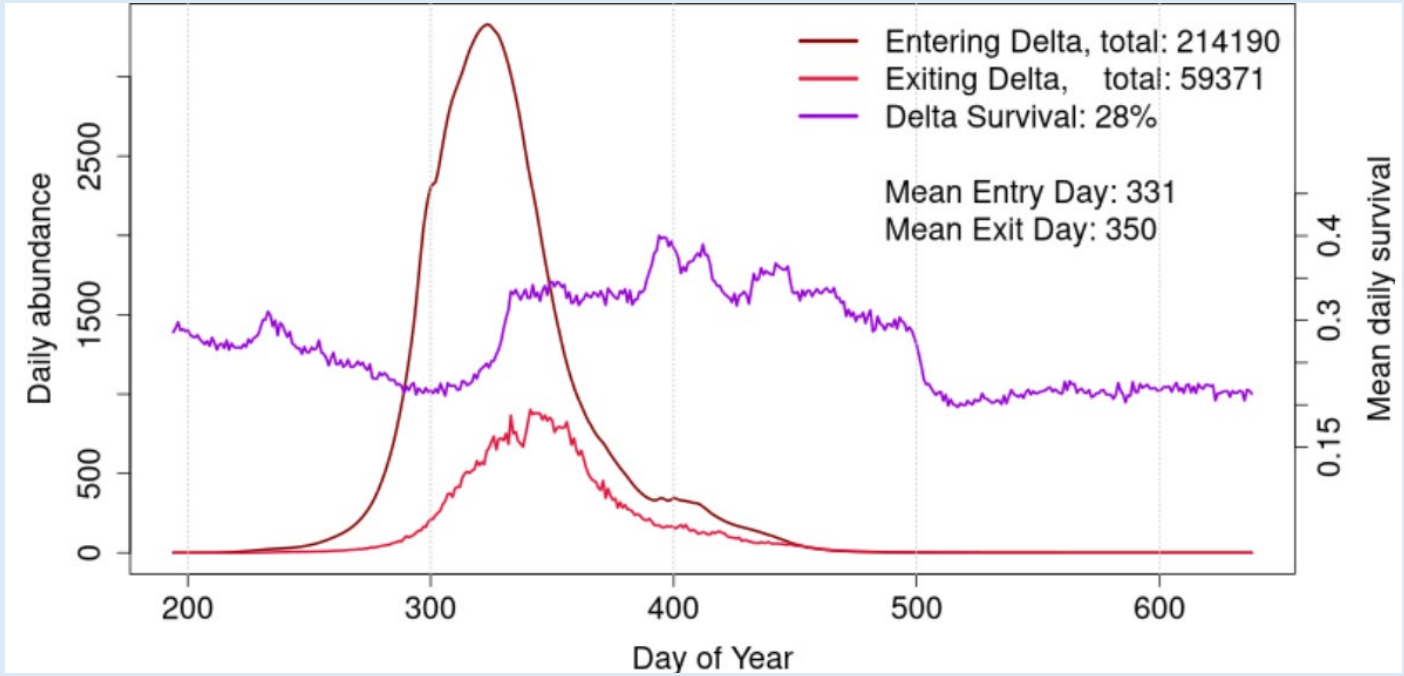
Mean arrival:	330 (37.9 Days)
Survival:	17%

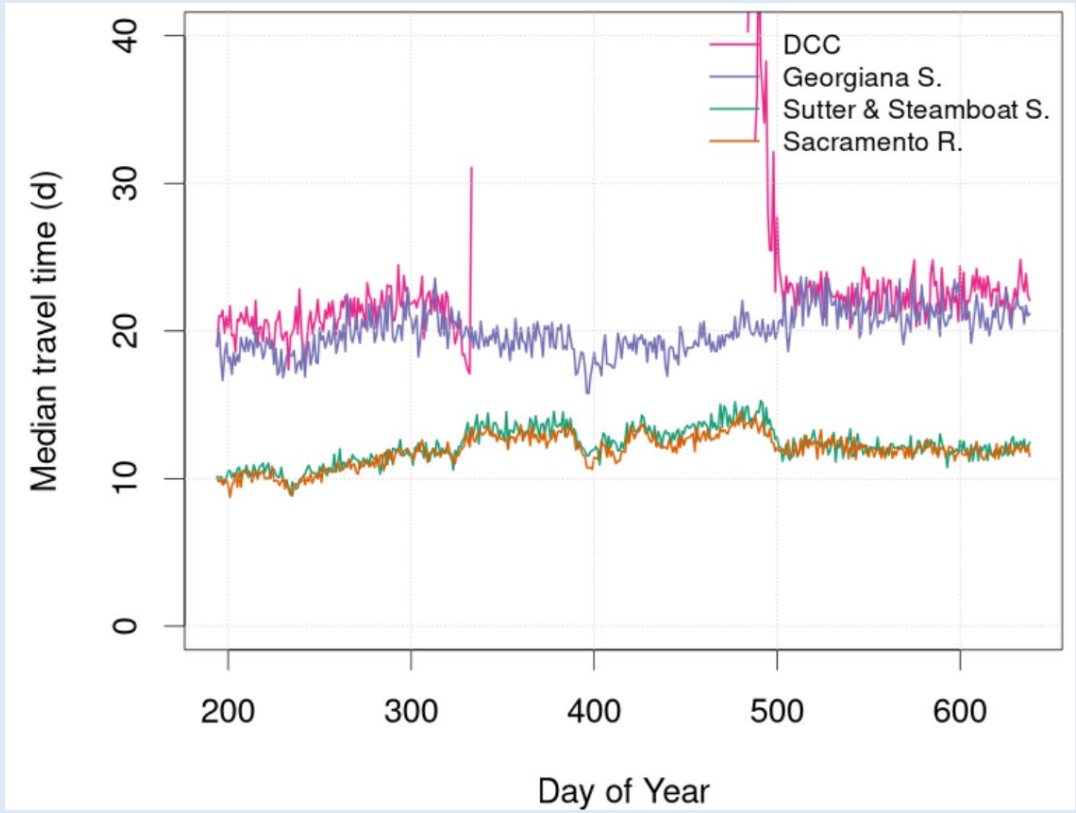
Feather River to Chipps Island (Delta)

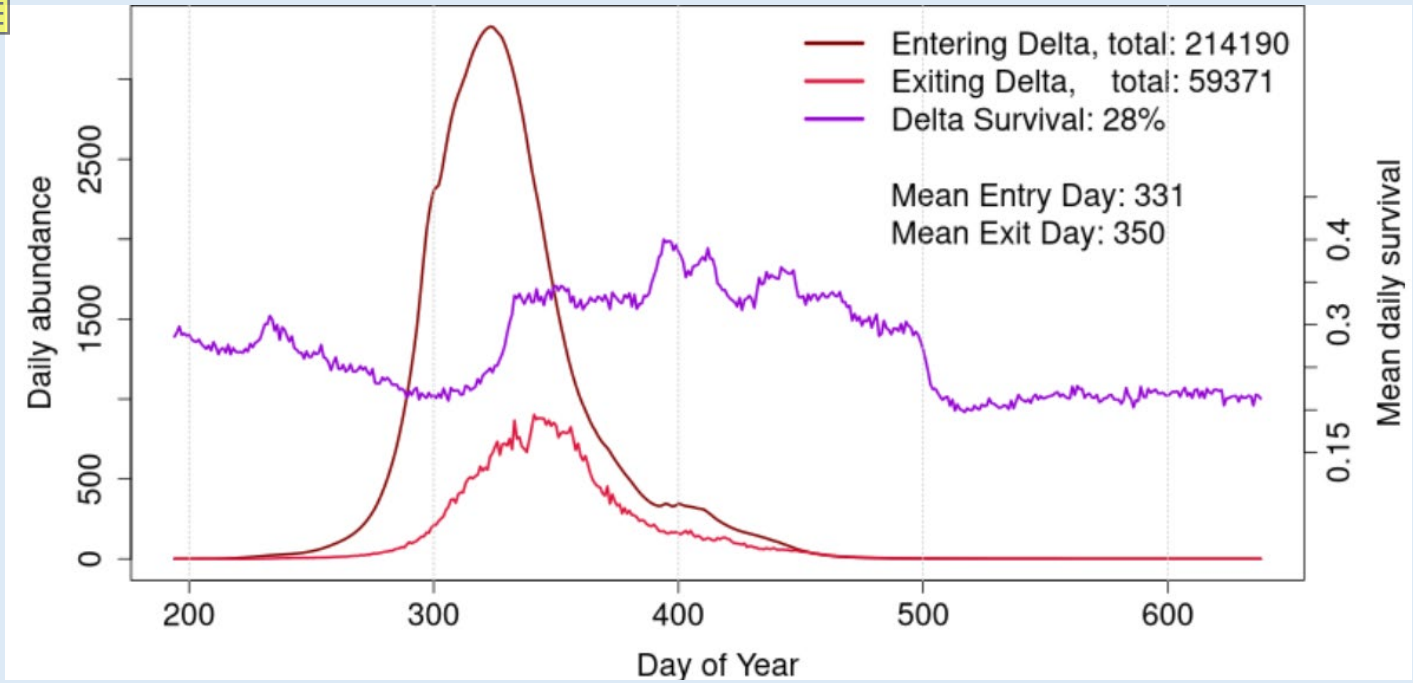
Mean arrival:	349 (18.9 Days)
Survival:	28%

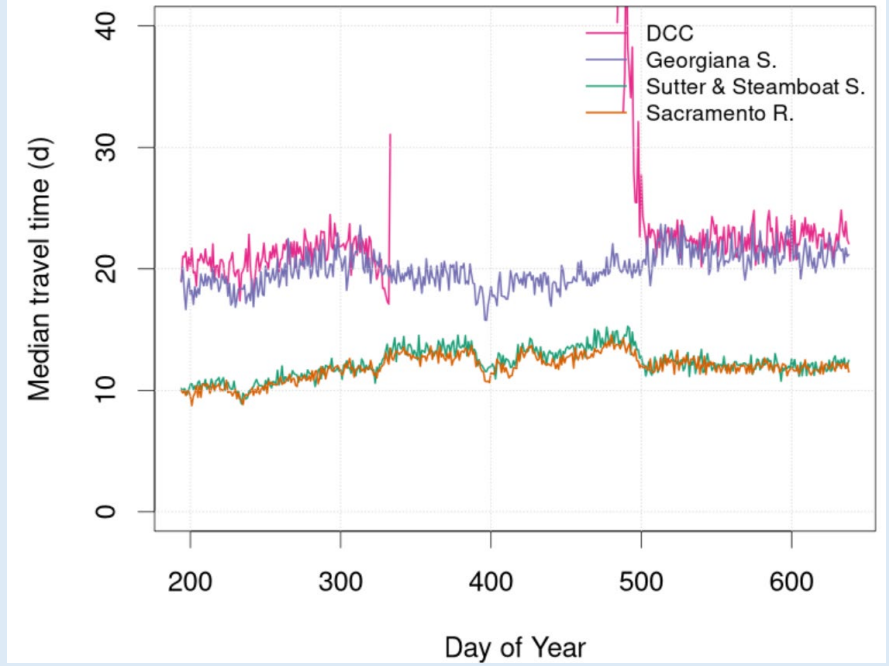
RBD Release to Chipps Island

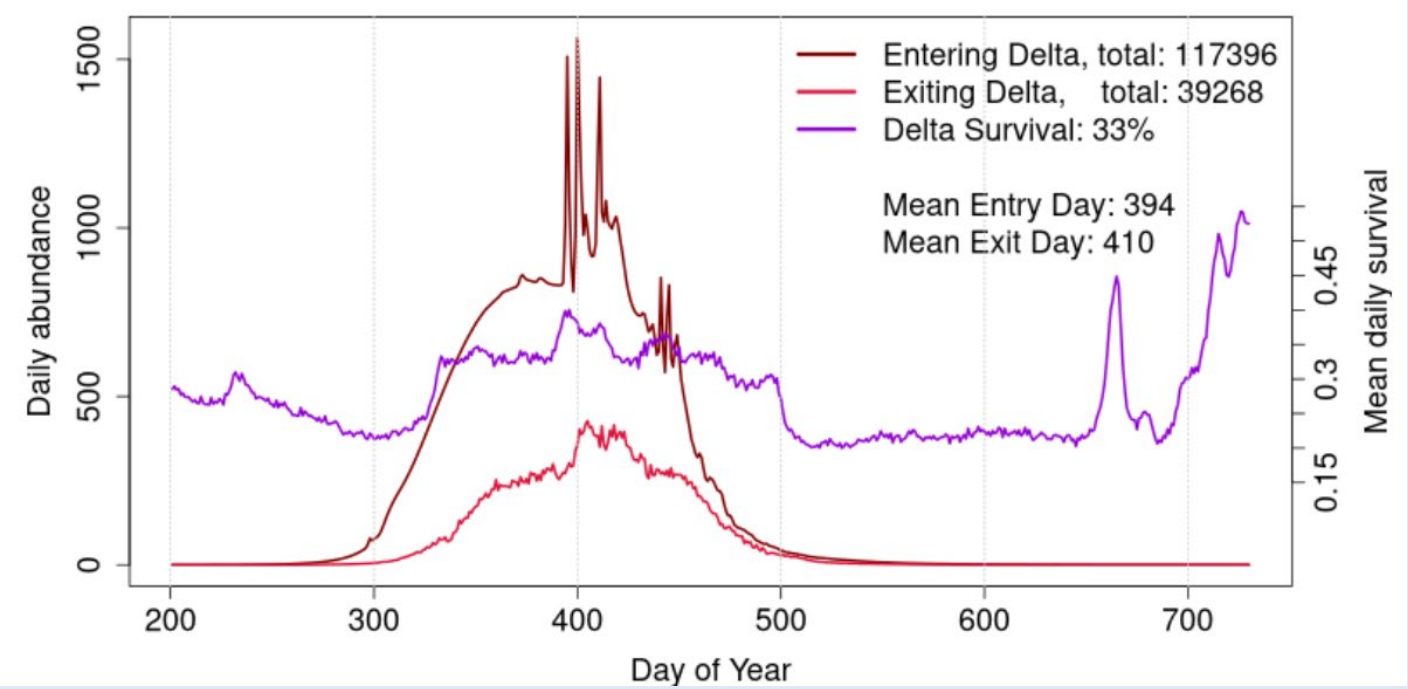
In-River Travel Time:	63.2 Days
Survival:	4.75%

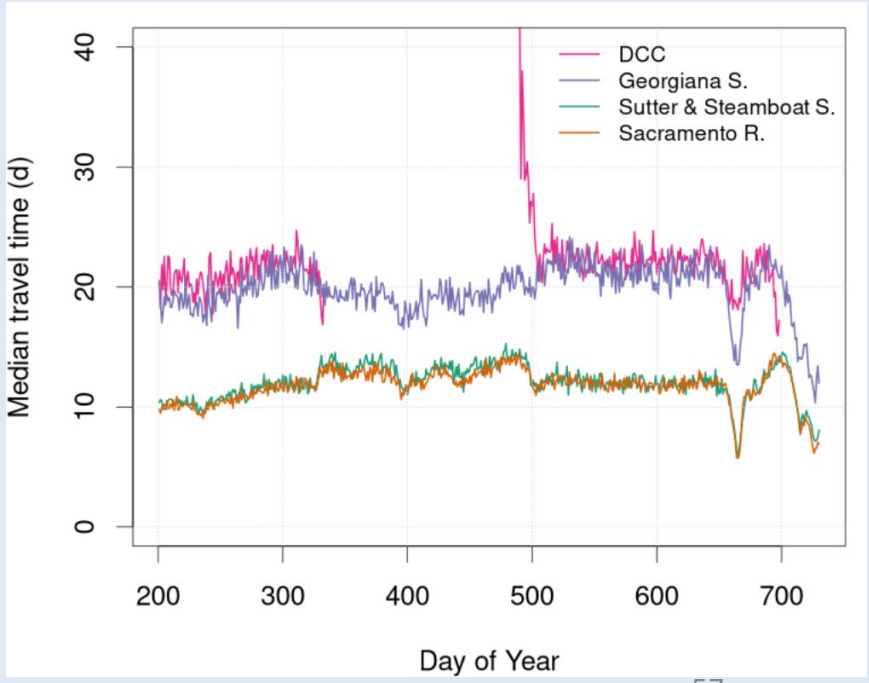

Entering Delta, total: 214190
Exiting Delta, total: 59371
Delta Survival: 28%
Mean Entry Day: 331
Mean Exit Day: 350
Daily abundance
0
500
1500
2500
Mean daily survival
0.15
0.3
0.4
200
300
400
500
600
Day of Year


DCC
Georgiana S.
Sutter & Steamboat S.
Sacramento R.
Median travel time (d)
0
10
20
30
40
200
300
400
500
600
Day of Year


Entering Delta, total: 214190
Exiting Delta, total: 59371
Delta Survival: 28%
Mean Entry Day: 331
Mean Exit Day: 350
Daily abundance
Mean daily survival
Day of Year


DCC
Georgiana S.
Sutter & Steamboat S.
Sacramento R.
Median travel time (d)
Day of Year


Entering Delta, total: 117396
Exiting Delta, total: 39268
Delta Survival: 33%
Mean Entry Day: 394
Mean Exit Day: 410
Daily abundance
Mean daily survival
Day of Year


DCC
Georgiana S.
Sutter & Steamboat S.
Sacramento R.
Median travel time (d)
Day of Year

SacPAS Fish Model

W. Nicholas Beer and Jennifer L. Gosselin

SacPAS
CENTRAL VALLEY PREDICTION AND ASSESSMENT OF SALMON
COLUMBIA BASIN RESEARCH
UNIVERSITY of WASHINGTON

- **SacPAS Fish Model Framework and Decision Support**

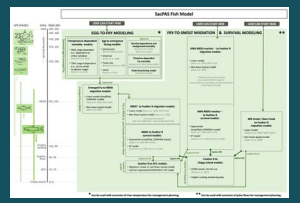




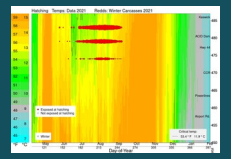
- **SacPAS Models**
  - Egg-to-Fry Survival (v4.0)
  - Migration & Survival
  - Delta Survival

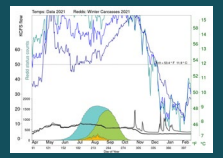


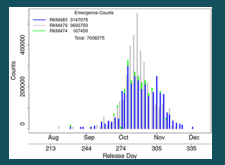
- **User Interface & Resources**
  - User Interface
  - SacPAS Fish Model manual

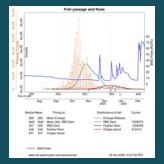


- **Examples**









Acknowledgments

We are grateful for the US Bureau of Reclamation for funding our SacPAS work. We thank Lisa Elliott (GOTR) and Josh Israel.

We also thank the field biologists and agencies who collect, curate and provide data:

- Redds and carcass survey data (CDFW, PSMFC)
- RBDD juvenile passage estimates (USFWS)
- Juvenile fish monitoring (CDFW, USFWS)
- Environmental data (CDEC)
- Temperature forecasts (NOAA)
- Fecundity (LSNFH)
- TDFM estimates (NOAA)

