Survival Analyses in Support of NOAA’s Draft Biological Opinion on California WaterFix

Russell W. Perry, USGS, Western Fisheries Research Center
A. C. Pope, J. G. Romine, A. Blake, and J. Burau, USGS
P, Brandes, USFWS,
A. Ammann and C. Michel, NMFS

23 January 2017
Overview

• New Bayesian Mark-Recapture Model
  – Overview of methods and results
  – Forms basis for BiOp Analyses

• Using these models for Cal WaterFix
  – Simulating survival under NAA and PA
  – Evaluating NDD Bypass Rules
  – Shaping operations with survival criteria
Acoustic Telemetry Data for Analysis

- Data from 2 Acoustic Telemetry Studies
  - NOAA (CALFED) and USFWS (Delta Action 8)
  - Late-fall Chinook salmon
  - Vemco acoustic telemetry
  - 2,170 Acoustic tagged fish
  - 5 Years (2007 – 2011)
  - 17 unique release groups
  - Migrated between late Nov. and early March
- Sacramento River Flows at Freeport
  - ~6,000 – 77,000 ft³/s
Multistate Model Schematic

3 types of parameters:

\( p = \) Detection probability

\( \Psi = \) Routing probability

\( S = \) Survival probability
Estimation Framework

- Time-varying individual covariates
  - Covariate values based on date of reach entry
- Date of entry unknown for undetected fish
  - Need to integrate likelihood over missing data
  - Requires a model for missing data
- Model for reach-specific travel times
  - Estimate parameters from observed travel times
  - Impute missing travel times
Strength of Bayesian Framework

• Time-varying individual covariates
  – Previous approaches used average values

• Single integrated model
  – Survival and travel time

• MCMC to integrate over missing data

• Random effects
  – Quantify “extra” variation among release groups
Model for Travel Times

• Assume travel times \((t_{i,j})\) distributed lognormally

\[ t_{i,j} \sim \text{lognormal}(\mu_j, \sigma_j) \]

\[ \mu_j = \text{mean of log}(t_{i,j}) \]

\[ \sigma_j = \text{standard deviation of log}(t_{i,j}) \]

\[ \exp(\mu_j) = \text{median travel time} \]

• Goal is to estimate \(\mu\) and \(\sigma\) for each reach
Effect of Discharge on Travel Times

• Relate median travel times to Delta inflows at Freeport

\[ \mu_{i,j} = \alpha_{0,j} + \alpha_{1,j} Q_{i,j,d} + \alpha_{2,j} I(DCC_{i,j,d} = \text{open}) + \varepsilon_{g,j} \]

\( \alpha_j \) = reach-specific slope parameters

\( Q_{i,j,d} \) = Freeport discharge on day \( d \) when \( i \)th fish entered \( j \)th reach

\( I(DCC_{i,j,d} = \text{open}) \) = binary indicator for reaches downstream of DCC

\( \varepsilon_{g,j} \) = deviation of \( g \)th release group, \( \sim \text{Normal}(0, \xi) \)
Effect of Discharge on Survival

- Relate survival to Delta inflows at Freeport

\[ \text{logit}(S_{i,j}) = \beta_{0,j} + \beta_{1,j} Q_{i,j,d} + \beta_{2,j} I(DCC_{i,j,d} = \text{open}) + \varepsilon_{g,j} \]

\( \beta_j \) = reach-specific slope parameters

\( Q_{i,j,d} \) = Freeport discharge on day \( d \) when \( i \)th fish entered \( j \)th reach

\( I(DCC_{i,j,d} = \text{open}) \) = binary indicator for reaches downstream of DCC

\( \varepsilon_{g,j} \) = deviation of \( g \)th release group, \( \sim \text{Normal}(0, \xi) \)
Parameter Estimates: Travel Time

- Negative slopes for all reaches
  - Except DCC (Reach 6)

- Travel time decreases with inflow in all reaches

- DCC effects less certain
  - Except Rio Vista – Chipps (Reach 7)
Flow-Survival Relations

Survival probability

Reach 1

Reach 2

Discharge (ft³/s x 1000)

NRDC-18

12 miles

12 km
Flow-Survival Relations

Survival probability

Reach 3

Reach 4

Reach 5

Discharge (ft³/s x 1000)

NRDC-18

12 miles

12 km
Parameter Estimates: Survival

Reach 7

Reach 8

NRDC-18

Survival probability

12 miles

12 km
Route-Specific Survival

Sacramento River Discharge at Freeport (ft³/s x 1000)

Sacramento R.
Sutter and Steamboat S
Georgiana Slough
Route-Specific Travel Times

**5,000 cfs**
- Sacramento R. (11.3 d)
- Sutter and Steamboat S. (11.9 d)
- Georgiana S. (17.9 d)
- Delta Cross Channel (19.7 d)

**25,000 cfs**
- Sacramento R. (6.6 d)
- Sutter and Steamboat S. (7.3 d)
- Georgiana S. (11.6 d)
- Delta Cross Channel (14.4 d)

**70,000 cfs**
- Sacramento R. (2.1 d)
- Sutter and Steamboat S. (2.5 d)
- Georgiana S. (4.5 d)
- Delta Cross Channel (NA)
Summary

• Inflows affect travel times in all reaches

• Inflows affect survival in some reaches
  – Upper reaches: high survival at all flows
  – Transition reaches: strongest flow-survival relations
  – Tidal reaches
    • no evidence of flow effect
    • imposes upper limit on route-specific survival
Simulating Survival, Travel Time, and Routing for NAA and PA

1. “Release” 10,000 fish at Freeport each day.
2. Reach 1 survival same for all fish.
3. Draw reach 1 travel times as $f(\text{flow})$
   - NAA: flow = Freeport discharge
   - PA: flow = Bypass discharge
4. At junction of Sutter/Steamboat and Sac, draw route as $f(\text{flow})$.
5. Reach-specific survival $f(\text{flow})$ at arrival time.
6. Repeat for all subsequent reaches.
Outputs for Each Year: Survival

1943 (WY type = W)

- NAA
- PA

Mean survival through DeBypass discharge [in³/s]

Difference in survival (PA - NAA)

Oct Nov Dec Jan Feb Mar Apr May Jun Jul
Outputs for Each Year: Travel Time

1943 (WY type = W)

- Median travel time through Delta (d)
- Difference in travel time (PA - NAA)

Graph showing median travel time through Delta (d) and difference in travel time (PA - NAA) for each month from October to July.
Outputs for Each Year: Routing

1943 (WY type = W)

Cumulative fraction using each route (PA)

Cumulative fraction using each route (NAA)

- DCC
- Georgiana S.
- Sutter & Steamboat S.
- Sacramento R.

Oct 01 Nov 01 Dec 01 Jan 01 Feb 01 Mar 01 Apr 01 May 01 Jun 01

NRDC-18
Summarizing Survival Differences

- Difference in survival (PA - NAA)
- Difference in survival (L1 - PA)

NRDC-18
Evaluating NDD Bypass Rules

• Apply rule sets under “equilibrium” conditions
  – Assume constant inflows and operations for cohort

• Calculate survival with and without diversion

• Evaluate survival differences for each rule set
Oct.-Nov. Bypass Rules

- Bypass flow
- Diversion flow

Sacramento River discharge at Freeport: 0 to 60 ft³/s

With DCC closed:

- Without diversion
- With diversion

Difference in survival rates:
- NRDC-18
Constant Low-Level Pumping

Sacramento River discharge at Freeport $\text{ft}^3/\text{s} \times 1000$

- Bypass flow
- Diversion flow

$S_{\text{data}}$ with DCC closed

Without diversion
With diversion

Difference in survival

NRDC-18
Level 1 Post-Pulse Operations

Sacramento River discharge at Freeport

- Bypass flow
- Diversion flow

Difference in survival with DCC closed
- Without diversion
- With diversion

Level 1 Post-Pulse Operations (Dec-Apr)

NRDC-18
Summary: NDD Bypass Rules

• Some large survival differences
  – Depends on
    • Bypass flows
    • Rule set

• In CalSim simulations

• How else might operations be structured?
Determining Operations based on Maximum Allowable “Take”

• Example criteria
  – No more than a 0.03 decrease in mean survival
  – 90% probability that survival is decreased by no more than 0.03

• Use survival model to identify diversions that satisfy criteria
  – Find by optimization routine
Diversions Based on Median Survival

Direct NDD mortality = 0

Median survival reduction
- 0.005
- 0.01
- 0.02
- 0.03
- 0.04
- 0.05

Discharge at Freeport [ft$^3$/s]

North Delta Diversion [ft$^3$/s]
Diversions Based on Full Posterior Distribution for 0.03 survival reduction

Median 90% probability of <0.03 difference
Survival Difference Based on 10\textsuperscript{th} percentile of NDD flows for 0.03 survival reduction
Summary

• Survival model can help identify operations that meet specific survival criteria

• Variability in survival can explicitly play a role in setting criteria

• New set of operations can be assessed with other models
  – CVLCM, DPM, etc.
  – More robust inferences
Acknowledgments

Delta Stewardship Council
NOAA
DWR
UC Davis
Important Assumptions

• Extending inferences:
  – Late Fall Chinook = Winter Run?
  – Nov. – Mar. = Apr. – Jun.?
  – Hatchery = Naturally produced?
  – Current system state = future system state?
  – Predicting outside range of observed data?

• Relative vs. Absolute comparisons
  – Relative more robust
    • NAA vs. PA
    • Shape of driving relationships similar
Diversions Based on Median Survival

Direct NDD mortality = 0.03

Median survival reduction
- 0.005
- 0.01
- 0.02
- 0.03
- 0.04
- 0.05

North Delta Diversion $\text{ft}^3/\text{s}$

Discharge at Freeport $\text{ft}^3/\text{s}$