Appendix 11P Riverine Flow-Survival

11P.1 Introduction

This appendix discusses methods applied to assess potential effects of Red Bluff and Hamilton City diversions on juvenile Chinook salmon riverine survival in the Sacramento River as a function of flow. Section 11P.2, *Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Diversion Criteria Based on Historical Juvenile Chinook Salmon Monitoring Data (Michel et al. 2021)*, provides an assessment of Sites Reservoir Project (Project) diversion criteria by application of published flow-survival relationships to daily flow data while accounting for historical fish migration patterns as represented in monitoring data. Section 11P.3, *References Cited*, provides the references cited in the appendix.

11P.2 Flow Threshold Survival Analysis to Assess Potential Effects of Sites Reservoir Project Diversion Criteria Based on Historical Juvenile Chinook Salmon Monitoring Data (Michel et al. 2021)

To assess potential effects of Project diversions on juvenile Chinook salmon as a result of flow-survival relationships, the flow thresholds from Michel et al. (2021) were applied to Sacramento River at Wilkins Slough. The flow thresholds and corresponding probability of survival (from Deer Creek confluence to Feather River confluence) were as follows[1]:

- 0–4,259 cubic feet per second (cfs): 0.030 (i.e., 3%)
- 4,259–10,712 cfs: 0.189 (i.e., ~19%)
- 10,712–22,872 cfs: 0.508 (i.e., ~51%)

This analysis covers water years 2009–2018, which are included in the Sites Reservoir Daily Divertible & Storable Flow Tool (version 20220602) Excel workbook. That spreadsheet-based tool is for illustrating potential Project diversions under various facility and regulatory assumptions (see Appendix 11P1, *Sites Reservoir Daily Divertible & Storable Flow Tool*),

[1] Michel et al. (2021) found that probability of survival above 22,872 cfs decreased to 0.353 (i.e., ~35%) but noted that this may have represented the effect of river bank overtopping and fish entering Sutter Bypass, thereby potentially reducing survival or ability to detect the fish. Given the focus on riverine flow-survival in this effects analysis, the 22,872-cfs threshold was not included in this effects analysis. The 10,712-cfs threshold was assumed to be 10,700 cfs for consistency with Project operations.

consistent with the alternatives[2]. Facility and regulatory assumptions used in the workbook are provided in Tables 11P-1 and 11P-2. A notable assumption is a conservatively low level of Sites Reservoir storage at the start of each year's diversion period (i.e., 60,000 acre-feet [AF]), which results in relatively high potential for diversions when other diversion criteria are met. Diversions included flow/fish pulse protection based on flow criteria, and there was no inclusion of diversion criteria based on fish monitoring. Both the assumption of conservatively low Sites Reservoir storage and the assumption of no diversion criteria based on fish monitoring would tend to result in estimates of flow-survival effects that are conservatively high relative to what would be expected to occur with implementation of actual operations of the Project.

Table 11P-1. Facility Assumptions for Daily Divertible & Storable Flow Tool (version 20220602).

Parameter	Assumption
Sites Storage Capacity	1.5 MAF
Initial Sites Storage	200 TAF
Sites Diversion Season	November–May
Red Bluff Diversion Capacity	2,100 cfs
Red Bluff Bypass Flow	3,250 cfs
TC Canal Minimum Pumping Level	125 cfs
Hamilton City Diversion Capacity	1,800 cfs
Hamilton City Bypass Flow	4,000 cfs
GCID Main Canal Minimum Pumping Level	100 cfs
GCID Main Canal Maintenance Window	January 25–February 7
Fremont Weir*	Fremont Weir Notch included

Notes: cfs = cubic feet per second; MAF = million acre-feet; TAF = thousand acre-feet.
*Facility not operated as part of Project.

Table 11P-2. Regulatory Assumptions for Daily Divertible & Storable Flow Tool (version 20220602).

Parameter	Assumption
Bend Bridge Pulse Protection Season	October*–May
Bend Bridge Pulse Protection Initiation Criteria	3-day average Sacramento River must exceed 8,000 cfs; 3-day average tributary flow must exceed 2,500 cfs
Bend Bridge Pulse Protection Duration	7 days upon initiation, or exceedance of 25,000 cfs at Sacramento River at Bend Bridge

[2] Although Alternative 2 includes a 1.3-million-acre-foot (MAF) reservoir compared to a 1.5-MAF reservoir under Alternatives 1 and 3, the assumption of initial annual Sites storage of 60 TAF during 2009–2018 did not result in any years exceeding 1.3 MAF in storage; therefore, the analysis presented herein is representative of all the alternatives.

Parameter	**Assumption**
Bend Bridge Pulse Protection Resetting Criteria	After completion of pulse protection period, resetting criteria must be met for another pulse protection period to commence: 3-day Sacramento River flow must go below 7,500 cfs for 7 consecutive days; 3-day moving average tributary flow must go below 2,500 cfs for 7 consecutive days
Wilkins Slough Bypass Flow	10,700 cfs October–June; all other times, 5,000 cfs
Fremont Weir Notch Criteria	None
Flows into the Sutter Bypass System	None
Freeport Bypass Flow	None
Surplus Delta Outflow	7 days of flow availability in February–March is required before diversions can be made in those months
SWP Incidental Take Permit Delta Outflow	44,500 cfs April–May

Notes: cfs = cubic feet per second; SWP = State Water Project.
*Bend Bridge pulse protection may initiate in October, which is earlier than the diversion season of November through May that is specified in the Daily Divertible & Storable Flow Tool. This protection criterion is consistent with the logic employed by CALSIM II, which simulates October diversions in 9% of the years. Pulse protection initiated in October may also affect Sites Reservoir diversions in the Daily Divertible & Storable Flow Tool by carrying over into November and/or changing the timing of the next pulse initiation.

The analysis estimated an annual mean probability of juvenile Chinook salmon survival in the Sacramento River from the Deer Creek confluence to the Feather River confluence, with annual mean survival being calculated from daily survival estimates. Michel et al. (2021) focused on the spring period (March 15–June 15), whereas for this analysis the period from October 1 to June 30 was used to capture the main period of Sites diversions and juvenile Chinook salmon migration periods, using annual input data provided by Michel (pers. comm.). The analysis was run by adapting code provided by Michel (pers. comm.) to include the October 1–June 30 period, to represent each race of Chinook salmon separately (rather than summing all races as done by Michel et al. [2021]), to replace Michel et al.'s (2021) flow scenarios with the flow scenarios described below, and to calculate additional summary quantiles as described below.[3] This code implements parametric bootstrapping, where the pertinent logit-transformed survival distribution from the Michel et al. (2021) Cormack-Jolly-Seber model (given flow levels at Wilkins Slough for that day) was resampled corresponding to the expanded daily total juvenile Chinook salmon catch at the Red Bluff Diversion Dam (RBDD) rotary screw traps.[4] The mean logit-scale survival was estimated across all days of the October 1–June 30 period, and then re-scaled (inverse-logit transform). For missing RBDD rotary screw trap daily catch values, catch was imputed using a

[3] Michel et al. (2021) applied this analytical framework to assess the potential effects of rearranging historical flows/reservoir releases in a pattern tied more directly to movements of fish, or augmenting historical flows with reservoir releases, in order to maximize juvenile Chinook salmon survival based on their flow-survival threshold relationships.

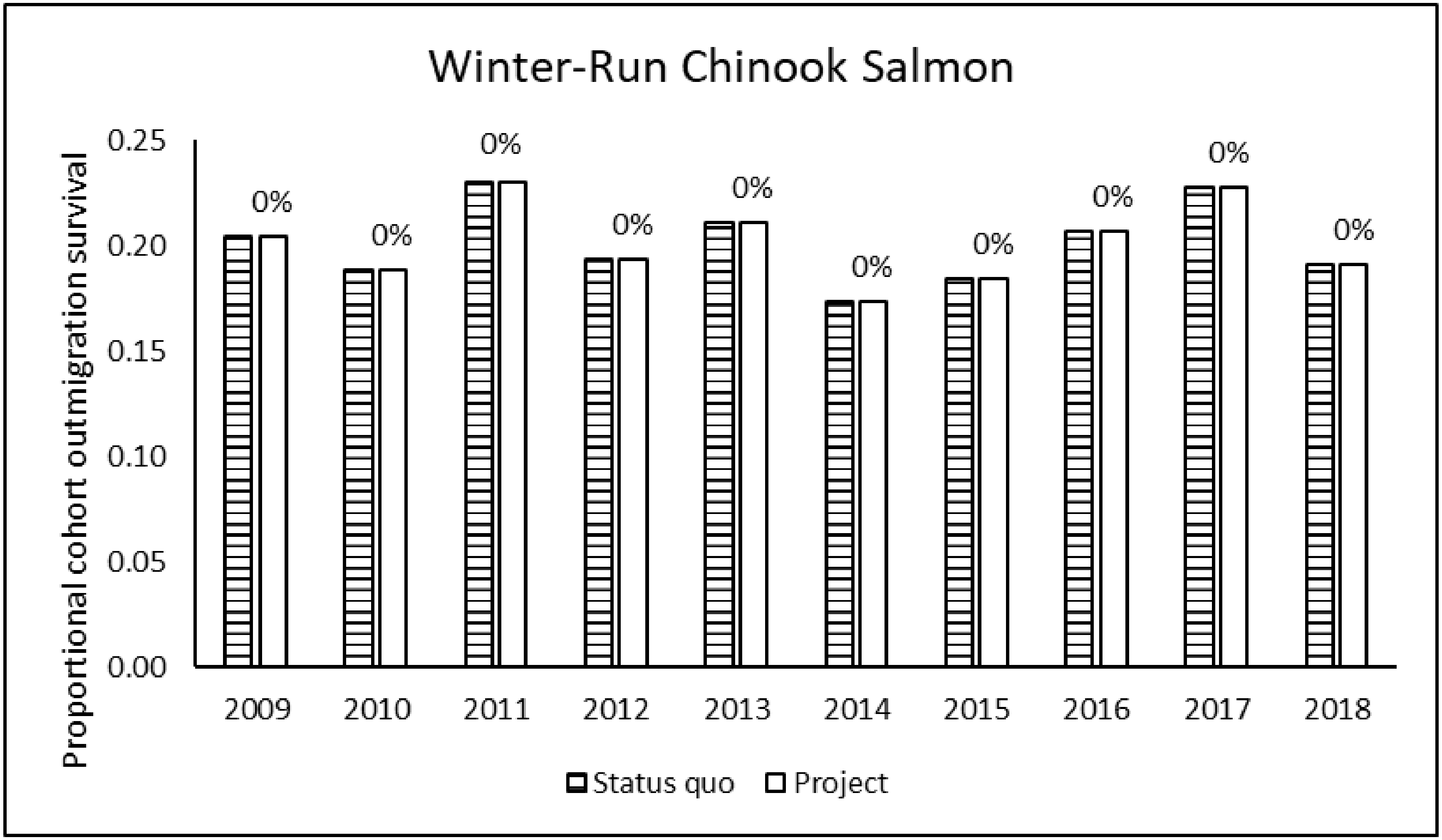
[4] The Red Bluff Diversion Dam, which was decommissioned in 2013, and the Red Bluff Pumping Plant are co-located, and the names may be used interchangeably when referring to the geographic location.

linear interpolation of the time-series.[5] As an example, if the RBDD screw trap collected 5,000 juvenile Chinook salmon on a given day, the calculation produced 5,000 parametric bootstrapped estimates for survival on that day, based on the mean and standard error for a given flow found by Michel et al. (2021). This process was repeated for all days in each year. All of the combined bootstrapped estimates for each year were then used to calculate annual mean survival probability, and the 5th and 95th percentiles were also calculated to illustrate the variability in survival by year.

The Sites Reservoir Daily Divertible & Storable Flow Tool provided daily Sacramento River at Wilkins Slough flows for the flow-survival analysis, which include daily diversions by the Red Bluff and Hamilton City diversions based on the assumptions documented in Appendix 11P1. In order to provide a representation of historical flow (Michel et al. 2021), the Red Bluff and Hamilton City diversions were added to the Sacramento River at Wilkins Slough flows. Thus, the two main scenarios included a representation of historical flows (termed "Status quo" for consistency with Michel et al. [2021]) and flows applying Sites diversion criteria (termed "Project"). These were the two scenarios that were compared to assess potential effects of Sites diversion criteria.

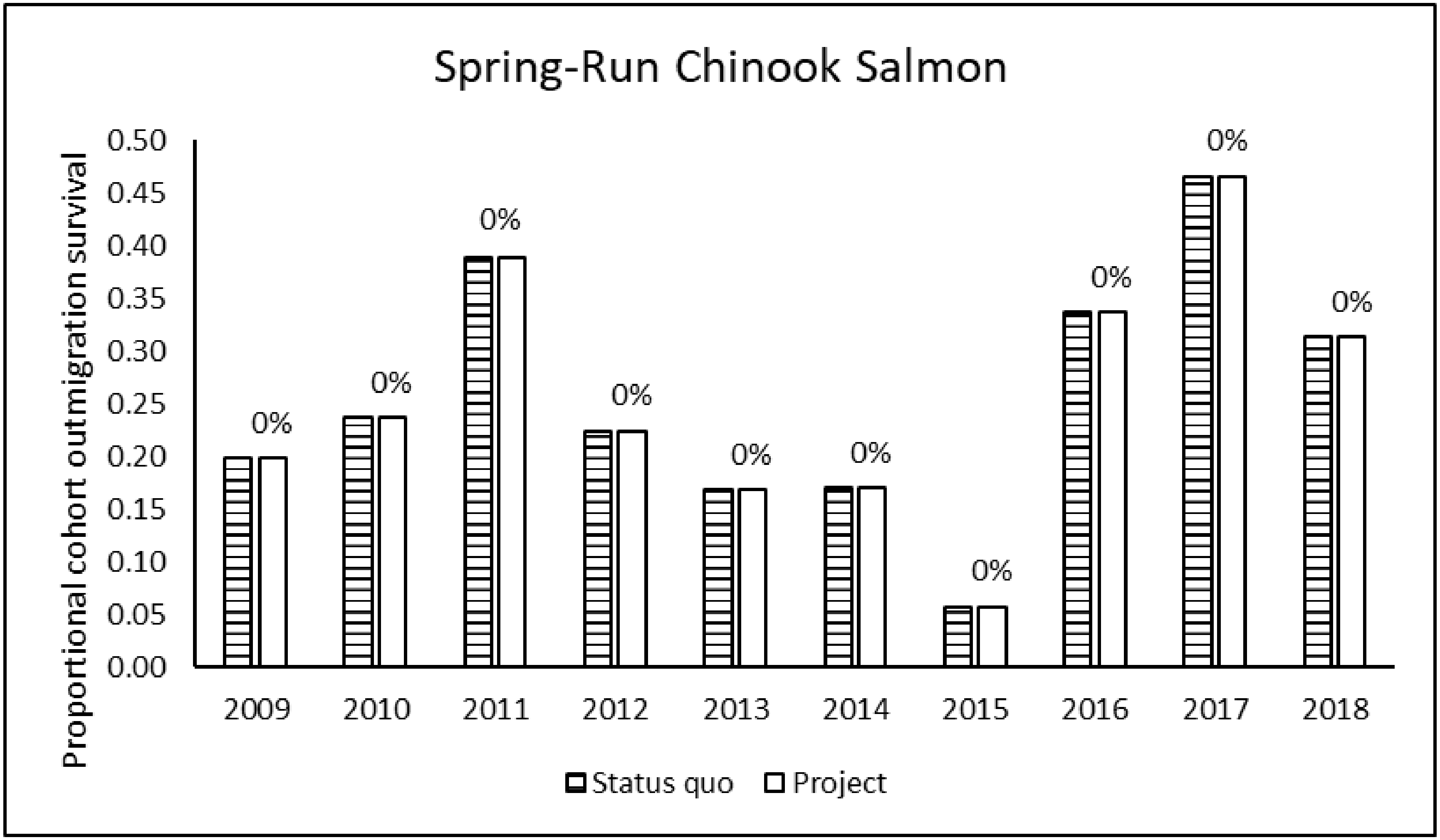
The analysis showed that estimated survival for the Status quo and Project scenarios was essentially the same for all runs (Figures 11P-1, 11P-2, 11P-3, and 11P-4), and the range from the 5th to 95th percentiles overlapped between both scenarios in all years (Figures 11P-5, 11P-6, 11P-7, and 11P-8). These results were as expected given the inclusion of the 10,700-cfs Wilkins Slough bypass flow in Sites Reservoir operations, ensuring that the Project does not diminish flows below the 10,700 cfs from the Michel et al. (2021) model.

[5] The linear interpolation used by Michel et al. (2021) and employed for this effects analysis estimated the screw trap catch on a given missing sampling date as the predicted value based on a linear regression of the catch on the prior and following sampled days versus dates.



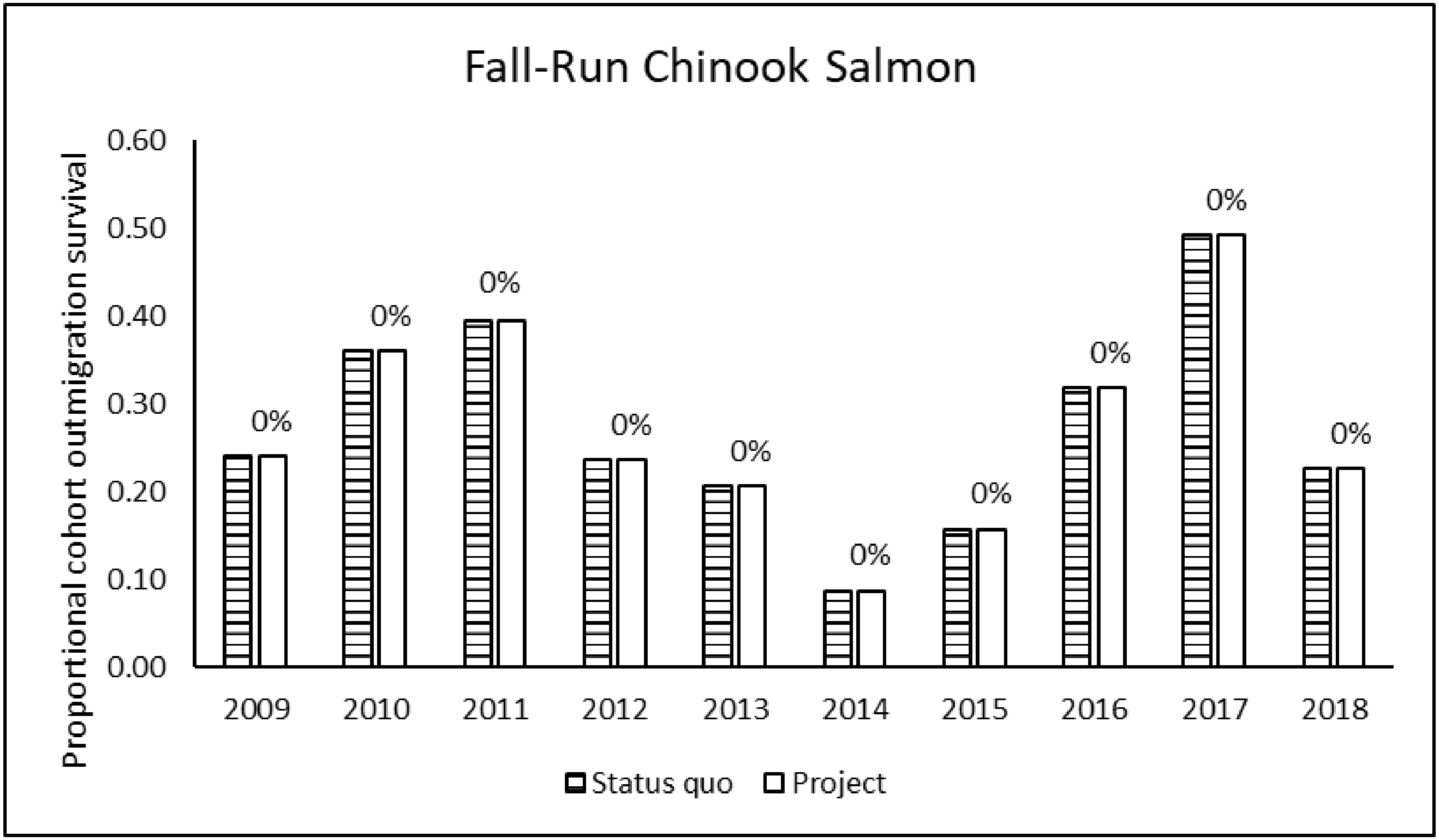
Note: Percentages above bars indicate differences compared to Status quo flows for Project. Mean represents mean of annual parametric bootstrapped values.

Figure 11P-1. Mean Annual Proportional Juvenile Winter-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool.



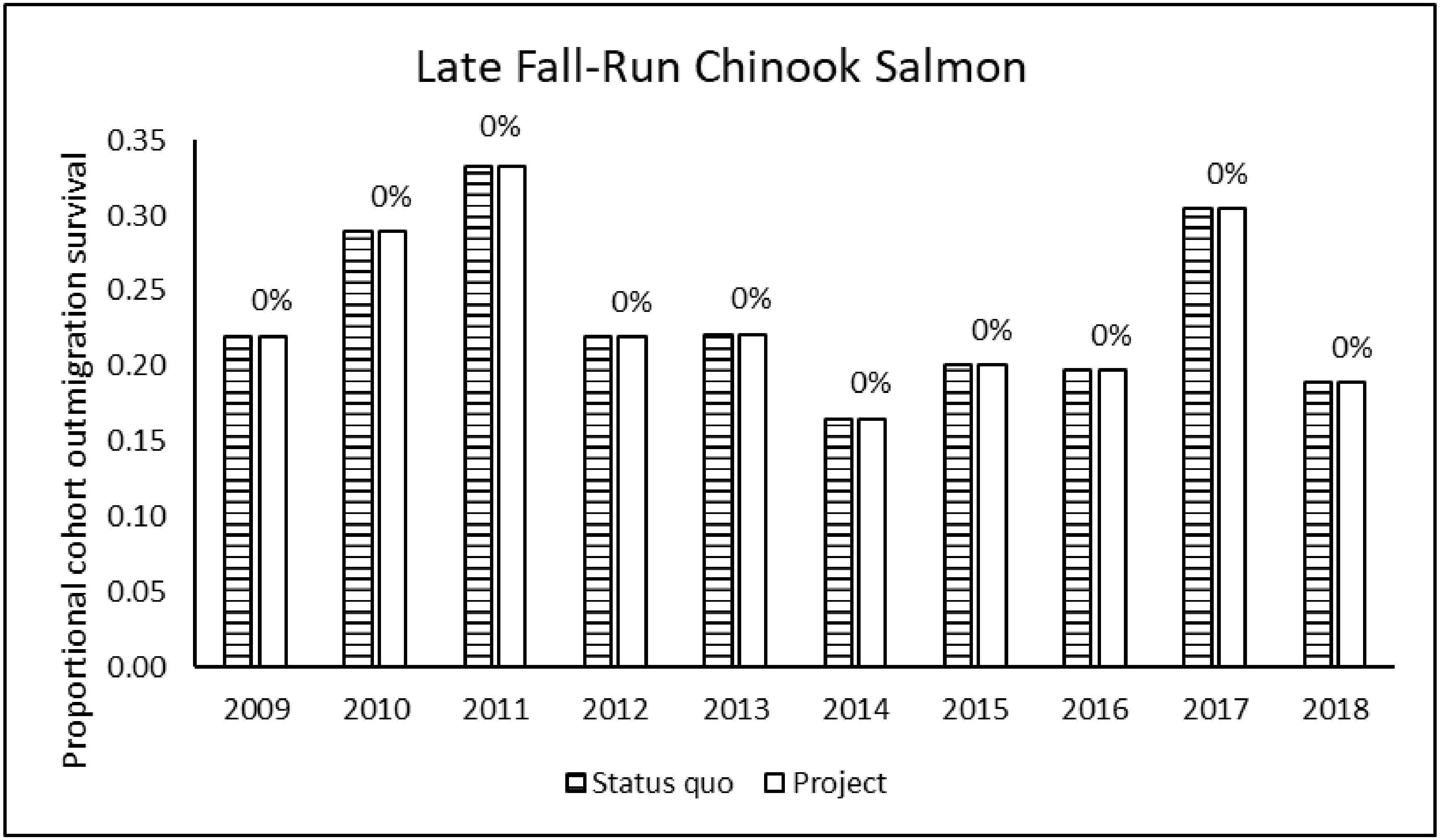
Note: Percentages above bars indicate differences compared to Status quo flows for Project. Mean represents mean of annual parametric bootstrapped values.

Figure 11P-2. Mean Annual Proportional Juvenile Spring-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool.



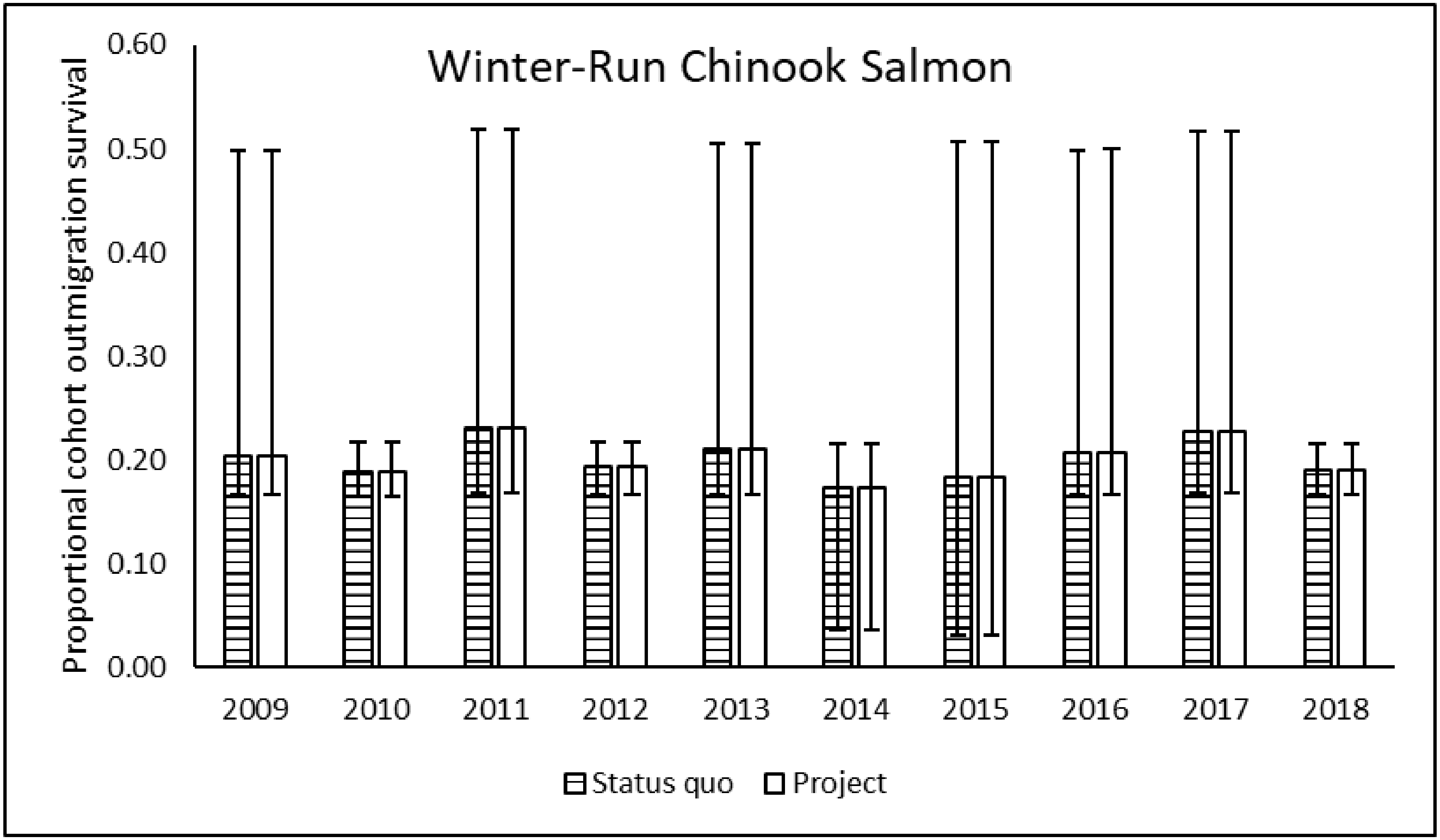
Note: Percentages above bars indicate differences compared to Status quo flows for Project. Mean represents mean of annual parametric bootstrapped values.

Figure 11P-3. Mean Annual Proportional Juvenile Fall-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool.



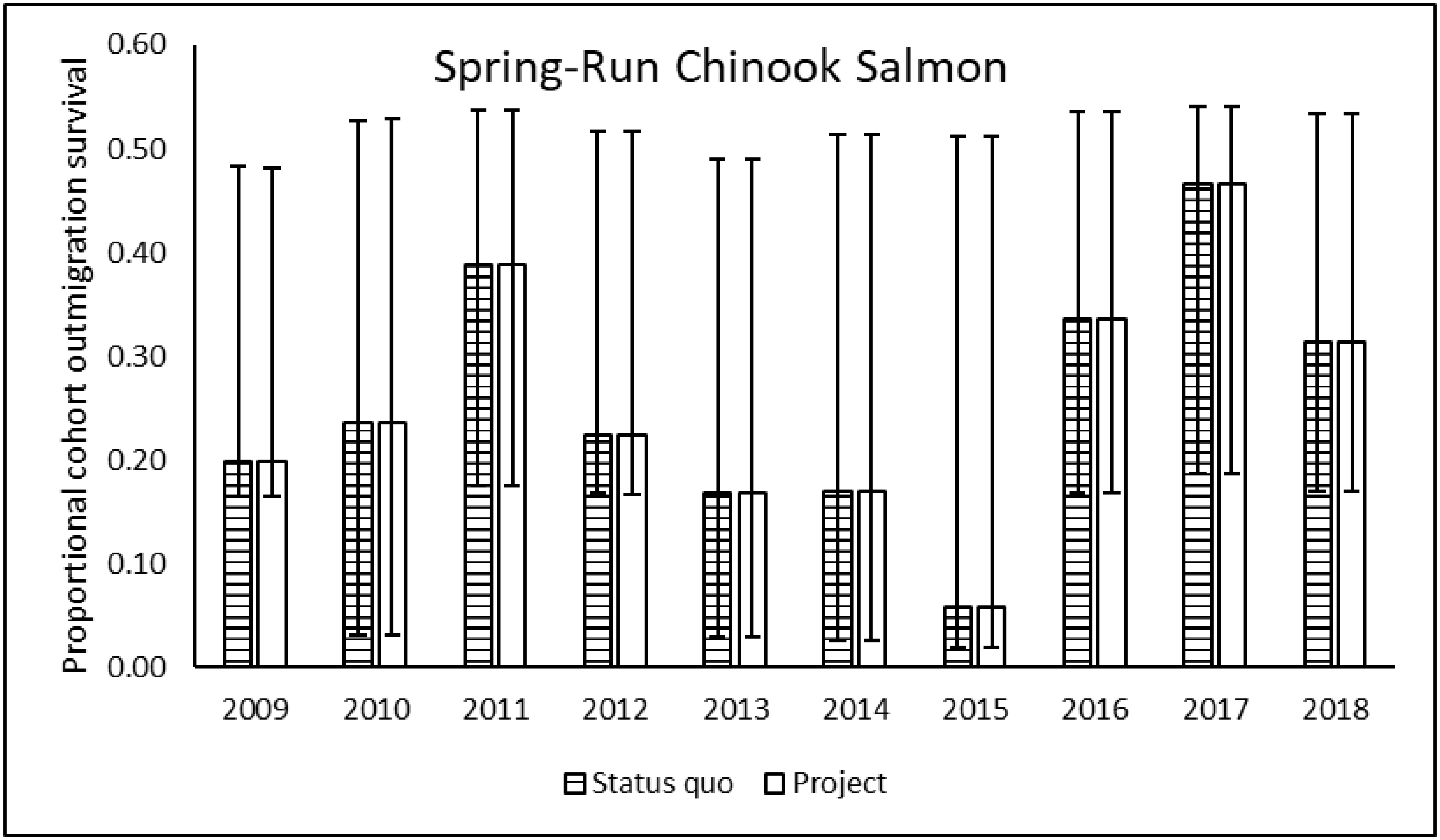
Note: Percentages above bars indicate differences compared to Status quo flows for Project. Mean represents mean of annual parametric bootstrapped values.

Figure 11P-4. Mean Annual Proportional Juvenile Late Fall–Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool.



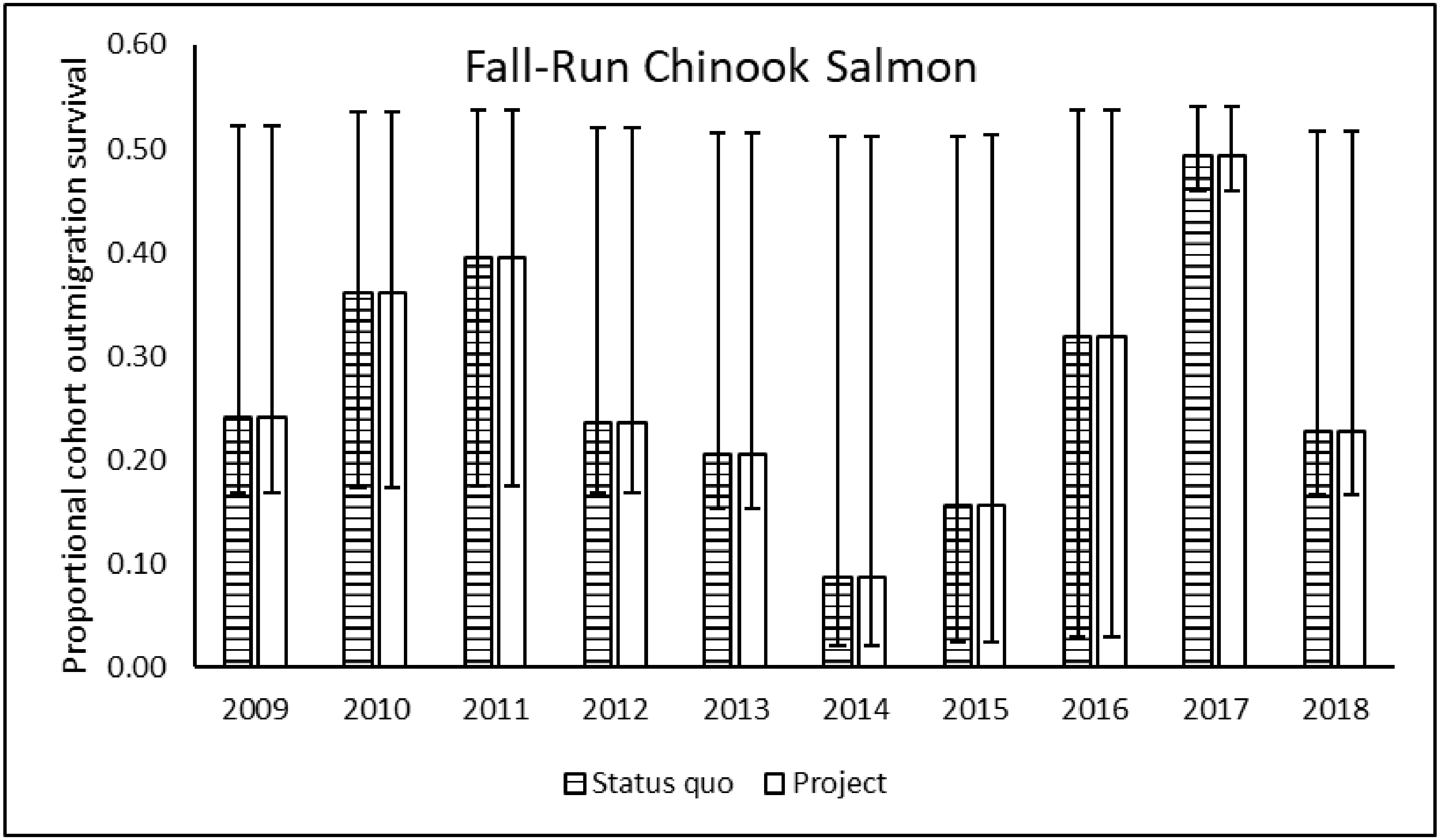
Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

Figure 11P-5. Mean Annual Proportional Juvenile Winter-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including 5th and 95th Percentiles.



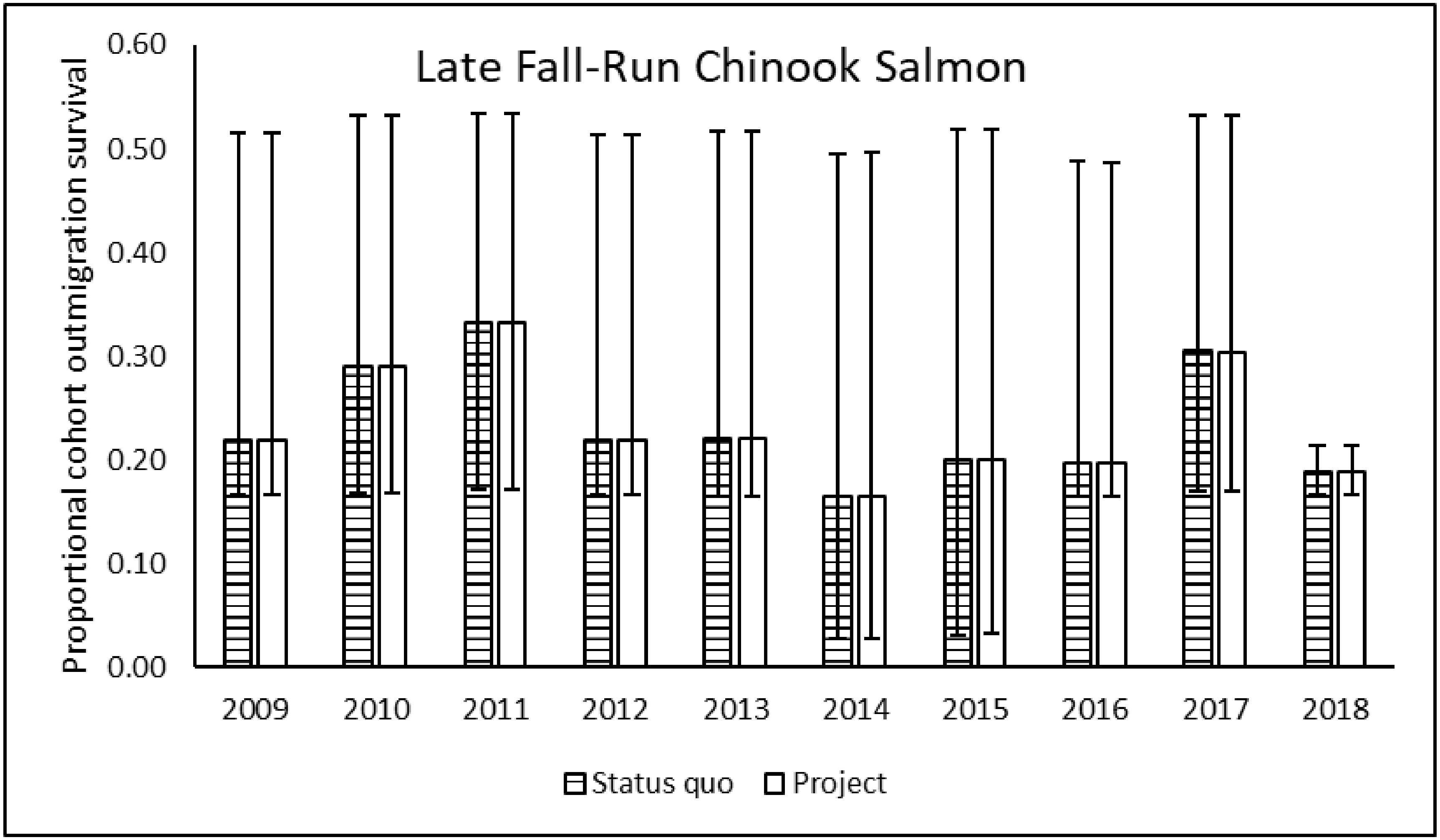
Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

Figure 11P-6. Mean Annual Proportional Juvenile Spring-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including 5th and 95th Percentiles.



Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

Figure 11P-7. Mean Annual Proportional Juvenile Fall-Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including 5th and 95th Percentiles.



Note: Mean represents mean of annual parametric bootstrapped values. Error bars represent 5th and 95th percentiles of annual parametric bootstrapped values.

Figure 11P-8. Mean Annual Proportional Juvenile Late Fall–Run Chinook Salmon Survival Based on Michel et al. (2021) Flow-Survival Threshold Analysis Applied to Flows from Sites Reservoir Daily Divertible & Storable Flow Tool, Including 5th and 95th Percentiles.

11P.3 References Cited

Michel, Cyril. Assistant Project Scientist. University of California, Santa Cruz; affiliated with Southwest Fisheries Science Center – Fisheries Ecology Division, National Marine Fisheries Service, Santa Cruz, CA. February 24, 2021—Email providing R code and related input files to reproduce Michel et al. (2021) analysis to Marin Greenwood, Aquatic Ecologist, ICF.

Michel, C., J. Notch, F. Cordoleani, A. Ammann, and E. Danner. 2021. Nonlinear Survival of Imperiled Fish Informs Managed Flows in a Highly Modified River. *Ecosphere* 12(5). DOI: 10.1002/ecs2.3498.