**Habitat indicators of Klamath and Sacramento salmon stocks:
Stoplight tables for Sacramento River and Klamath River fall Chinook salmon**

Rebuilding plans in 2019 for Sacramento River and Klamath River fall Chinook salmon runs prompted annual updates of habitat indicators for these stocks (Harvey et al. 2020). After review by multiple scientists and members of various advisory bodies, members of the Habitat Committee developed a suite of 22 indicators for Sacramento River fall Chinook salmon (SRFC) and 18 indicators for Klamath River fall Chinook salmon (KRFC), spanning the full life history of natural-area fish and also including indicators related to hatchery-origin fish (Table J.1). These indicators illustrated a combination of poor freshwater and marine conditions associated with the poor productivity of three critical brood years that triggered the rebuilding plan. Recognizing that these leading indicators could inform risk assessment for poorly-assessed stocks, the Pacific Fishery Management Council (Council) recently requested additional indicators be developed for Central Valley spring-run Chinook salmon (CVSC).

Many of the indicators combined in these habitat stoplight tables are already included in other portions of this Ecosystem Status Report (ESR). The indicators in Table J.1 have been shown in previous studies or were proposed in rebuilding plans to be strongly related with life-stage-specific Chinook salmon productivity, and these studies helped determine expected directionality of indicators with stock productivity (see Harvey et al. 2020 for additional justification). Four of the five broad categories of indicators in the stoplight charts align with the simpler stoplight chart for Central Valley fall Chinook salmon presented in the main body of this report (Table 3.2 in ESR): Adult Spawners, Incubation conditions, Freshwater/Estuarine Residence conditions, and Marine Residence conditions (for the first year of marine residence). The fifth category of indicators, Hatchery Releases, expands the scope of these tables relative to the 4-indicator chart (Table 3.2 in ESR) that focuses only on natural-area fish. The habitat indicator charts also share qualities with the stoplight chart developed for Columbia Basin Chinook salmon and Oregon coast coho salmon (Table 3.1 in ESR) by including regional and basin-scale oceanographic indicators as part of early marine residence conditions. Data on krill biomass off northern California (Figure 3.2 in ESR) are also presented within the table for KRFC.

The indicators in Table J.1 and in the stoplight tables below have undergone several important adjustments from previous reports:

- Updates to SRFC and KRFC include changes in some indicators to ensure more reliable and timely data capture. Due to delays in posting of online datasets, broken links, and reduced monitoring budgets, over 10 indicators could not be automatically updated, which necessitated the assistance of a number of individuals at different agencies to update indicators. Even so, brood year updates for egg-fry indicators can no longer be included in the current ESR, and the seabird predation indicator will no longer be updated. These challenges underscore the importance of including multiple indicators, highlight the potential fragility of these annual summaries, and point to the importance of many individuals for maintaining the databases required for summarizing habitat indicators.
- This is the first year that habitat indicators for CVSC have been developed. This run differs from SRFC not only in migration timing but also in their behavior and spatial distribution.

These differences necessitated modifications to the suite of habitat indicators to characterize early upstream migration starting in February, holding in pools through the summer, and spawning in a small number of creeks in the late summer and fall. Adult numbers focused on spawner counts in Butte, Mill, and Deer Creeks. Butte Creek spawners migrate from the Sacramento River through Sutter Bypass to Butte Creek, and outmigrants may rear within Sutter Bypass during outmigration. Hence, flow and temperature metrics relied on gages from these systems in addition to the Sacramento mainstem, and Sutter Bypass inundation instead of Yolo Bypass. Finally, the hatchery for CVSC is from Feather River, so releases and timing metrics focused on data from just this hatchery.

- The stoplight tables are categorized from favorable to poor conditions using the same new approach as described for the Northern California Current salmon indicator stoplight table (see main body, Table 3.1). Specifically, after indicator datasets were collected, all indicators were "directionalized" to account for potential inverse relationships of some indicators with stock productivity (based on the "Effect" column in Table J.1) and converted into standardized values. These values are reported in the stoplight tables below, with colors delineating statistical departures toward poorer (warm shades) or more productive (cool shades) conditions. The main difference for the tables shown here relative to Table 3.1 is that we have not yet determined a fixed historic reference period for the SRFC, KRFC and CVSC tables, due in part to missing data from one or more indicators in large portions of the time series.

Below we present stoplight table updates for habitat indicators for all three stocks. Previous examination of the KRFC and SRFC stoplights indicated that these indicators tended to cycle every 5 to 10 years; that the cycles were out of phase for freshwater and marine conditions; and that freshwater conditions for the Klamath stock exhibited a long-term decline since the 1990s. Updates for the most recent brood year and previous trends show that these patterns continue to hold. In addition, indicators trended negative for all three stocks in 2021 (fall spawning) and 2022 (outmigration). These results suggest that a combination of poor freshwater and marine habitat conditions continued for KRFC, and may have returned for Sacramento stocks.

Klamath River fall Chinook salmon: For brood year 2021, 14 of 18 habitat indicators were within 1 s.d. of the long-term average (Table J.2A). However, 10 of those 14 were below average, in addition to the four indicators that were >1 or >2 s.d. below normal; this combination resulted in 2021 being the second-worst brood year for the cumulative freshwater condition score, which continued a 25-year declining trend in these indicators (Table J.2B). It was also the fourth-worst year for marine conditions. The coincidence of relatively poor freshwater and marine conditions resulted in the poorest overall year for this indicator suite in the 39-year record. All three indicators for adult migration were within 1 s.d. below average. Two of three incubation indicators were below average, and incubation temperature was the third-worst year on record. Likewise, freshwater residence indicators tended to score poorly: four of five indicators were below average and maximum flushing flow was the worst year in the 39-year record. In addition, all indicators of hatchery releases trended negative. Timing of releases was >2 s.d. below average and marine timing was the worst on record. FW timing was the second-worst on record. In addition, three of five marine indicators were below average.

Sacramento River fall Chinook salmon: Habitat indicators for SRFC did not trend much differently. As with the KRFC table, most of the indicators for the 2021 brood year fell within 1 s.d. of average (Table J.3A). However, 13 of 20 indicators for which there are data were below-average, often by larger degrees (Table J.3A). Three of four habitat indicators for spawners were below-average, and incubation temperature and flow indicators were the third- and fourth-worst on record, respectively. Six of seven freshwater and delta residence indicators were below-average, and Sacramento mainstem flows were the second-worst in this 39-year record. Hatchery release indicators were mixed. Release year 2022 was the second-lowest year for release number, and all releases were made out of system, resulting in the highest Net.pen score but indicative of the very poor conditions for in-stream releases. Early marine conditions were mixed, as one of four marine indicators were below average. The cumulative effects of multiple poor indicators resulted in the fourth-worst freshwater score since the early 1990s (Table J.3B). Cumulative marine conditions were just above average; hence, across all indicators, conditions for the 2021 brood year have been below-average.

Central Valley Spring Chinook salmon: CVSC shares 11 indicators with SRFC, so it should come as no surprise that habitat conditions for CVSC were also relatively poor for brood year 2021. Again, a majority of the indicators for brood year 2021 were within 1 s.d. of their time series averages (Table J.4A). However, 19 of 23 indicators were below average, and some indicators trended worse than those of their Fall-run counterparts. Habitat indicators for upstream migration and spawning were mixed, as four of five indicators were below average. Despite the second-strongest adult return of the time series, the Butte Creek spawning run suffered the worst holding temperatures in its 22-year record as well as record pre-spawn mortality (nearly 92 percent), severely impacting juvenile production. Furthermore, all three incubation indicators and all eight freshwater/ delta indicators were below-average. Hatchery release indicators were mixed. Despite the largest hatchery release of the time series, the other three indicators were below-average, and timing indicators were both >1 s.d. below average (i.e., relatively poor conditions for natural-area fish). Three of four early marine residence indicators were below-average.

Brood year 2021 contributed to a recent trend of declining freshwater indicators for CVSC, cycling between good and poor conditions about every five years (Table J.4B). Like other populations, marine habitat indicators vary in an opposite phase compared to freshwater indicators, and there have been a few years when both freshwater and marine conditions were below average. Like SRFC, this occurred most recently for CVSC during the 2014-2015 marine heat wave. Based on the combined score across both freshwater and marine indicators, brood year 2021 was the third-worst in the 39-year record. In summary, these indicators suggest a year of poor productivity for CVSC, and likely below average adult returns in 2024-25.

Management implications for the Council: The Council has a long history of engaging with other agencies to advocate for improved habitat conditions for the Sacramento and Klamath Chinook salmon. While many possible management “dials” exist for improving habitat, few can easily be tracked annually. In both systems, river flow is highly managed through reservoir operations, diversions and export pumping, and flows at particular stages can influence water temperature. Flow and water temperature indicators have shown evidence of long-term change as well as recent variability during brood years highlighted by the rebuilding plan (2012-2014) and years thereafter. In particular, temperature conditions for the Sacramento River (during spawning and spring rearing) and flow conditions for the Klamath River continue to remain at relatively low status, suggesting that improved flow management can support improvements for populations (Munsch et al 2020). In the Klamath River, freshwater conditions have trended very poorly, so efforts to initiate dam removal this year come at a fortuitous time to restore the natural flow regime; we will continue to track these conditions as dam removal proceeds to determine if restoration leads to improvements in these indicators over time. In the Sacramento River, above-average flows favor adult survival and rearing conditions in freshwater, in the floodplain, and in the delta; thus, improved management of flows during freshwater residence periods would likely ameliorate the poor conditions of 2021-2022 for both fall and spring runs. From an ecosystem indicator perspective, the outlook for both Klamath and Sacramento stocks suggest below-average adult ocean abundance in 2024-2025.

Table J.1. Klamath River fall (KF), Sacramento fall (SF), and Central Valley spring-run (CS) Chinook salmon habitat indicators, definitions, and key references. Months indicate the time period for which indicators were summarized, Effect is the predicted directionality of the indicator's effect on productivity, and Stock indicates the runs for which indicators were produced. With the addition of Central Valley Spring indicators, abbreviations of indicator names have changed slightly from previous Ecosystem Status Reports.

Life stage-specific indicator	Abbreviation	Months	Effect	Reference	Stock
Adult spawners					
Spawner counts	Spawners		+	Friedman et al. 2019	KF, SF, CS
Fall closures of Delta Cross Channel	CChannel.F	Sep-Oct	+	Rebuilding plan	SF
Low flows during upstream migration	Flows.U	Sep-Oct*	+	Strange et al. 2012	KF, SF, CS
Temperatures during upstream mainstem	Temp.U	Sep-Oct*	–	Fitzgerald et al. 2020	KF, SF
Holding period flows in Butte Creek	Flows.H	Jun-Sep	+	USFWS, 1995	CS
Holding temperature in Butte Creek	Temp.H	Jun-Sep	-	USFWS, 1995	CS
Prespawn mortality rate	PrespawnM		-	USFWS, 1995	CS
Incubation and emergence					
Fall-winter low flows in tributaries (7Q10)	Flows.I	Oct-Dec*	+	Jager et al. 1997	KF, SF, CS
Egg-fry temperatures (avg of max daily)	Temp.I	Oct-Dec*	–	Friedman et al. 2019	KF, SF, CS
Egg-fry productivity	FW.surv		+	Hall et al. 2018	KF, SF, CS
Freshwater/delta residence					
Winter-spring tributary flows	Flows.T	Feb-May	+		CS
Winter-spring mainstem outmigration flows	Flows.O	Dec-May	+	Friedman et al. 2019	KF, SF, CS
Delta outflow index	Delta	Apr-Jul	+	Reis et al. 2019	SF, CS
7-day flow variation (SD)	SDFlow.O	Dec-May	–	Munsch et al. 2020	KF, SF, CS
Maximum flushing flows	Max.flow	Nov-Mar	+	Jordan et al. 2012	KF
Total annual precipitation	Precip	Annual	+	Munsch et al. 2019	KF, SF, CS
Spring outmigration temperatures	Temp.O	May-Jun	–	Munsch et al. 2019	KF, SF, CS
Spring closures of Delta Cross Channel	CChannel.S	Feb-Jul	+	Perry et al. 2013	SF, CS
Days floodplain bypasses were accessible	Floodpln	Annual	+	Limm & Marchetti 2009	SF, CS
Marine residence					
Coastal sea surface temperature	CSTarc	Mar-May	–	Wells et al. 2008	KF, SF, CS
North Pacific Index	NPI	Mar-May	+	Wells et al. 2008	KF, SF, CS
North Pacific Gyre Oscillation	NPGO	Mar-May	+	Wells et al. 2008	KF, SF, CS
Marine predation index	Predation		–	Friedman et al. 2019	SF, CS
Krill biomass	Prey	Mar-Aug	+	Robertson & Bjorkstedt 2020	KF
Hatchery releases					
Release number	Releases		+	Sturrock et al. 2019	KF, SF, CS
Prop net pen releases	Net.pen		+	Sturrock et al. 2019	SF, CS
Release timing relative to spring transition	FW.Timing	Jan-Aug	+	Satterthwaite et al. 2014	KF, SF, CS
Release timing relative to peak spring flow	M.Timing	Jan-Aug	+	Sykes et al. 2009	KF, SF, CS

*For CS, adult upstream migration time period and incubation period is Feb-May and Sep-Dec, respectively.

Table J.2: (A) Habitat indicators for five life history components of Klamath River fall Chinook salmon. Each row is an indicator (grouped by life stage at left) and each column is a brood year. Colors represent a given year's indicator relative to the full time series. Blue: >2 s.d. above the mean (= highly favorable); green: >1 s.d. above the mean; yellow: ±1 s.d. of the mean; orange: >1 s.d. below the mean; red: >2 s.d. below the mean (= highly unfavorable). (B) Trend over brood years in the average of habitat indicators for freshwater life stages (Adult migration and spawning, incubation, freshwater and delta residence, and all hatchery indicators except marine timing) is shown as the thick black line, and trend for marine habitat indicators (marine timing, early marine residence suite) is shown as the dashed blue line. Brood years on x-axis match years of the indicator suite in A.

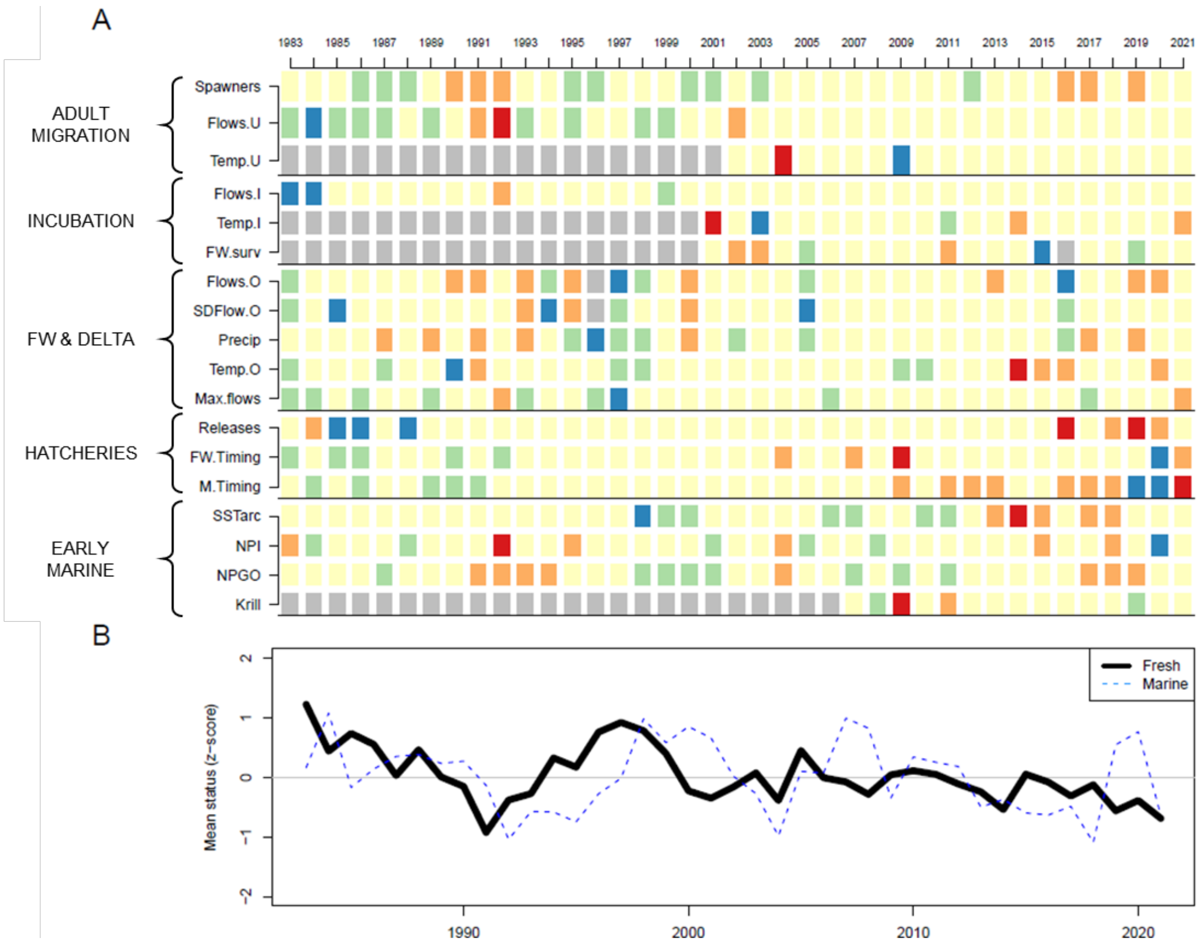

Table J.3: (A) Habitat indicators for five life history components of Sacramento River fall Chinook salmon. Each row is an indicator (grouped by life stage at left) and each column is a brood year. Colors are as in Table J.2A. (B) Trend over brood years in the average of habitat indicators for freshwater life stages (black line, as in Table J.2B) and marine habitat indicators (blue line, as in Table J.2B). Brood years on x-axis match years of the indicator suite in A.

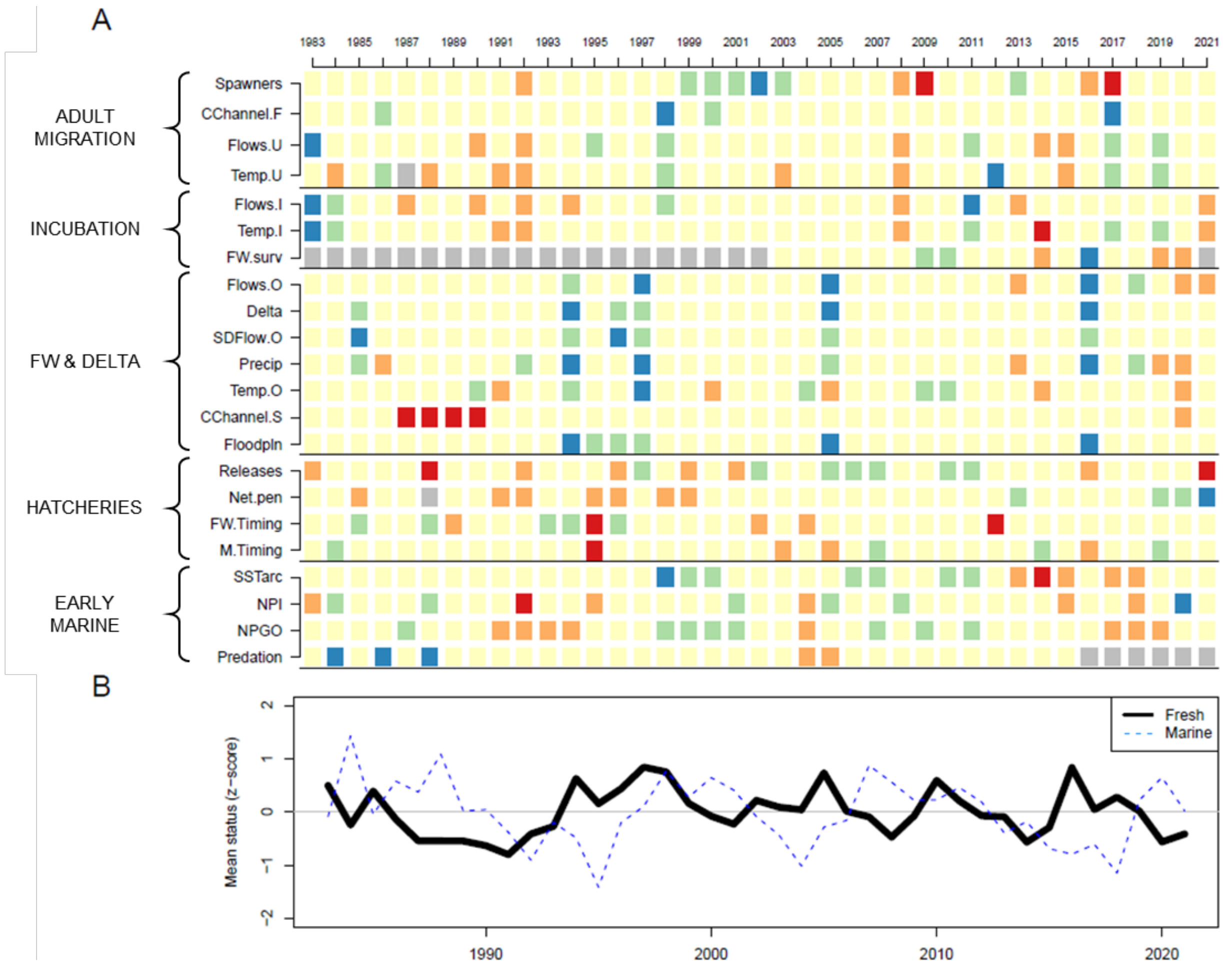

Table J.4: (A) Habitat indicators for five life history components of Central Valley spring Chinook salmon. Each row is an indicator (grouped by life stage at left) and each column is a brood year. Colors are as in Table J.2A. (B) Trend over brood years in the average of habitat indicators for freshwater life stages (black line, as in Table J.2B) and marine habitat indicators (blue line, as in Table J.2B). Brood years on x-axis match years of the indicator suite in A.