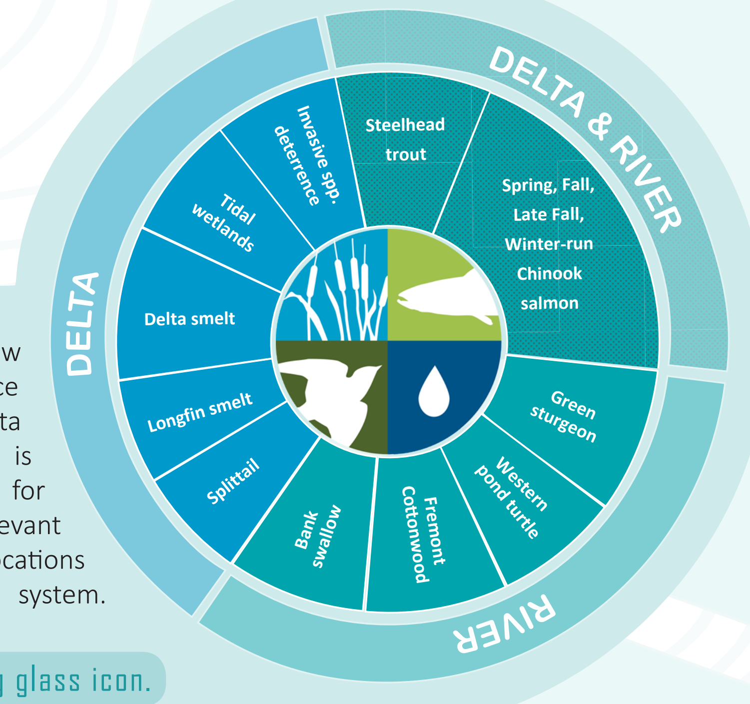
EFT
Ecological Flows Tool



The **Ecological Flows Tool (EFT)** is a decision support framework for developing and testing how flow management alternatives and other actions change physical habitats and influence **multiple** ecological targets. Through the management of Shasta dam releases and Delta export pumping and application of a novel "turn taking" optimization approach, EFT is able to flexibly balance a suite of numerous functionally distinct performance indicators for multiple key species and habitats over time. "Indicators" are quantifiable measures relevant to the success of a species' life-history stage. This map highlights important indicator locations used by EFT to determine effects on these key species and habitats within the Delta system.

Detailed EFT Indicator Briefs are available for species marked with a magnifying glass icon.

Salmonids (CS)

Steelhead trout and four Chinook run-types reproduce and rear at different locations. Habitat requirements for seven life-stage indicators simulate spawning habitat area, scouring and dewatering of spawning redds, thermal conditions during egg maturation, rearing habitat area, stranding of juveniles during rearing and heat stress during downstream migration. Each salmonid follows a unique life-history calendar but the indicators all share a common conceptual framework.

Green Sturgeon (GS1)

The Sacramento River is home to one of three known populations. The indicator is based on water temperature at two locations during egg maturation period.

Fremont Cottonwood (FC)

This dominant tree in riparian forests provides stream shade, wildlife habitat, and stabilizes banks. One indicator measures the potential for new seedlings to survive by maintaining contact with ground water as flow is reduced. A second tracks very high flow events which can scour banks and kill young trees.

Bank Swallows (BASW)

Bank swallows nest in burrows found in steep river banks. Burrows become unsuitable over time and require freshly exposed banks. Indicators are based on simulation of meander migration and measure the amount of suitable newer bank and the presence of very high flow conditions that may flood nests or trigger bank collapse.

Western Pond Turtle (LWD)

Large woody debris is a proxy for turtle habitat. When overlying vegetation consists of older forest, debris created through bank erosion and meander migration provides good habitat.

Sacramento Splittail (SS)

Endemic to the Delta and reliant on prime spawning habitat in the floodplains of the Yolo Bypass. Indicator is proportion simulated versus potential maximum suitable habitat available during the spawning season.

Invasive Species Deterrence (ID)

Non-native species have altered physical habitats and trophic structure. Indicators are based on timing of flow and salinity conditions which are unfavorable to each species: high salinity for waterweed, very high flow and low salinity for overbite clam ,and low flow and high salinity for Asiatic clam.

Tidal Wetlands (TW)

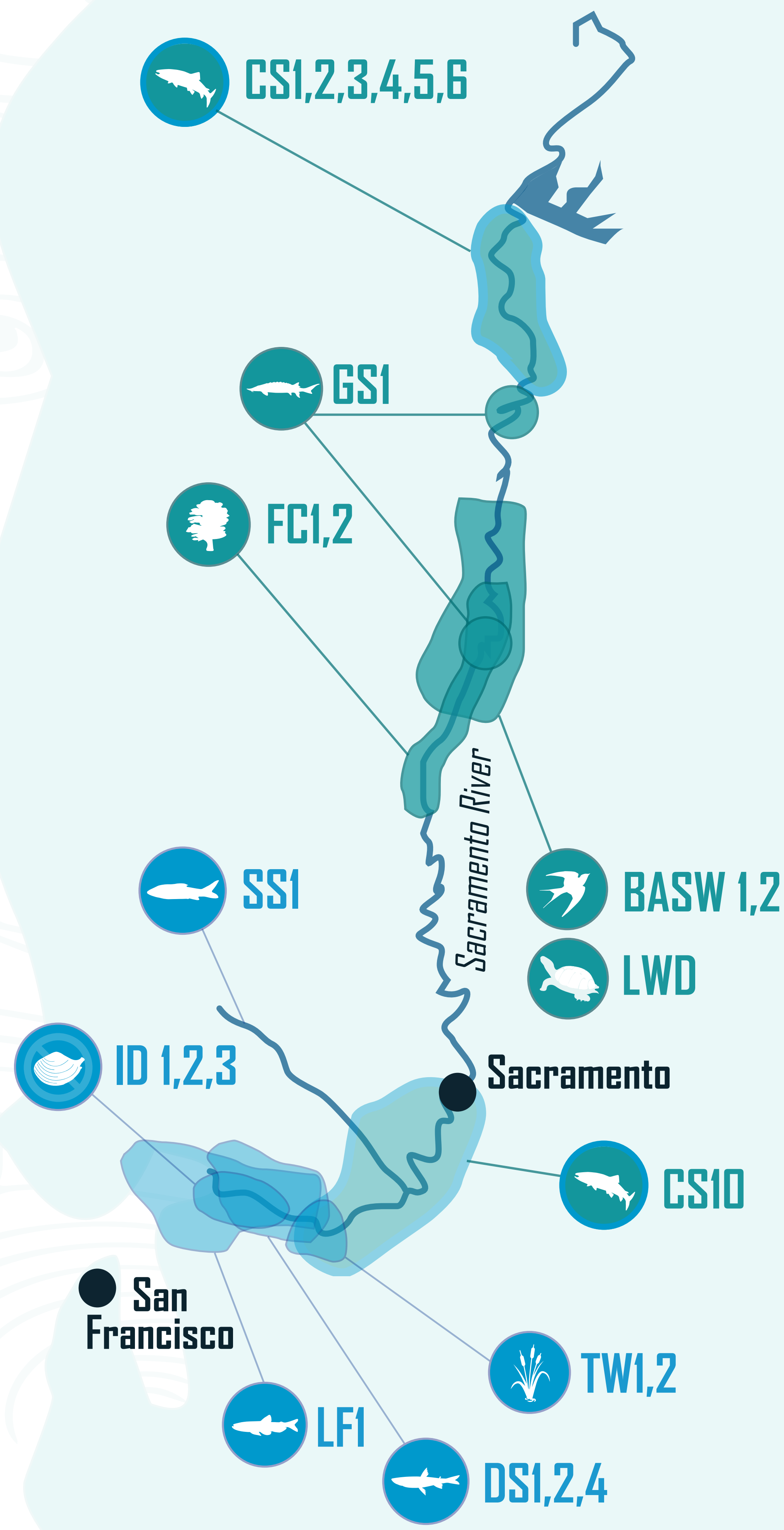
Productive freshwater or brackish marshes which form an important part of the Delta food web. Remaining areas are at risk of loss from human development and sea level rise. Indicators measure the area in freshwater and brackish water wetlands, and require a high resolution digital elevation model of tidal areas.

Longfin Smelt (LF)

Reside in the upper Delta and lower Sacramento River, populations have been declining over last 40 years. Indicator is based on the relationship between abundance index and salinity (X2).

Delta Smelt (DS)

Endemic to the Delta and in long term population decline. Indicators relate to good spawning conditions, requiring cool low salinity water; good rearing habitat with low salinity (low X2); and low entrainment of larvae and juveniles measured through positive flow in the Old and Middle Rivers, signifying a low Export-to-Import ratio for the pumps.



The Nature Conservancy
ESSA

Bank Swallow

Background

Bank swallows are an important riparian species in the Sacramento River riparian ecosystem, and require suitable nesting sites to maintain their population. Bank swallows nest in colonies found in tall vertical banks with friable soils along streams, lakes, and in coastal areas. High flow before the late-Mach breeding season is a key factor influencing colonization (Moffatt et al. 2005) and benefits bank swallows by carving new banks, creating suitable habitat. The meandering of the (unrocked) river channel occurs naturally during high flow events, creating new bank swallow burrowing/ nesting areas. Older nesting sites also become unsuitable after about three years as they become infested with ectoparasites. Erosive lateral river migration is therefore periodically necessary in order to create new nesting habitat with steep slopes and fresh surfaces for new nests.

Based on Garrison's (1989) conceptual model, EFT provides two indicators which describe changes in the physical habitat available for bank swallows. The first provides an annual estimate of the weighted useable length (WUL) of recently eroded bank available for nesting. The second provides daily estimates of the potential for bank sloughing during the nesting period, with sporadic high flows creating a high potential for bank failure (BASW2) (ESSA 2011). Because the second indicator depends on extremely high flows (> 50,000 cfs) and is insensitive to typical flow management operations, it is described further in Alexander et al. (2014).

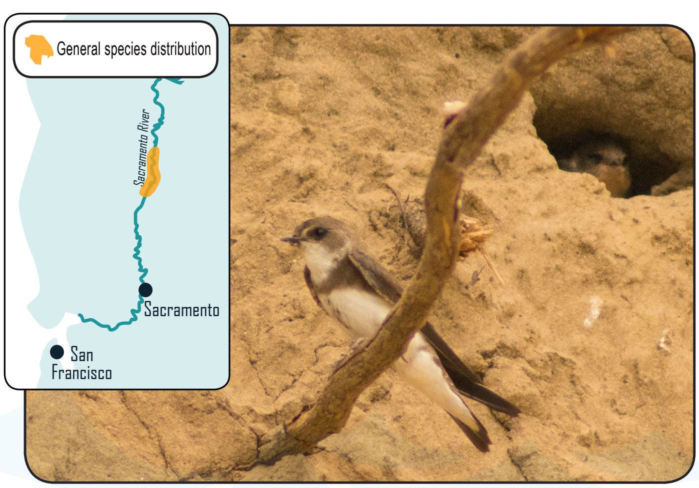


Figure 1: Bank swallows nest in cavities within tall, vertical banks along streams, lakes, and coastlines (photo by CDFW).

Indicator Overview

Bank Swallow Habitat Suitability (BASW1)

Coupled to a Johannesson-Parker (JP) River Meander Migration model (Johannesson and Parker 1989; Larsen and Greco 2002; Larsen et al. 2006), EFT simulates and reports the length of suitable bank habitat areas produced annually from approximately Butte City (RM 170) to Woodson Bridge (RM 222).

Nesting habitat potential is based on a simplification of Garrison's (1989) model and includes 3 factors: length of the recently eroded bank, elapsed time since the bank was sculpted by more than 1 meter, and soil suitability. The indicator of habitat potential is the WUL of bank and is calculated for each bend based on soil suitability and years since last major erosion event (Figure 2). The JP Meander Migration model incorporates soil type (and other variables that control channel erodability) and cumulative effective stream power to simulate the meander migration process that creates new bank on an annual timescale. Suitability is measured using a simple classification system where Columbia and Gianella loams are the only suitable soils.

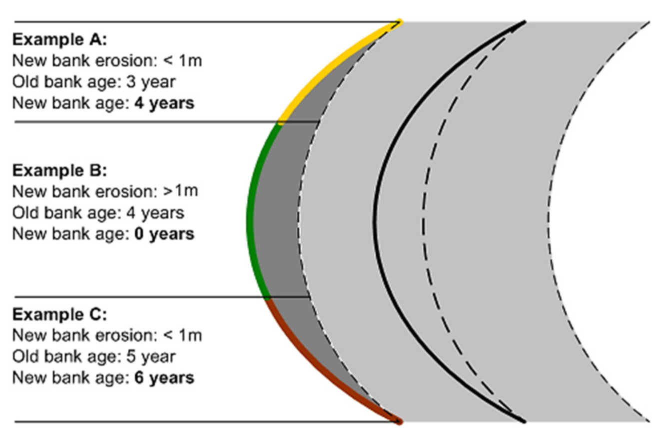


Figure 2: If a bank segment erodes more than 1m, the new bank age is set to 0 (B). If the bank segment has not been sufficiently eroded, the new bank age is calculated as age of the nearest old bank + 1 year (A and C). The new bank segment in A is considered marginal habitat according to the age-weighting scheme, the bank segment in C is no longer suitable.

Interpreting Indicator Output

BASW1 Index of Risk of Entrainment

Bank swallow habitat potential – measured as a weighted useable length (WUL, measured in meters) – is calculated for each bend based on two weighting factors: years since last major erosion event and soil suitability.

1. As banks increase in age their nesting suitability declines starting in the third year due to crowding, soil compaction and parasites in colony nests (Figure 3).

2. At the same time, meander migration can create fresh bank which, if deep enough, is suitable for colonization. Adding up the total WUL over a total of 37 meanders in 3 river segments between Vina and Butte City (RM 170 – 222) creates an aggregate total WUL for each year.

3. The breakpoints for EFT's color-coded Good/Fair/Poor Relative Suitability scoring system (Alexander et al. 2014) are based on discontinuities in the multi-year distribution (1940-1994) of WUL, and informed by expert opinion.

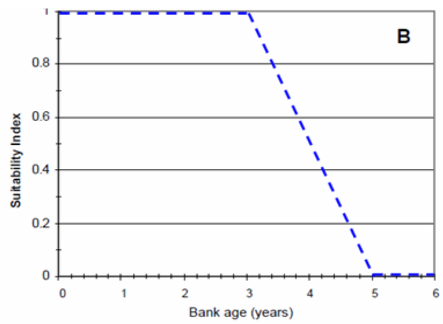


Figure 3: Habitat Potential vs. bank age (time since last major bank erosion event). Habitat decreases rapidly after 3 years because of ectoparasites. Most of the colonies in the Sacramento valley are used for no more than 7 consecutive years in the absence of erosion (Stillwater Sciences 2007).

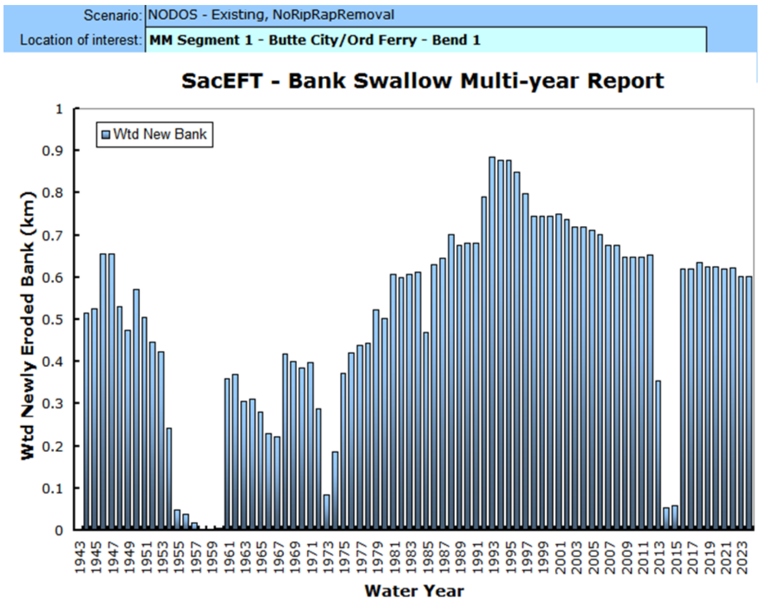


Figure 4: An example of an Excel report for BASW1 – Habitat potential. This example shows the Weighted Useable Length (WUL; km) for each year for Bend 1 in the Butte City/Ord Ferry segment.

Implications for Management

Bank swallows nest colonially in river cut banks, and require active channel meandering to create habitat suitable for nesting. EFT simulations have revealed how widespread bank stabilization (rocking) limits channel migration, and conversely how removal of revetment dramatically improves opportunities for natural river migration and high flow processes to renew suitable habitats for colonization. Consideration of levee modifications and revetment removal must be balanced with management of flood risk.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Final Report to The Nature Conservancy, Chico, CA. 228 p. + appendices.

ESSA [ESSA Technologies Ltd]. 2011. Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 111 p. + appendices.

Garrison BA. 1989. Habitat suitability index model: Bank Swallow (*Riparia riparia*). U.S. Fish and Wildlife Service. Sacramento, California.

Garrison BA. 1999. Bank Swallow (Riparia riparia). In: The Birds of North America, No. 414 (Poole A, Gill F, eds.). The Birds of North America, Inc., Philadelphia, PA.

Larsen EW, Greco SE. 2002. Modeling channel management impacts on river migration: a case study of Woodson Bridge State Recreation Area, Sacramento River, California, USA. *Environmental Management* 30:209-224.

Moffatt KC, Crone EE, Holl KD, Schlorff RW, Garrison BA 2005. Importance of hydrologic and landscape heterogeneity for restoring bank swallow (Riparia riparia) colonies along the Sacramento River, California. *Restoration Ecology* 13: 391–402.

Stillwater Sciences. 2007. Linking biological responses to river processes: Implications for conservation and management of the Sacramento River – a focal species approach. Final Report. Prepared by Stillwater Sciences, Berkeley for The Nature Conservancy, Chico, California.

The Nature Conservancy ESSA

Delta Smelt

Background

The Delta smelt were once common, thriving inhabitants of the Delta and elsewhere in the open waters of San Francisco Estuary (Moyle 2002, Bennett 2005, IEP 2015). They are the most estuary-dependent of the native fish species in the San Francisco Estuary, inhabiting open surface waters, and prefer clear, cool water of low salinity (Bennett 2005). They spawn in freshwater areas followed by migration to shallow, open-water areas of the West Delta and Suisun Bay to feed and mature. Some year-round populations of Delta smelt may exist in central locations (e.g. Cache Slough), suggesting they may show several life history strategies. As shown by the Fall Mid-Water Trawl index, Delta smelt populations have shown a long-term decline with the 2014-2016 drought pushing the species to the brink of functional extinction (Figure 1 inset).

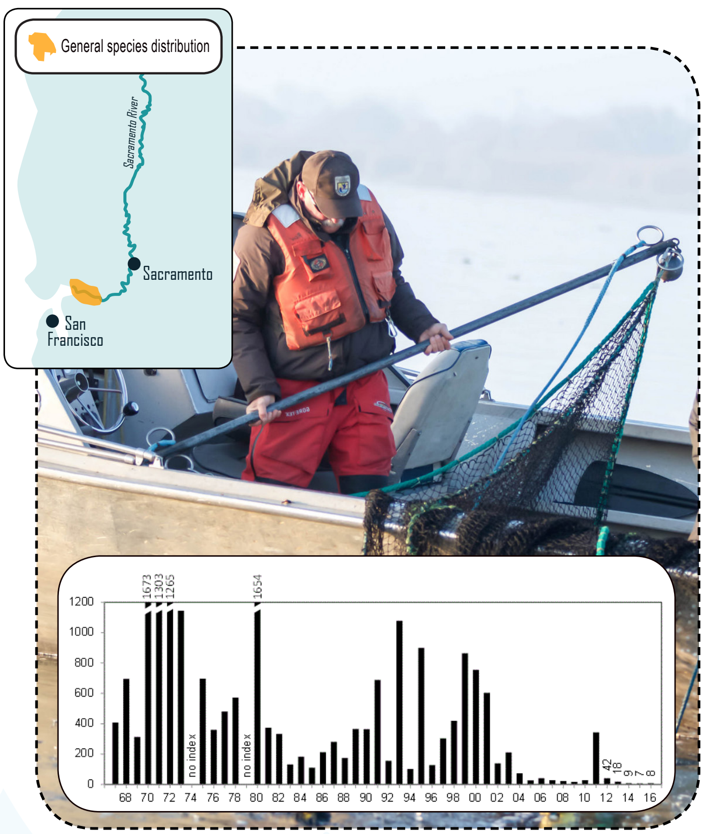


Figure 1: Delta smelt inhabit open waters of the Delta, where the USFWS Pacific Region monitors their populations via research trawls. As shown in the inset, these surveys show steep population decline over time (CDFW 2017).

Three EFT indicators for Delta smelt evaluate important aspects of their life history: spawning (spawning success), rearing (habitat suitability), and mortality (risk of entrainment in export facilities).

Indicator Overview

Index of Spawning Success (DS1)

Empirical evidence suggests that salinity and water temperature affect the spawning success of Delta smelt between February and May. Cool water and low salinity in this period typically results in more spawning events and more abundant cohorts (Kimmerer 2002, Bennett 2005). Flows which provide cool fresh water are therefore likely to provide the greatest benefit to spawning Delta smelt.

Index of Habitat Suitability (DS2)

Habitat location and extent is strongly influenced by freshwater flow into the estuary. Tides, bathymetry, and climate are also factors which influence temperature, salinity, and turbidity. However, the relationships between these factors and abundance is not simple (Moyle et al. 1992, Bennett 2005).

Index of Risk Entrainment (DS4)

The risk of entrainment into export facilities varies seasonally and annually. Low flow years historically have higher entrainment because in these years more adults and juveniles live and rear in the lower salinity Delta, closer to the facilities (Moyle et al. 1992). Entrainment is highest from December to April for adults, coinciding with spawning (Moyle 2002), and from April to July for juveniles (Nobriga et al. 2008). Effects on juveniles are poorly understood because larvae are not sampled effectively at the fish screening facilities. In one study (Kimmerer 2008), on average 13% of the larvae and juveniles were entrained annually between 1995 and 2005, with losses up to 25% in dry years.

Interpreting Indicator Output

DS1 Index of Spawning Success

In EFT the index of spawning success depends on water temperature and salinity. Peak spawning occurs between 12 and 16°C and declines above and below this range (Moyle 2002). The distribution of Delta smelt is also closely tied to salinity, with most found in waters below 6 ppt salinity.

1. EFT compares daily temperature and salinity values against the general indices of spawning success shown in Figure 2 to calculate joint-optimum temperature-salinity range at 24 representative locations, with the salinity index given twice the importance of temperature, to create a Daily Suitability Index for each location.

2. The longest run of consecutive days with both optimal temperature and salinity during the February-May spawning period is the annual index value at each location, which is averaged over all 24 locations to create an annual score for the Delta (Figure 3).

3. Based on the distribution of historical annual scores, the terciles of the distribution define EFT's color-coded Good/Fair/Poor Relative Suitability scoring system (Alexander et al. 2014).

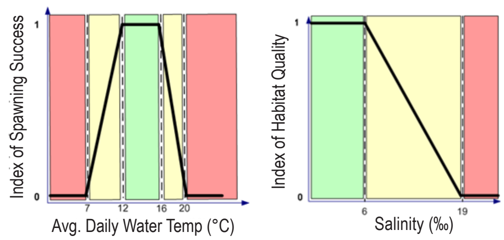


Figure 2: General index of spawning success across temperature (a) and salinity (b). Optimal conditions shown in green.

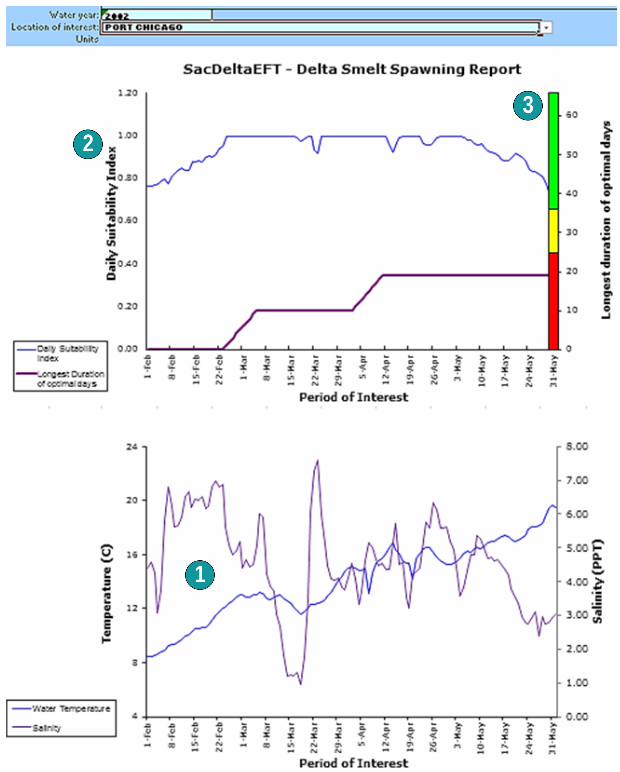


Figure 3: Example Excel annual rollup report for the DS1 indicator at Port Chicago in 2002. Here, multiple short optimal spawning periods, rather than a longer sustained period, result in poor performance.

DS2 Index of Habitat Suitability

EFT incorporates the habitat suitability model developed by Feyrer et al. (2011). This non-linear model is based on empirical sampling of abundance, temperature, salinity and turbidity from the CDFW fall midwater trawl survey from September to December, and calculates habitat index as a function of X2, defined as the distance from the Golden Gate Bridge to 2 ppt bottom salinity (Figure 4).

1. EFT calculates X2 from daily salinity at gages from Martinez (54 rkm) to Emmaton (92 rkm) (rkm = river kilometer).

2. The annual value of the index is the average of daily indexes from September to December (Figure 5).

3. Based on an analysis of the reasoning given in the Delta smelt BiOp (2008), EFT's color-coded Good/Fair/Poor Relative Suitability scoring system defines index breakpoints that correspond to X2 at 81 km and 74 km (Alexander et al. 2014).

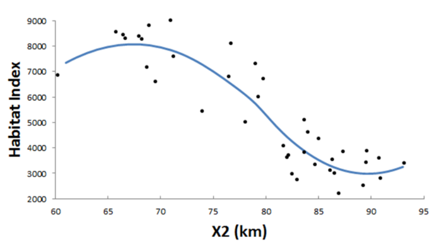


Figure 4: The X2-Habitat index relationship developed by Feyrer et al. (2011). The blue line shows LOESS regression with an r2 of 0.85, the black dots are Habitat Index values for individual years.

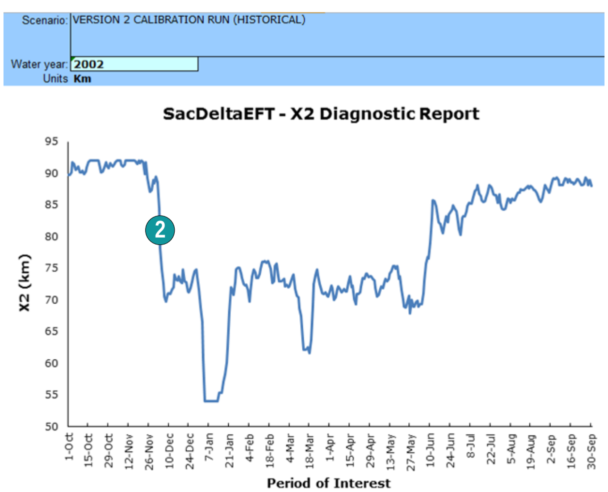


Figure 5: An example of a screen capture from the X2 Diagnostic Report. This example shows the daily location of X2 for WY 2002 (October 1st 2001 to September 30th 2002) for historical data. Note that X2 values are bound by 54 and 92 km.

DS4 Index of Risk of Entrainment

Larval and juvenile Delta smelt have limited active swimming, and so these fish can be modeled assuming they are free-flowing particles. Entrainment risk is evaluated using the Particle Tracking Model (PTM) developed by Kimmerer and Nobriga (2008). This model incorporates 8 locations known to be utilized by Delta smelt. EFT uses the PTM simulation results to estimate entrainment from these source locations under a range of inflow ("import") and outflow ("export") assumptions (Figure 6).

1. Combined daily Old and Middle River Flows (OMR) over the March-July spawning period are multiplied by a daily weight (gray bars) based on the probability of spawning on a given day for the given location, which is determined from research trawls (Figure 6).

2. All daily OMR flows are multiplied by their daily weight are summed together to obtain a single Annual Weighted Flow.

3. Using the Annual Weighted Flow, an export-to-import ratio (E:I) is calculated based on a known relationship between the export-to-import ratio and OMR Flow (Figure 7).

4. Based on this E:I, the daily proportion of larval and juvenile Delta smelt arriving at the export facilities (i.e., entrainment) is predicted from the PTM calibrated for each source location.

5. To determine the score, the level of entrainment for the Annual Weighted Flow is compared against a Location Weight, which is based on the number of fish observed at that location during research trawls. At this location, high entrainment (X) in this year and location is offset by the low location-weight (very small green bar to the right) (Figure 8).

6. Summing over all locations, EFT's color-coded Good/Fair/Poor Relative Suitability scoring system defines index breakpoints that correspond to 4% and 11% entrainment (Alexander et al. 2014).

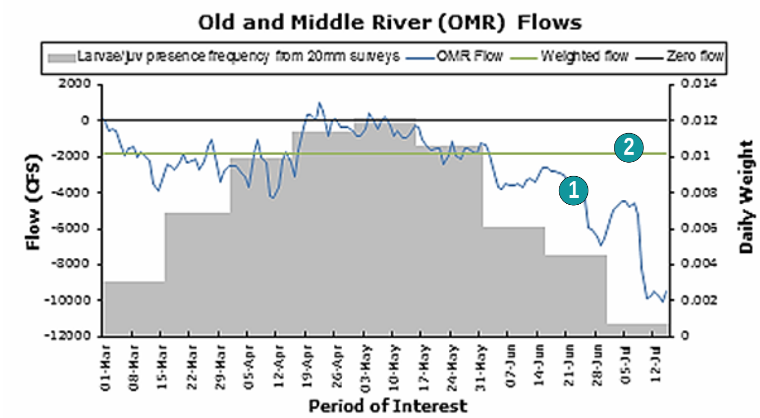


Figure 6: Combined daily OMR flows and their daily weights..

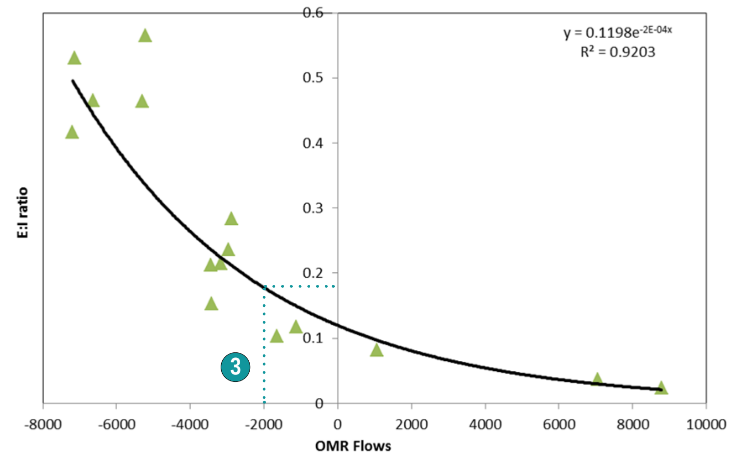


Figure 7: Logarithmic regression for Export:Import ratio as a function of OMR flows. Data are from the DAYFLOW program from 1987 to 2002 based on average values from April 1st to May 15th. Green triangles are data points for each year and the black curve shows the data predicted by the regression.

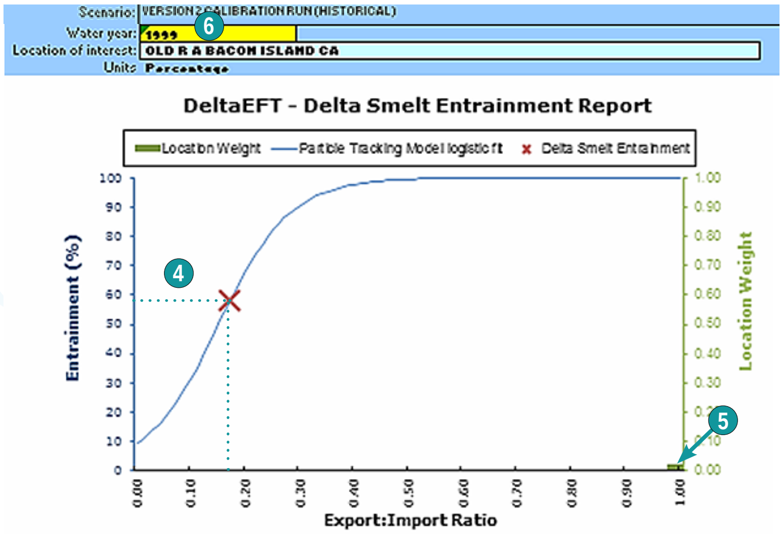


Figure 8: Example Excel annual rollup report for the DS4 indicator.

Spatial Data Reports

EFT can also display indicator outputs as spatial reports. The examples shown here (Figure 9) are spatial reports for the spawning success indicator for Delta smelt (DS1) for a year considered to have good overall performance.

1. The report shows dots at each model location that are color-coded by the final indicator score, which is the same as for the Excel output. In other spatial reports for indicators that are weighted, such as DS4, the size of each dot shows the spatial weight.
2. Clicking on each dot activates pop-ups that provide more information on temperature and salinity profiles over time at that location.
3. Spatial reports can also be generated to show multi-year rollups of performance data, where a pie chart at each location represents the number of years the location was assigned a Good, Fair or Poor performance over a given period (here, 17 years). This report is useful for quickly finding spatial patterns in performance over time. A location-specific breakdown for number of years in each category can be displayed by selecting the location with the Select tool.

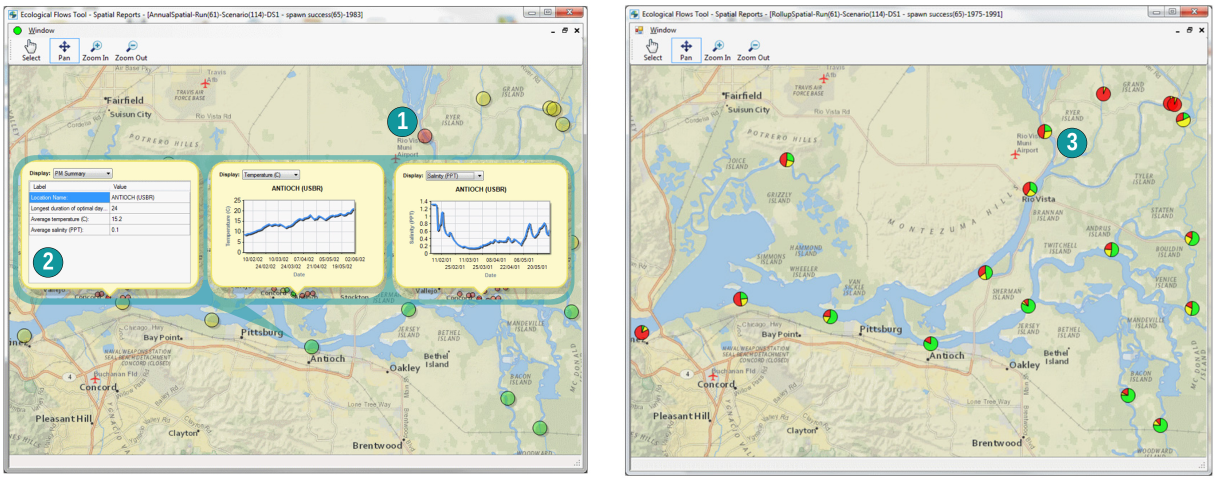


Figure 9: Spatial data reports showing the performance of the DS1 indicator at each location for a single year (A) and over multiple years (B).

Implications for Management

The mechanisms described by the Delta smelt indicators vary in the degree to which they govern outcomes, and there are other important factors and conditions in any given year that drive population outcomes (IEP 2015). Nevertheless, flow management actions which improve habitat conditions and reduce mortality will help limit some of the factors which contribute to the dwindling populations of Delta smelt. Unlike some other species, Delta smelt indicators DS2 and DS4 are very high priority and need to be favorable every year to support populations, while indicator DS1 need only be favorable every 2 years.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Report to The Nature Conservancy, Chico, CA. 228 p.

Bennett, W.A., 2005. Critical assessment of the Delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science, 3(2).

California Department of Fish and Wildlife (CDFW). 2017. Trends in Abundance of Selected Species. Retrieved from: http://www.dfg.ca.gov/delta/data/fmwt/Indices/index.asp

Delta smelt BiOp. 2008. The Sacramento Fish and Wildlife Office's Biological Opinion (BiOp) on the Long-Term Operational Criteria and Plan (OCAP) effects on Delta smelt. December 15, 2008.

Feyrer F, Newman K, Nobriga M, Sommer T. 2011. Modeling the effects of future outflow on the Abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34: 120-128.

Interagency Ecological Program (IEP). 2015. An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish. Available: http://www.water.ca.gov/iep/docs/Delta_Smelt_MAST_Synthesis_Report_January%202015.pdf Accessed: June 30 2017

Kimmerer WJ. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 242:39-55.

Kimmerer WJ 2008. Losses of Sacramento River Chinook salmon and Delta smelt (Hypomesus transpacificus) to entrainment in water diversions in the Sacramento-San Joaquin delta. San Francisco Estuary and Watershed Science 6, Issue 2, Article 2.

Kimmerer WJ, Nobriga ML. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin delta using a particle tracking model. San Francisco Estuary and Watershed Science 6, Issue 1, Article 4.

Miller WJ, Manly BFJ, Murphy DD, Fullerton D, Ramey RR. 2012. An investigation of factors affecting the decline of Delta smelt (Hypomesus transpacificus) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science 20:1-19.

Moyle, PB. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Moyle PB, Herbold B, Stevens DE, Miller LW. 1992. Life history and status of Delta smelt in the Sacramento-San Joaquin estuary, California. Transactions of the American Fisheries Society 121:67-77.

Nobriga, ML, Sommer TR, Feyrer F, Fleming K. 2008. Long-term trends in summertime habitat suitability for Delta smelt, Hypomesus transpacificus. San Francisco Estuary and Watershed Science 6, Issue 1, Article 1.

Sommer, T., F. Mejia, M. Nobriga, F. Feyrer, and L. Grimaldo. 2011. The spawning migration of Delta smelt in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 9(2). Available at: http://www.escholarship. org/uc/item/86m0g5sz.

The Nature Conservancy

ESSA

September 2017

EFT
Ecological Flows Tool
Indicator Brief

Fremont Cottonwood

Background

Fremont cottonwood is the dominant tree species of the riparian forests of the California Central Valley. It shades side channels and stabilizes banks, and provides an important source of habitat for riparian wildlife. The Sacramento Valley has lost over 98% of its riparian forests since 1850 (Greco 1999). EFT defines 2 indicators for Fremont cottonwood. One indicator, scour potential, is sporadic and driven by high flow events typically beyond the control of water managers, and is not described here. The other indicator measures initiation success and recruitment potential and depends on the ability of the seedling tap root to maintain contact with groundwater as the elevation of the river declines.

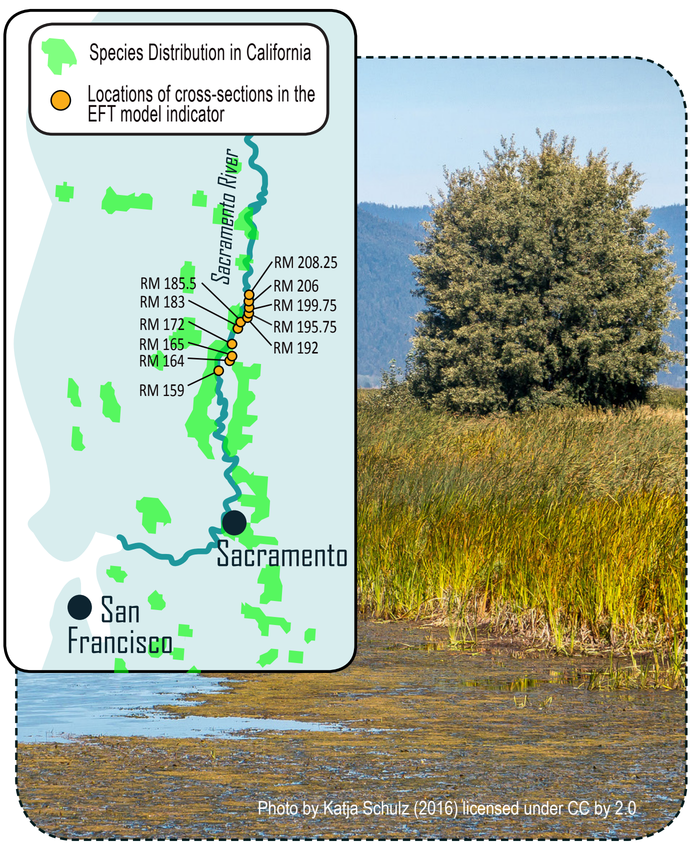


Figure 1: Fremont cottonwood frequently grow along riverbanks. Inset shows the known distribution of Fremont Cottonwood around the Sacramento River (map modified from Little et al. 2017) and the locations of cross-sections used in the EFT model.

Indicator Overview

Riparian Initiation (FC1)

This performance measure predicts the response of Fremont cottonwood seedlings to gradual reductions in flow at 11 index locations from River Mile 159 to 208 along the Sacramento River. Seedling success is based on Mahoney and Rood's (1998) recruitment box model, which predicts the success of riparian initiation as a function of the gradual reduction in flow and water surface elevation. Important variables such as seed dispersal timing, taproot growth rate, capillary fringe, drought tolerance and viable root depth are also integrated into this performance measure. Seedlings that germinate too high on the bank cannot grow roots fast enough to keep up with the receding water table (or river "stage") during the hot summer months, while those that grow too low on the bank are removed by scour during high flow events during the subsequent winter or spring (Figure 2). A second indicator (FC2) is tracked by EFT to determine whether seedlings in the target initiation zone are subsequently scoured and killed by high flows (flows >80,000 - 90,000 cfs).

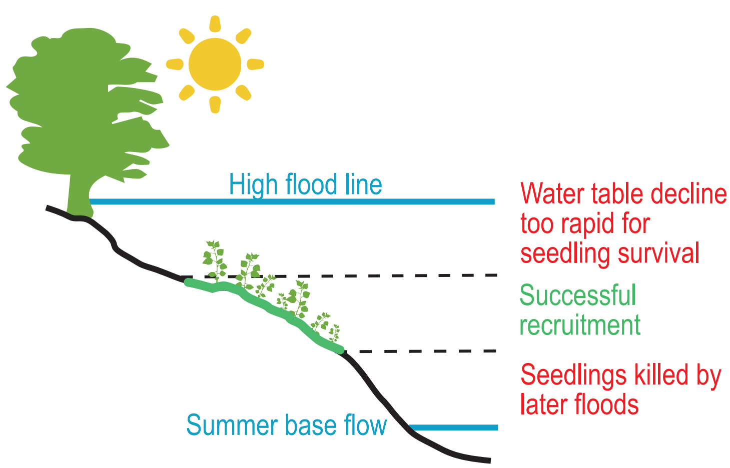


Figure 2: Generalized pattern of successful seedling initiation observed for cottonwoods along alluvial rivers. Modified from Stillwater Sciences poster presentation, Calfed Science Conference (2008).

Interpreting Indicator Output

FC1 Riparian Initiation

The example EFT Excel output for Fremont cottonwood seedling initiation success shown in Figure 3 is based on a good water year in 1998.

1. The riparian initiation model determines whether cottonwood seedlings will successfully initiate at a given location along a river cross section.

2. Seeds are released during a mid-April to mid-June dispersal window and begin to grow roots downward from the elevation at which they were deposited. After accounting for capillary action, the rate of decline of the water table (or river "stage") over time determines whether the taproot can maintain contact with the water table. If the root is unable to maintain contact (allowing for a 5-day "grace period" to reflect drought tolerance), the seedling dies.

3. For successful initiation the rate of stage decline cannot move faster than the taproot maximum daily growth rate of 22 mm. Cottonwood seedlings whose roots reach a depth of 0.5 m are assumed to be successful in reaching more permanent groundwater which is able to maintain them through the remainder of their first year.

4. The annual cottonwood performance measure tallies the total number of initiation successes and failures over the cross-sections used in the model to determine the overall score.

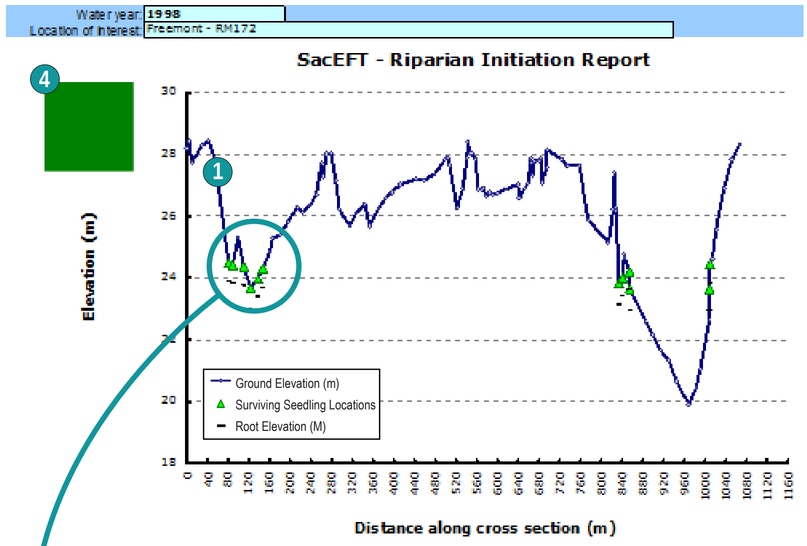
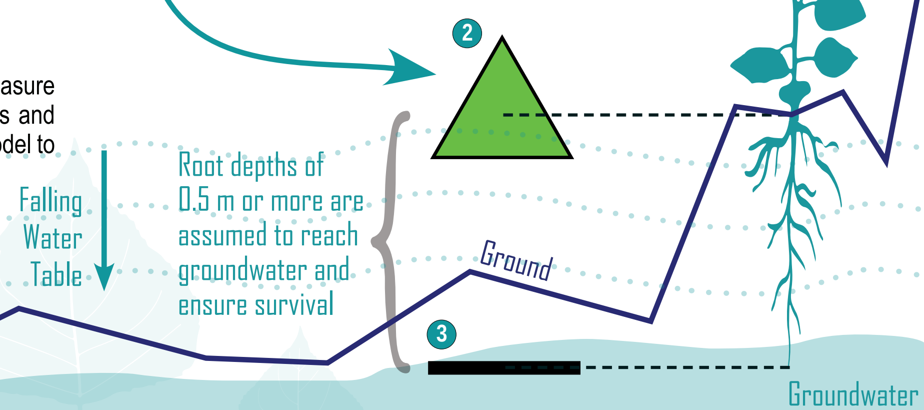


Figure 3: Sample EFT Excel output for Fremont cottonwood

The breakpoints for EFT's 3-level Good/Fair/Poor Relative Suitability scoring system (Alexander et al. 2014) are based on a comparison of simulation results with aerial photography in years with strong recruitment, combined with expert opinion.



Implications for Management

Periodic scour events remove all size classes of Fremont cottonwood (and other vegetation), creating woody debris that may be beneficial to other species, and exposing new river and stream bank for ecological succession. Flow dynamics that allow for renewal of riparian vegetation are therefore important for maintaining the stability of the physical stream bank as well as creating habitat and shade. Fremont cottonwood do not require successful initiation events every year, but initiation every 8-10 years is necessary to maintain preferred habitat characteristics.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Final Report to The Nature Conservancy, Chico, CA. 228 p. + appendices.

Little E. U.S. Department of Agriculture, Forest Service, and others. 2017. USGS Geosciences and Environmental Change Science Center: Digital Representations of Tree Species Range Maps from "Atlas of United States Trees" by Elbert L. Little, Jr. (and other publications)

Greco S. 1999. Modeling habitat suitability for the yellow-billed cuckoo over time and space along the Sacramento River. Doctoral dissertation. University of California, Davis.

Mahoney JM, Rood SB. 1998. Streamflow requirements for cottonwood seedling recruitment - an integrative model. Wetlands 18:634-645.

The Nature Conservancy ESSA

Longfin Smelt

Background

The longfin smelt has experienced a severe decline in the Bay-Delta over the past four decades, and its abundance in the last decade is the lowest recorded in the 40-year history of monitoring surveys. Some of the decline is attributed to trophic changes in the Delta (Mount et al. 2013), including the introduction of the overbite clam. Due to the long-term decline and significant threats to the population, longfin smelt was listed as a threatened species under California's Endangered Species Act in 2009. With life history and habitat requirements similar to Delta smelt, Longfin smelt occur primarily in the lower Sacramento River and throughout the upper Delta. Outside of their spawning periods they are most often concentrated in Suisun, San Pablo and north San Francisco Bays (Moyle 2002), downstream of the CVP and SWP pumping facilities. They are also common in nearshore coastal marine waters outside the Golden Gate Bridge in late summer and fall (Baxter 1999). Abundance is heavily influenced by freshwater flow, possibly because the high flow creates better freshwater incubation habitat for larval and juvenile Delta smelt. Several studies have confirmed a positive correlation between longfin smelt abundance and freshwater flow, noting that abundances of both adults and juveniles were significantly lower during the 1987–1994 drought than during either the pre- or post-drought periods.

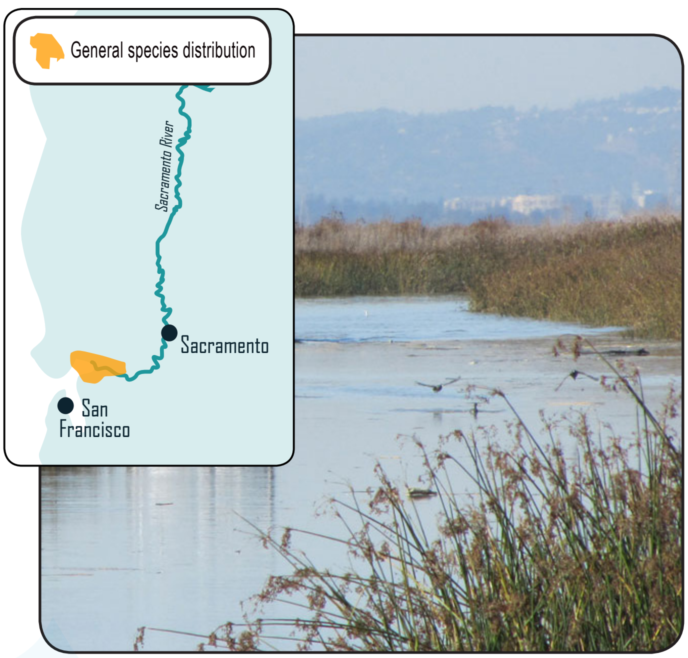


Figure 1: Main location of suitable habitat for longfin smelt, which include shallow water habitats such as the Alviso Slough shown here (H. Gibbons, 2011, USGS)

Indicator Overview

Abundance Index (LS1)

EFT defines one indicator for longfin smelt: an abundance index based on a statistical relationship between the average location of X2 (salinity) from January to June, and the annual index of longfin smelt abundance from the fall midwater trawl survey. X2 position is generally inversely correlated with freshwater flow. Mount et al. (2013) fitted this relationship for 3 periods (pre-1988, 1988-2002 and post-2002), with those periods chosen by considering ecosystem shifts following the introduction of overbite clam and the POD (Sommer et al. 2007) (Figure 2). EFT makes use of the most recent data (2003 - 2012), so that the indicator is most representative for current and future conditions. X2 itself is calculated by EFT from daily salinity at gages from Martinez (54 rkm) to Emmaton (92 rkm).

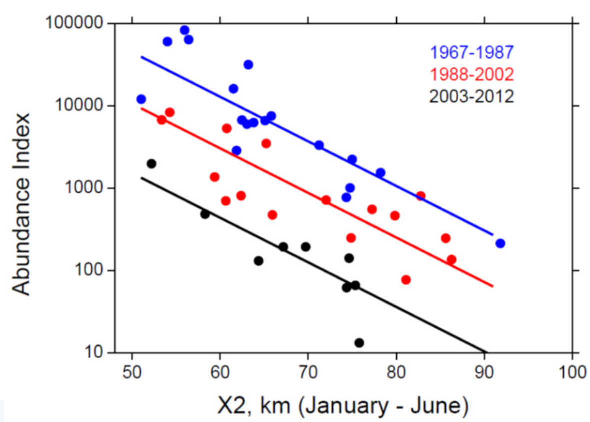


Figure 2: Abundance-X2 relationship for longfin smelt.

Interpreting Indicator Output

LS1 Abundance Index

An example of the multi-year rollup report for LS1 from 1975 to 1991 for modeled data is shown in Figure 3.

1. The lower graph shows the average annual X2 location measured in km from the Golden Gate Bridge, where X2 can range from 54 to 92 km. A low average X2 corresponds to a high abundance index.

2. The upper panel shows the annual longfin smelt abundance index based on the statistical relationship. The performance for a given year can be found by comparing the annual habitat index value with the bar on the right.

3. The breakpoints for EFT's 3-level Good/Fair/Poor Relative Suitability scoring system (Alexander et al. 2014) are based on a combination of historical and simulation results, selecting natural breakpoints in the cumulative distribution of the index.

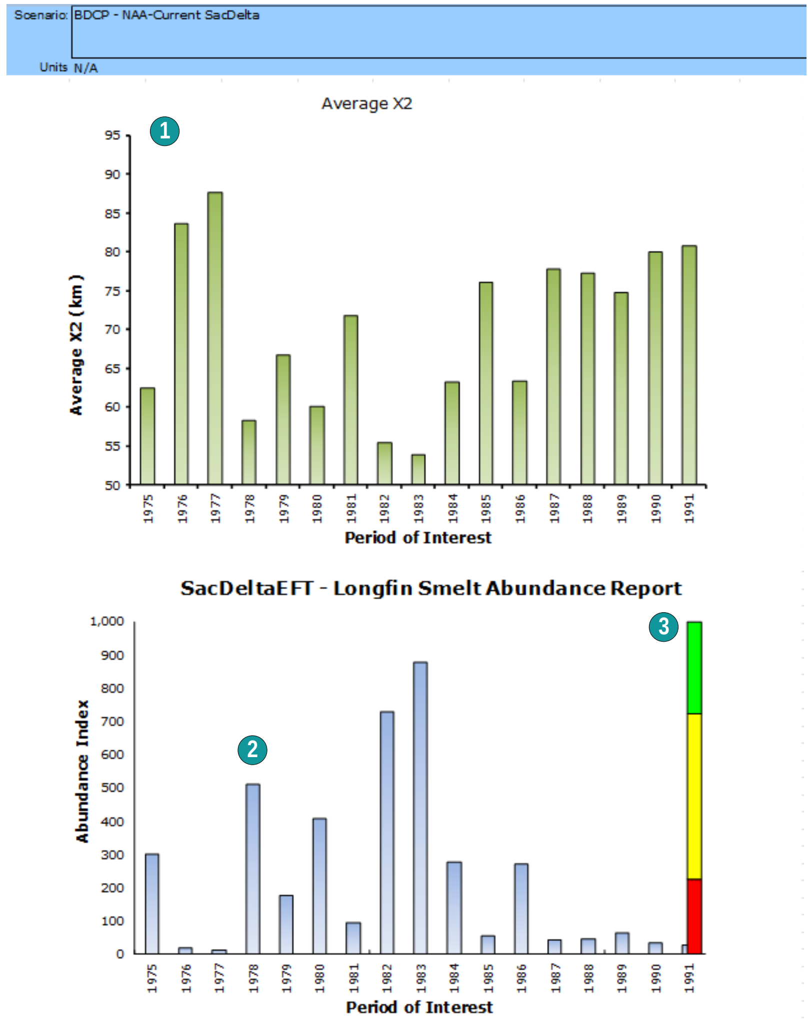


Figure 3: Sample EFT Excel output for longfin smelt

Implications for Management

Because of its dependence on low salinity conditions (a low X2) in the Bay, the longfin smelt abundance index is sensitive to flow management operations which are able to deliver more fresh water into the Delta. In most cases the indicator does not need to be favorable every year. The best estimate of the frequency of favorable years needed to support longfin smelt is 4 years out of every 10.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Final Report to The Nature Conservancy, Chico, CA. 228 p. + appendices.

Baxter RD. 1999. Osmeridae. In Orsi J (ed.). Report on the 1980 to 1995 fish, shrimp and crab sampling in the San Francisco Estuary. Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Pp.179–216.

Mount J, Fleenor W, Gray B, Herbold B, Kimmerer W. 2013. Panel Review of the Draft Bay Delta Conservation Plan: Prepared for The Nature Conservancy and American Rivers.

Moyle PB. 2002. Inland Fishes of California. Revised and Expanded. University of California Press, Berkeley, CA.

Sommer T, Armor C, Baxter R, Breuer R, Brown L, Chotkowski M, Culberson S, Feyrer S, Gingras M, Herbold B, Kimmerer W, Mueller-Solger A, Nobriga M, Souza K. 2007. The collapse of pelagic fishes in the Upper San Francisco Estuary. Fisheries 32:270–277.

The Nature Conservancy

ESSA

September 2017

EFT Ecological Flows Tool Indicator Brief

Salmonids

Background

The Sacramento River supports populations of steelhead trout and 4 seasonal run-types of Chinook salmon. Each run-type is distinguished by timing of upstream migration. Winter and Spring run-types are both listed as endangered by state and federal agencies, and Fall and Late-Fall run-types are listed as Species of Concern by the ESA. Currently Fall-run Chinook are the most abundant run-type in the Central Valley and are maintained through natural recruitment and hatchery programs. EFT does not predict salmonid population dynamics but simulates the habitat suitability of 7 key life history stages of all salmonids using a common conceptual framework which focuses on the role of flow and temperature on each life history stage. Spawning and rearing habitat are simulated at up to 5 main-stem locations (RM298-301, RM280-298, RM272-280, RM252-272, RM218-243), and smolt habitat is simulated across 6 estuarine routes downstream of Hood (RM49).

Indicator Overview

Of the 7 life history stages, 6 are significantly influenced by flow management and are described in more detail in the next sections, while the other indicator is described in ESSA (2011). EFT also considers temperature stress for two life history stages.

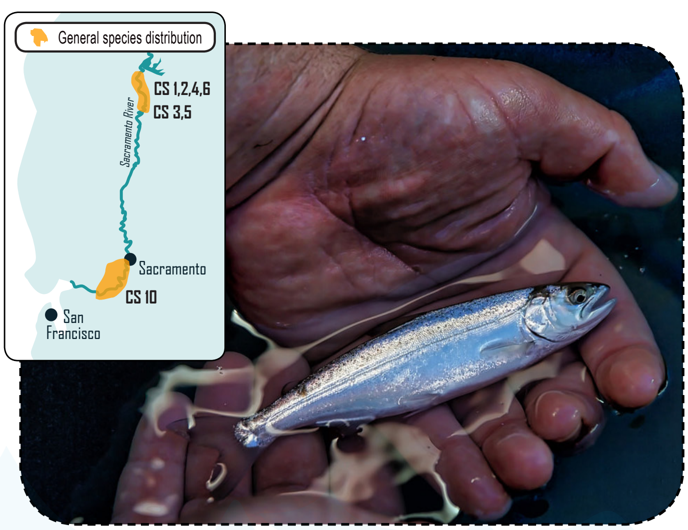


Figure 1: Juvenile Chinook salmon migrate through the San Francisco Bay Delta, where the USFWS conducts monitoring trawls.

WUA - Spawning (CS1)

Spawning habitat is represented using Weighted Usable Area (WUA), a concept which incorporates the empirical preferences of Chinook and steelhead for particular ranges of flow, depth and gravel size, as developed by Mark Gard of the USFWS. During each run-type's spawning period, the daily combination of flow, depth and gravel modifies the quality of the spawning area (USFWS 2003, 2005a). Parameterization of the flow-depth relationship at 5 representative main-stem spawning locations creates a flow-dependent measure of spawning habitat quality (Figure 2), a relationship that is further adjusted by the daily temporal pattern of the spawning period distribution. When summed over all locations and the entire spawning period, an annual measure of habitat quality is created for each run-type.

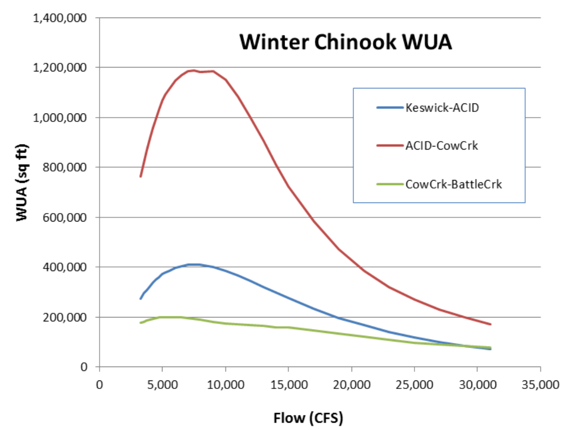


Figure 2: EFT combines gravel, depth and flow to simulate spawning habitat (WUA) using daily flow in key reaches of the Sacramento River. Specific amounts of habitat depend on local conditions in each reach, but in all reaches the best spawning habitat for winter-run Chinook occurs when flow is between 5,000 and 10,000 CFS.

WUA - Rearing (CS2)

Following spawning and emergence, rearing habitat is represented using the spawning WUA concept but using rearing-specific flow and depth preferences (USFWS 2005b). Like the Spawning WUA indicator, summing the flow-based WUA relationship at 5 main-stem spawning locations creates a flow-dependent measure of rearing habitat quality.

An annual measure is created by summing over all locations during the rearing period, with each day-cohort weighted by the temporal pattern of the rearing period. The temporal pattern for day-cohorts is based on the initial temporal distribution of spawning followed by temperature driven egg-maturation (Crisp 1981) (Figure 3) and a run-specific residency period.

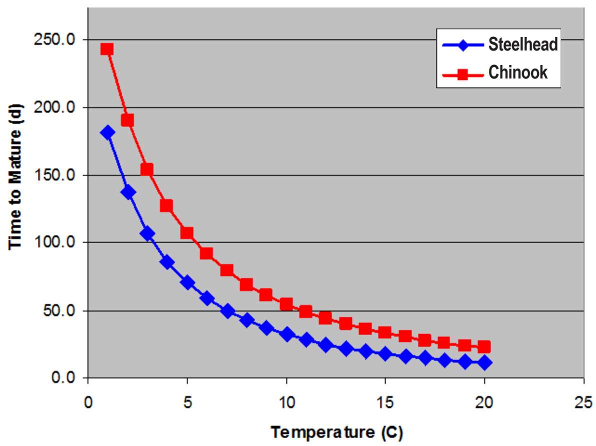


Figure 3: Based on relationships developed by Crisp (1981) for Chinook salmon and rainbow trout (steelhead), eggs at a given temperature will mature in a corresponding number of days. The reciprocal of the number of days is the proportion of maturation occurring over one day, and maturation is complete when the cumulative proportion of daily maturation reaches 1.0.

Egg Thermal Mortality (CS3)

During the egg development period, maturation of eggs is faster in warmer water (Crisp 1981, see Figure 3 of this Fact Sheet). Above about 15 °C, warm water can reduce the survival of developing eggs (Figure below in this document). Using a temperature-mortality relationship from Bartholow & Heasley (2006), daily mortality is simulated based on the temperature in each of 5 main-stem spawning locations. The annual average mortality for each run-type is based on the temperature-dependent egg development period, with each day-cohort weighted by the spawning calendar (grey area in Figure 4 of this Indicator Brief).

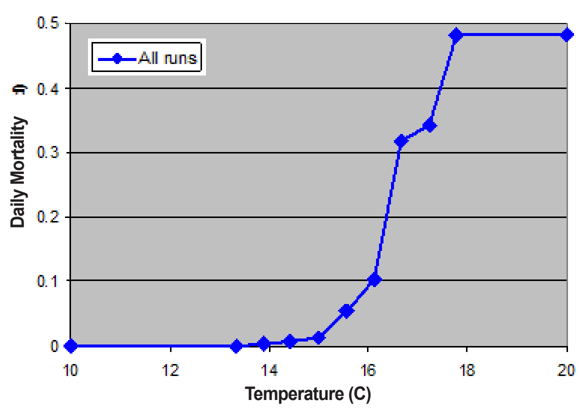


Figure 4: Salmonid eggs of all species experience significant mortality in water warmer than 15C. (Bartholow and Heasley 2006)

Juvenile Stranding (CS4)

During the juvenile rearing period, day-to-day declines in flow can affect young salmonids, stranding them or stranding them through dewatering. During this period, each rearing day-cohort is affected by these declines using the proportional change in daily WUA (USFWS 2006) weighted by the temporal pattern of the rearing period. Juvenile salmonids may possess behaviors that help them avoid stranding, so the index is considered a proxy for stranding and not an exact representation.

Redd Dewatering (CS6)

Prior to emergence, day-to-day declines in flow can dewater redds containing developing eggs. During this period, each day-cohort is affected by these declines using the proportionate decline in daily WUA (USFWS 2006) weighted by the initial temporal pattern of spawning combined with temperature-driven egg maturation (Crisp 1981). The methodology for calculating the index is the same as the one used for juvenile stranding (CS4), but is based on cumulative proportional losses experienced by each egg day-cohort as daily flow declines relative to the spawning day flow.

Smolt Temperature Stress (CS10)

As juveniles end their rearing period and migrate downstream they continue to rear in the Bay-Delta, becoming more adapted to marine conditions. They typically follow one of 6 routes through the Delta network (Perry et al. 2010). During this migration period and depending on the route they follow, smolts of each run-type experience physical and biological effects which can promote or hinder growth. EFT summarizes the physical effects of temperature on weight gain (Brett et al. 1969), with smolts rearing in cooler conditions generally experiencing less temperature stress and gaining more weight (see Figure 5, which also includes ration effects). Finally, EFT accounts for changes to migration speed as a function of flow in each route, as well as the proportional role of each route for the entire year-cohort.

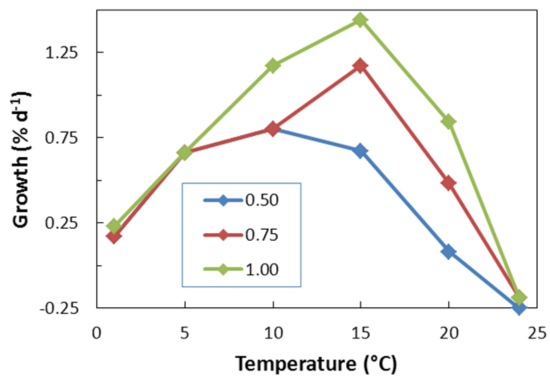


Figure 5: The relationship between daily weight gain and temperature for 7-12 month sockeye smolts (Brett et al. 1969, Figure 11 and Table 3) for three levels of daily ration. A ration of 6% of body weight/day is assigned as ration level of 1.00, and lower rations are expressed in relation to this level.

Interpreting Indicator Output

CS1 Weighted Usable Area - Spawning

Each salmonid run-type follows a unique spawning calendar (Bartholow & Heasley 2006), which is summarized in Figure 6 for the salmonids represented in EFT.

1. This spawning calendar is translated into the grey bars in Figure 7.
2. Daily flow (not shown) during this period affects the amount of WUA (blue line), which when summed over all days and locations where the run-type is known to spawn, creates a cumulative annual measure of spawning habitat.
3. Based on the natural breakpoints in the multi-year distribution of annual scores, supplemented by expert opinion, EFT assigns a Good/Fair/Poor Relative Suitability rating (Alexander et al. 2014).

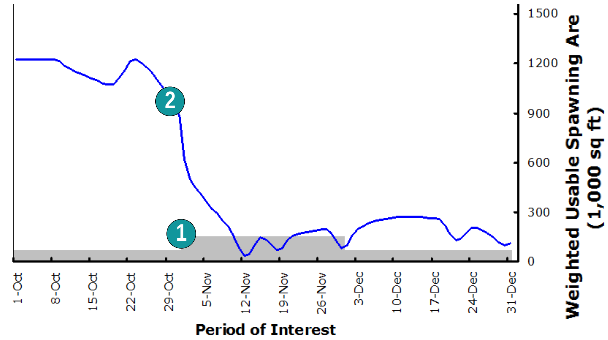


Figure 7: EFT Chinook and steelhead spawning WUA report for Reach 2 in 1969.

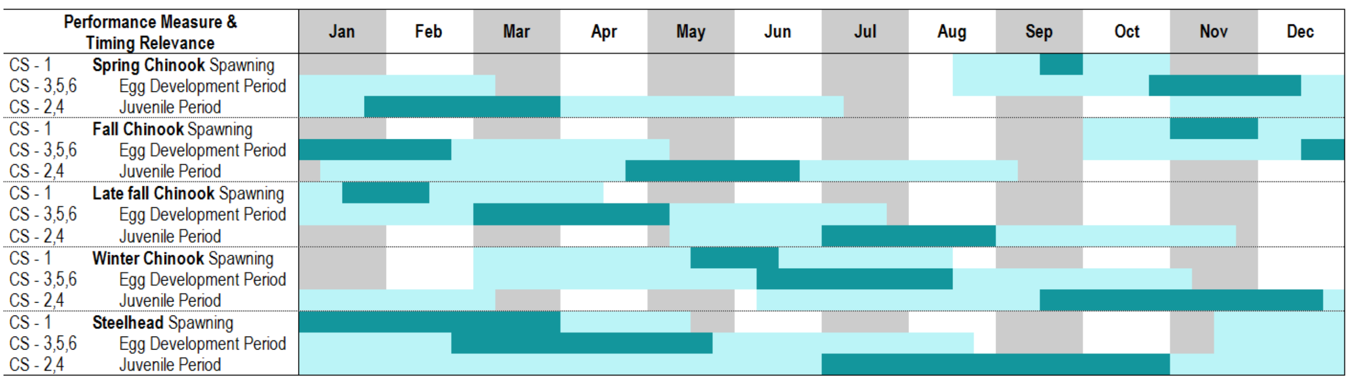


Figure 6: Only those performance measures (PMs) requiring information on life history timing are shown here, including some not described in this indicator brief (CS-3, 5). Dark blue denotes periods of greater importance. In the case of the spawning indicators (CS-1), for each run-type/species, dark blue denotes the period when half the spawning takes place. In the case of the other salmonid indicators, dark blue denotes the period when half of the population is present. Specific timing of these events depends on ambient water temperature and flow scenario, and values may shift by as much as five days earlier or later, depending on year and reach.

CS2 Weighted Usable Area - Rearing

EFT models emergence from the spawning redds using a temperature-based relationship (Crisp 1981) followed by a residency period specific to each salmonid run-type.

1. The temperature-driven egg-emergence function described in Figure 3 is used to generate daily juvenile rearing weights.
2. Daily flow during this period (not shown) affects the amount of WUA (blue line), which when weighted by day-cohort proportion and summed over all days and locations where the run-type is known to spawn, creates a cumulative annual measure of spawning habitat.
3. Based on the natural breakpoints in the multi-year distribution of annual scores and supplemented by expert opinion, EFT defines the colour-coded Good/Fair/Poor Relative Suitability rating system (Alexander et al. 2014).

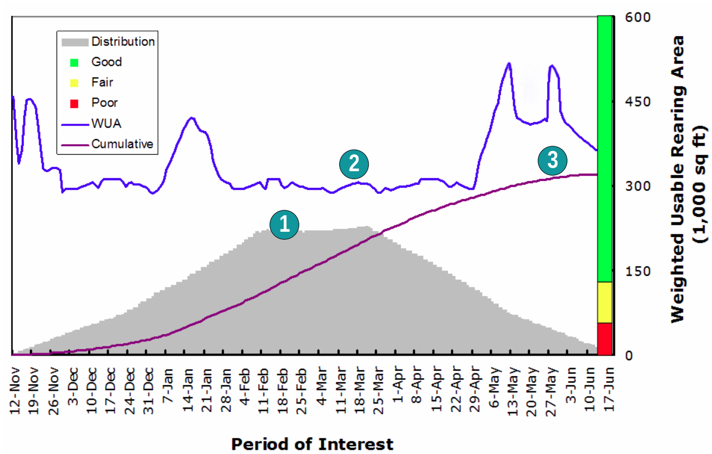


Figure 8: An example of the Version 2 Excel report for CS2 – Chinook juvenile rearing WUA using fall-run Chinook from Reach 5. The purple cumulative distribution lines show that Reach 5 receives a Good (Green) ranking relative to all reaches.

CS3 Egg Thermal Mortality

EFT models thermal egg mortality using two temperature-based relationships.

1. The first (Crisp 1981) determines the time necessary for eggs to mature (Figure 3 of this Indicator Brief).

2. The second (Bartholow & Heasley 2006) simulates the mortality caused by high temperature to yield mortality thresholds.

   Weighting by day-cohort proportion (3) and summing over all days and locations where the run-type is known to spawn (4) creates a cumulative annual measure of egg mortality (5).

6. EFT defines the 3-level Good/Fair/Poor Relative Suitability rating system (Alexander et al. 2014) based on threshold values of 5% and 10% mortality.

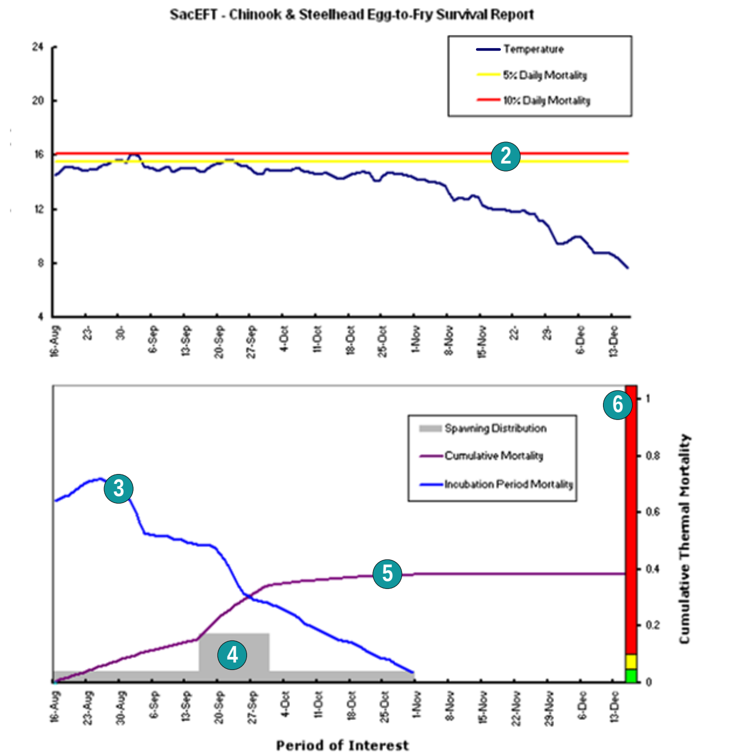


Figure 9: Egg-to-fry thermal mortality using spring-run Chinook from Reach 4 in 1988. System-wide, this year was reported as a Poor year.

CS4 Juvenile Stranding

Juvenile salmonids can become stranded or exposed when flow declines too quickly. EFT simulates stranding following emergence and during the juvenile residency period.

1. EFT simulates juvenile stranding based on daily negative changes in rearing weighted usable area (WUA), which cause the loss of a proportion of rearing habitat relative to the previous day's habitat (blue line, before weighting by day-cohort proportion).

2. These habitat losses are further weighted by the temporal distribution of the rearing day-cohorts (grey area in figure, which also tracks losses), which is influenced by spawning day, egg-maturation and the length of the rearing residency period.

3. As this weighted loss is accumulated over the entire rearing period and summed over all rearing locations, a cumulative index of total loss is calculated (purple line) for the entire year.

4. Based on natural breakpoints in the multi-year distribution of annual scores and supplemented by expert opinion, EFT defines the colour-coded Good/Fair/Poor Relative Suitability rating system (Alexander et al. 2014). The vertical horizontal R/Y/G shows the cumulative distribution of the reach and year relative to the annual rollup distribution.

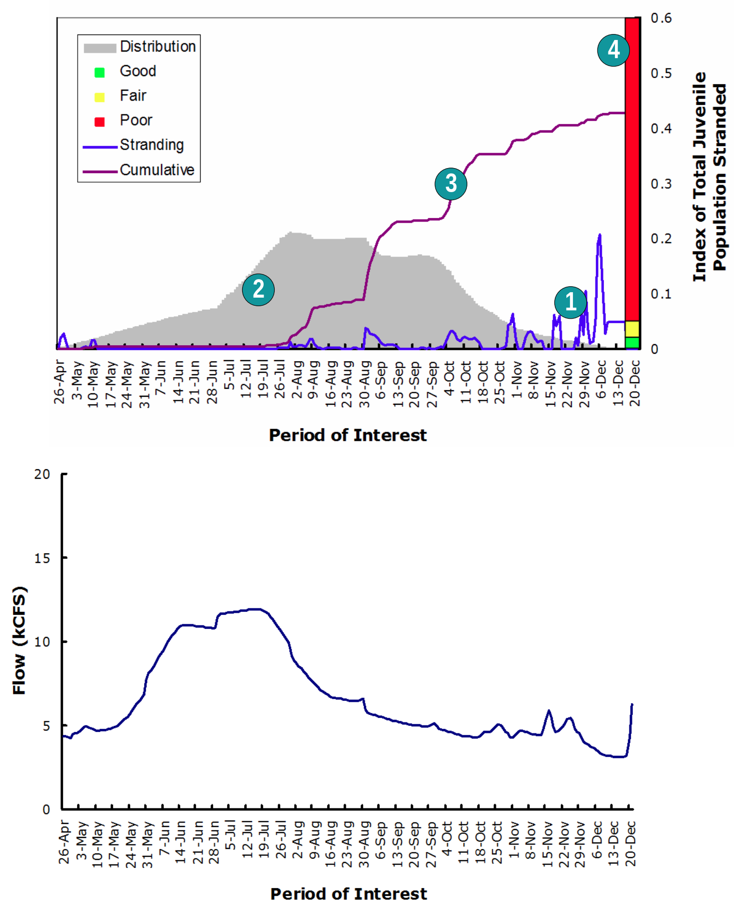


Figure 10: Excel Report for CS4 – Juvenile Stranding, showing winter-run Chinook in Reach 5 for 1979. The index is very sensitive to declining changes in flow, even though the discharge is quite low. The impact of stranding index upon the juvenile distribution can be seen in the quick declines of the bell-shaped gray distribution that accompany drops in flow, coupled to a sharp jump in the stranding index.

CS6 Redd Dewatering

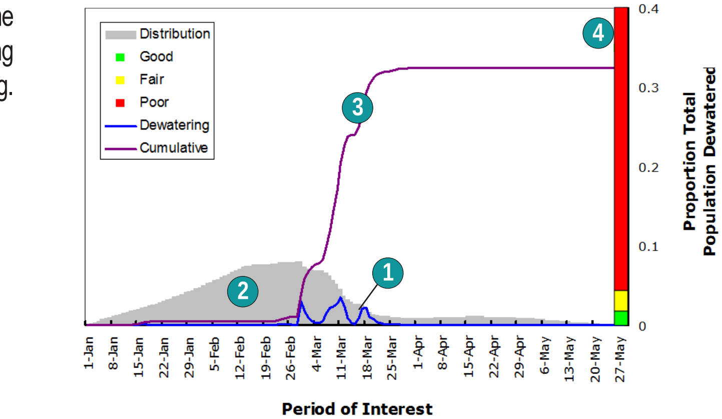
Salmonid eggs will die if the spawning redd is exposed between the time of spawning and the time of emergence. EFT models redd dewatering through changes in spawning WUA relative to the WUA at the time of spawning.

1. EFT simulates salmonid redd dewatering based on daily negative changes in spawning WUA, which cause the loss of a proportion of spawning habitat relative to each day-cohort's spawning habitat (blue line below, before weighting by day-cohort proportion loss).

2. These habitat losses are further weighted by the temporal distribution of the spawning day-cohort (gray area in figure, which also tracks losses), which is influenced by spawning day and egg-maturation.

3. As this daily loss is accumulated over the entire spawning and egg maturation period and summed over all rearing locations, a cumulative index of total loss is calculated (purple line below) for the entire year.

4. Based on natural breakpoints in the multi-year distribution of annual scores and supplemented by expert opinion, EFT defines the color-coded Good/Fair/Poor Relative Suitability rating system (Alexander et al. 2014). The vertical horizontal R/Y/G shows the cumulative distribution of the reach and year relative to the annual rollup distribution.



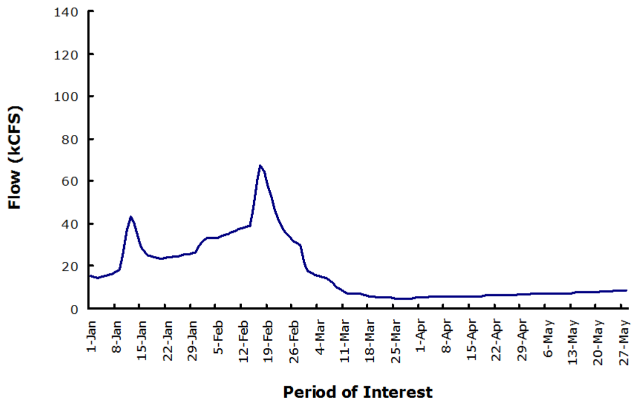


Figure 11: Excel Report for CS6 – Redd dewatering showing late-fall-run Chinook in Reach 4 for 1980. The index is sensitive to declining changes in flow. The impact of dewatering upon the egg distribution can be seen in the decline of the bell-shaped gray distribution that accompanies drops in flow and the sharp pulse of high dewatering index.

CS10 Juvenile Stranding

Beginning at Hood (RM49) and ending at Mallard Island (RKM75), each run-type of salmonid smolts follows an empirically based migration calendar. As they migrate downstream and encounter channel branching, each day-cohort is partitioned according to the simulated division of flow among the branches, following one of 6 routes based on Perry et al. (2010).

- Along each route the simulated flow determines the migration speed and the ultimate duration of transit, and simulated temperature affects daily growth.
- The annual value for each route is expressed in Excel reports as the cumulative degree-day departure from the optimal growth temperature, as well as grams weight gain. The temporal pattern for each route is also shown (Figure 12), along with the average flow and temperature for each day-cohort in each route.

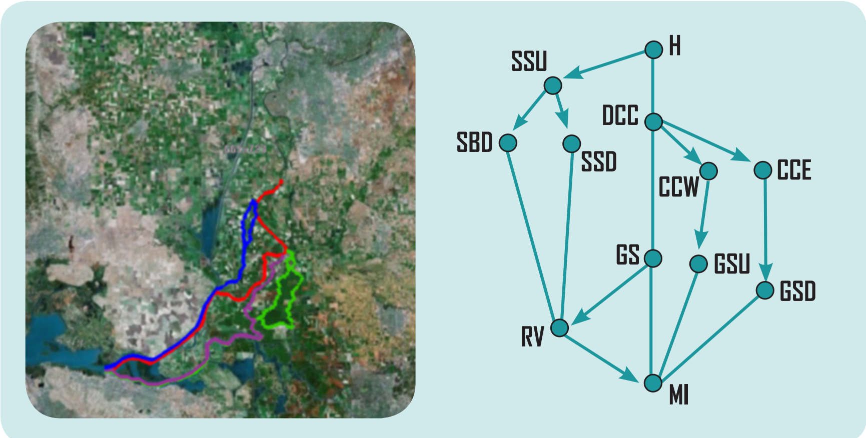


Figure 12: The CS10 Performance Measure includes six routes through the eastern Delta, from Hood to Mallard Island. In the left panel, the two blue paths extend through Steamboat and Sutter Sloughs; the red path follows the Sacramento River; the green path follows two paths downstream from the Delta Cross Channel gate, and the purple path follows Georgiana Slough. A schematic view of the routes is shown at right. Route splitting logic governs the division of day-cohorts of migrating juveniles. Node abbreviations: H=Hood; SSU=Sutter Slough Upstream; SSD=Sutter Slough Downstream; SBD=Steamboat Slough Downstream; DCC=Delta Cross Channel; CCE=Cross Channel East; CCW=Cross Channel West; GS=Georgiana Slough; GSU=Georgiana Slough Upstream; GSD=Georgiana Slough Downstream; RV=Rio Vista; MI=Mallard Island.

Juvenile Stranding (cont'd)

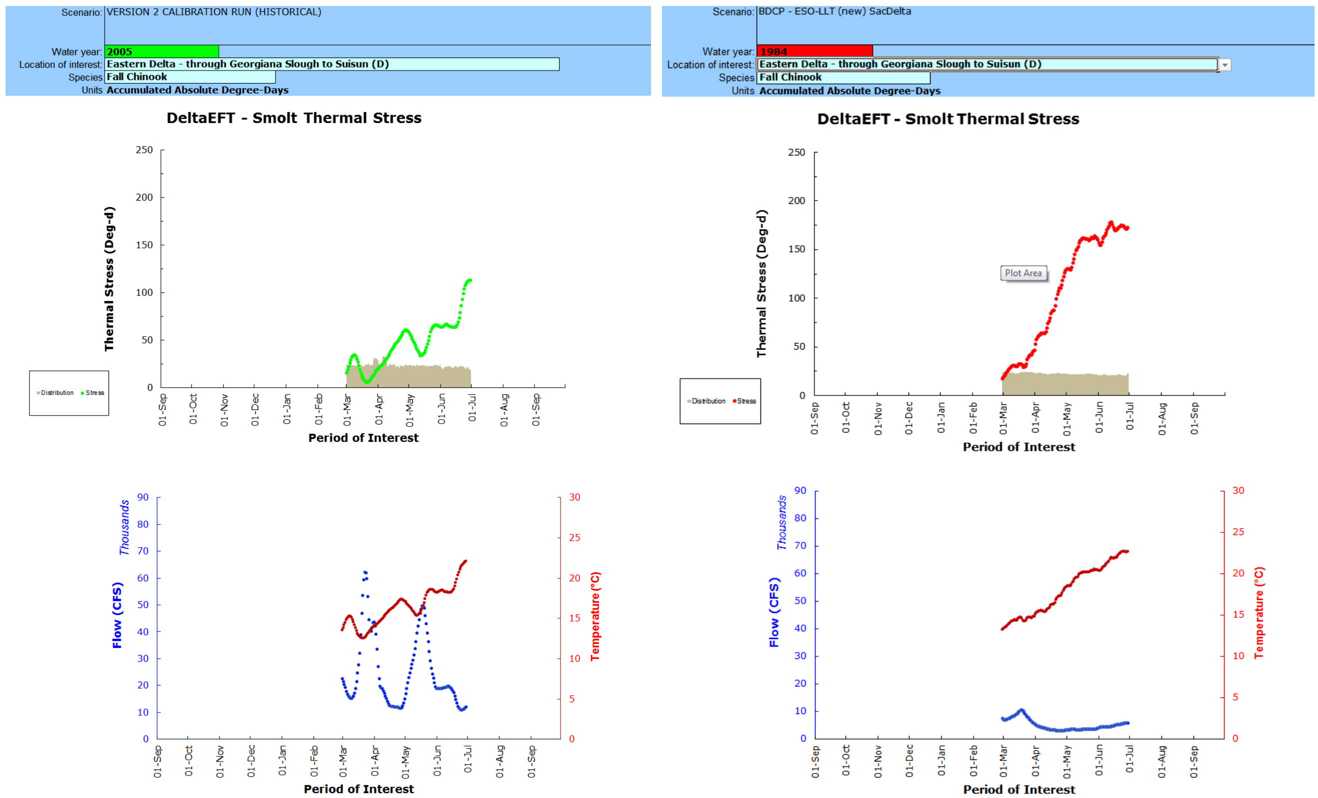


Figure 13: Example screen captures from the Annual Rollup report for CS10: Smolt Thermal Stress. This example shows Fall-run Chinook from WY2005 (Historical scenario) and WY1984 (ESO-LLT scenario) along the Georgiana Slough route. Note the steady lower flow in the ESO-LLT simulation compared to the higher pulsing flow in the Historical simulation.

- Based on natural breakpoints in the multi-year historical distribution of degree-day departure supplemented by additional simulation results, EFT defines the color-coded Good/Fair/Poor Relative Suitability rating system (Alexander et al. 2014) (Figure 14). Each route is assigned a route-based rollup score and the year is assigned an overall rollup score. Metrics provided in route summary represent the weighted average experienced by all day-cohorts in each route; those in the Annual Network Summary are day- and route-weighted averages and thus represent the entire year-cohort.

Annual Route Summary

Name	Route Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
Eastern Delta - through Sutter Slough to Suisun (B1)	1	15968	16.65	0.600	58.2	0.1319	7.90	0.47	12.6	60	60
Eastern Delta - through Steamboat Slough to Suisun (B2)	1	16082	16.65	0.600	57.6	0.1319	7.80	0.47	12.4	59	59
Eastern Delta - through Georgiana Slough to Suisun (C)	1	25315	16.65	0.600	67.2	0.2285	7.43	0.45	11.7	55	55
Eastern Delta - through DCC, east branch to Georgiana to Suisun (E1)	2	22059	17.07	0.600	88.1	0.1396	9.32	0.56	15.6	80	80
Eastern Delta - through DCS, west branch to Georgiana to Suisun (E2)	2	22863	17.04	0.600	79.6	0.1396	8.39	0.50	14.1	71	71
Eastern Delta - through Georgiana Slough to Suisun (D)	1	24897	16.41	0.600	59.9	0.2285	6.82	0.41	10.5	47	47

Annual Network Summary

Name	Annual Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
All Routes	1	22070	16.71	0.600	67.7	1.0000	7.76	0.47	12.5	60	60

Annual Route Summary

Name	Route Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
Eastern Delta - through Sutter Slough to Suisun (B1)	3	5797	18.09	0.600	58.2	0.1667	7.91	0.47	17.0	106	106
Eastern Delta - through Steamboat Slough to Suisun (B2)	3	5850	18.08	0.600	57.6	0.1667	7.81	0.47	16.7	104	104
Eastern Delta - through Georgiana Slough to Suisun (C)	3	6919	18.08	0.600	67.2	0.2186	8.17	0.49	17.7	111	111
Eastern Delta - through DCC, east branch to Georgiana to Suisun (E1)	3	3121	18.67	0.600	88.1	0.1147	13.55	0.81	30.9	206	206
Eastern Delta - through DCS, west branch to Georgiana to Suisun (E2)	3	3246	18.59	0.600	79.6	0.1147	12.25	0.73	27.6	182	182
Eastern Delta - through Georgiana Slough to Suisun (D)	3	4978	17.92	0.600	59.9	0.2186	8.43	0.51	17.7	108	108

Annual Network Summary

Name	Annual Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
All Routes	3	5302	18.17	0.600	66.3	1.0000	9.15	0.55	20.1	128	128

Figure 14: An example of the metadata provided for CS10 based on the two simulations shown in Figure 13.

Implications for Management

Many of the Sacramento River Chinook run-types are listed as threatened or endangered, and have declined relative to their historical abundance. Flow management can address some of the needs for salmonids, and can improve spawning and rearing habitat when timed appropriately and with consideration for flows which create good spawning and rearing habitat. Flows which alternate up and down abruptly during spawning and rearing periods increase the potential for redd losses and juvenile stranding losses. EFT simulations have shown that habitat quality can be improved for most Chinook run-types if flow and recession are appropriate. Steelhead rear for long periods (one full year in EFT) and appear to be less responsive to habitat improvements that are based on a shorter management window. Upstream water temperatures are currently able to maintain a cool water environment for maturing eggs, but in years with low flow, salmonid smolts migrating through the eastern Delta may experience high temperature stress. Warming climate change may increase temperature stress to eggs and smolts.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Final Report to The Nature Conservancy, Chico, CA. 228 p. + appendices.

Bartholow JM, Heasley V. 2006. Evaluation of Shasta Dam scenarios using a salmon production model. Draft Report to U.S. Geological Survey. 110 p.

Benigno GM, Sommer TR. 2009. Just add water: sources of chironomid drift in a large river floodplain. Hydrobiologia 600:297-305.

Brett JR, Shelbourn JE Shoop CT. 1969. Growth rate and body composition of fingerling sockeye salmon, Oncorhynchus nerka, in relation to temperature and ration size. Journal of the Fisheries Research Board of Canada 26:2363-2394.

Crisp DT. 1981. A desk study of the relationship between temperature and hatching time for the eggs of five species of salmonid fishes. Freshwater Biology 11:361-368.

ESSA (ESSA Technologies Ltd). 2011. Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 111 p. + appendices.

ESSA (ESSA Technologies Ltd.). 2013. The Delta Ecological Flows Tool: Record of Design (v.1.1). Final. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 142 p. + appendix.

Perry WR, Skalski JR, Brandes PL, Sandstrom PT, Klimley AP, Ammann A, MacFarlane B. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River delta. North American Journal of Fisheries Management. 30:142-156.

USFWS (U.S. Fish and Wildlife Service). 2003. Flow-habitat relationships for steelhead and fall, late-fall and winter-run Chinook salmon spawning in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 79p.

USFWS (U.S. Fish and Wildlife Service). 2005a. Flow-habitat relationships for fall-run Chinook salmon spawning in the Sacramento River between Battle Creek and Deer Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 104p.

USFWS (U.S. Fish and Wildlife Service). 2005b. Flow-habitat relationships for fall-run Chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 258p.

USFWS (U.S. Fish and Wildlife Service). 2006. Relationships between flow fluctuations and redd dewatering and juvenile stranding for Chinook salmon and Steelhead in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 94p.

EFT
Ecological Flows Tool
Indicator Brief

© The Nature Conservancy

September 2017

Sacramento Splittail

Background

The endemic Sacramento splittail were once among the most abundant estuarine species in the Sacramento-San Joaquin estuary. Much of the historical lowland floodplain and riparian habitats used for spawning and rearing have been developed for agriculture and cities, driving population decline. This habitat is characterized by the presence of dense vegetation in shallow, clear, cold flowing water (Moyle et al. 2004). Spawning occurs in the floodplains of the Sacramento and San Joaquin Rivers, especially in the Yolo Bypass (Figure 1), as well as in smaller tributaries such as the Petaluma River, Napa River, and Butte Slough. Provision of adequate spawning and rearing habitat is key to the long-term conservation of splittail, including flow regimes that result in periodic inundation of riparian and floodplain habitat during winter and spring.

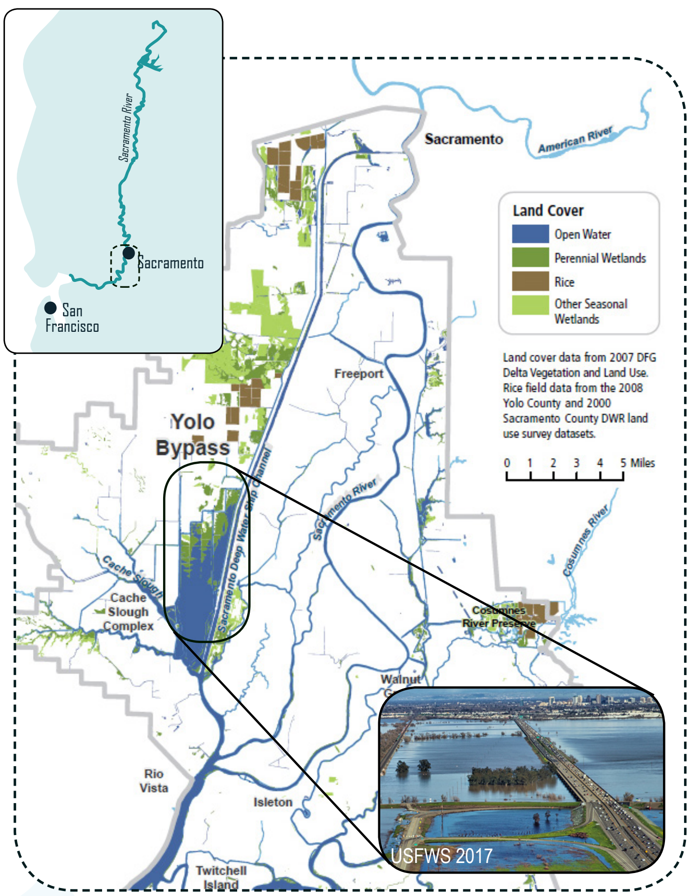


Figure 1: Main location of suitable spawning habitat for Sacramento splittail in the floodplains of the upper Yolo Bypass. Bypass map modified from USGS 2014.

Indicator Overview

Proportion of Maximum Suitable Habitat (SS1)

EFT uses a single indicator for splittail performance: the proportion of maximum suitable habitat, defined using the area of inundated habitat under 2 meters depth available in Yolo Bypass over the February-April spawning period. This area is determined using a flow-area relationship for the Bypass, provided by DWR (Sommer 2011) (Figure 2). Splittail spawning habitat is calculated by EFT annually, based on shallow water habitat created by sustained inundation during the spawning period. Other spawning areas are known to be important for splittail spawning, and could be incorporated into the EFT indicator if flow-area relationships were available for those locations.

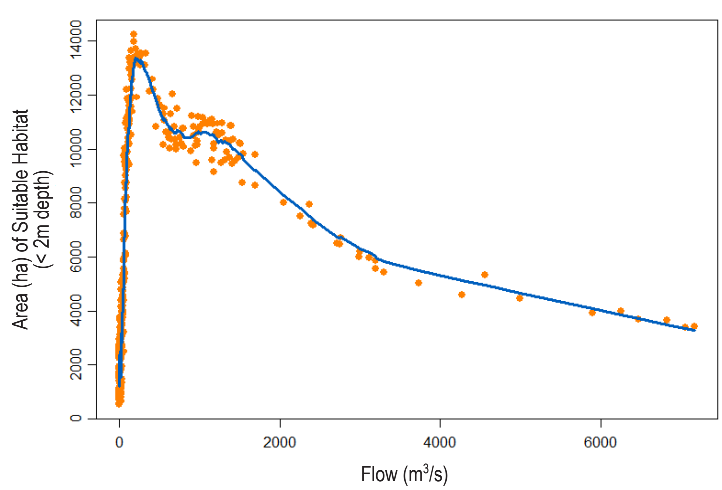


Figure 2: Flow-habitat relationship for Sacramento splittail (Sommer 2011).

Interpreting Indicator Output

SS1 Proportion of Maximum Suitable Habitat

The example EFT Excel output for Sacramento splittail shown in Figure 3 is based on flooding in 2006.

1. The input is a historical or proposed flow profile.
2. Daily Flow is compared against the flow-habitat relationship to derive the proportion of maximum area of suitable habitat (A_{prop}).
3. A_{prop} is cross-referenced against a 15-day moving window of persistent inundation required for successful hatching to derive the minimum proportion of suitable habitat area over the entire window (A_{min15}). Only flow events lasting at least 15 days contribute to the year's spawning indicator.
4. A_{min15} is weighted by multiplying by the proportion of the population expected to spawn on the first day of the window (i.e., the "spawning day-cohort") as described by the bell curve.
5. The weighted A_{min15} is summed over time to obtain the overall annual Cumulative Proportion of Maximum Possible Spawning Extent, the indicator of spawning success.
6. Based on literature and expert opinion, a cumulative value > 5% of the maximum possible relative inundated area is assigned a Good score in EFT's 3-level Good / Fair / Poor Relative Suitability scoring system and reported in the "Water Year" output cell (Alexander et al. 2014).

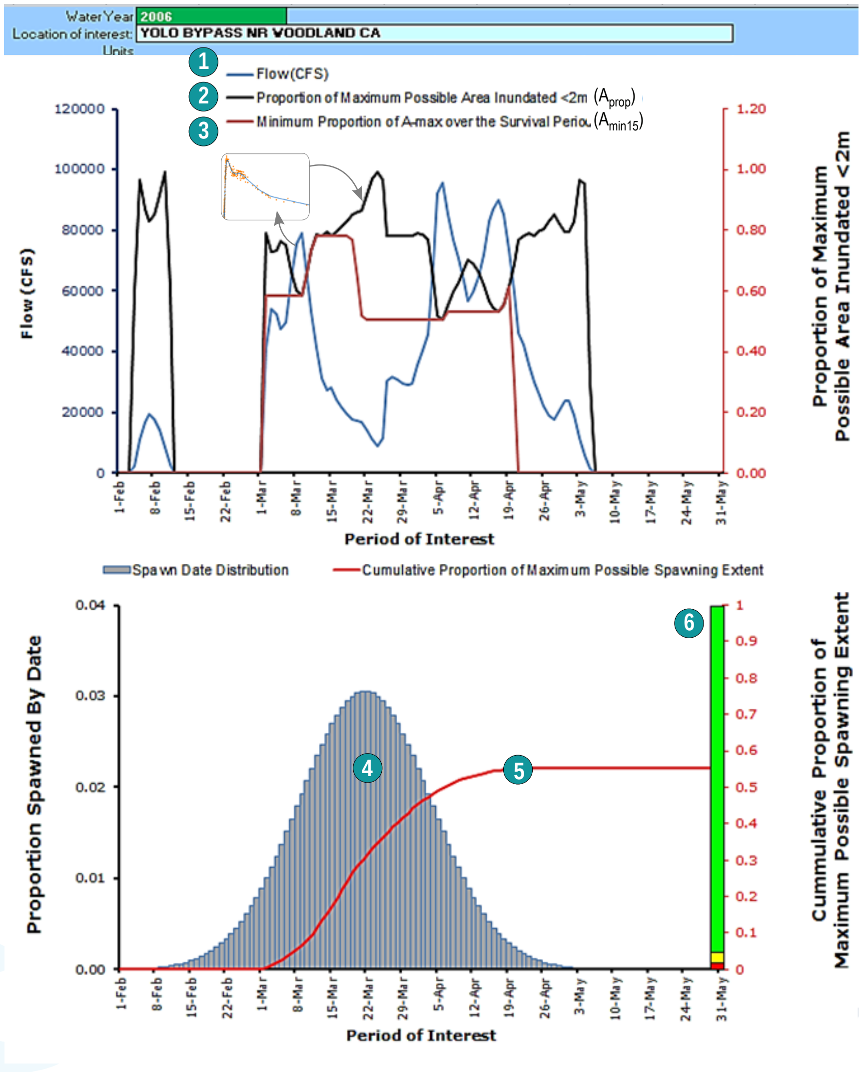


Figure 3: Sample EFT Excel output for Sacramento splittail

Implications for Management

Active management of flow especially in dry years could increase total area of inundated floodplain for spawning. The EFT indicator used for splittail is responsive to floods which periodically inundate Yolo Bypass, and EFT produces Good scores for splittail in these years. Although spawning happens throughout the estuary, the Bypass is one area in which hydrosystem managers have the ability to enhance spawning habitat through changes to the functioning of the Fremont Weir. EFT simulations based on CalSim scenarios which simulate weir notching are responsive to this alteration of the weir. In most cases the indicator does not need to be favorable every year. The best estimate of the frequency of favorable years needed to support splittail is 4 years out of every 10.

References

Alexander CAD, Robinson DCE, Poulsen F. 2014. Application of the Ecological Flows Tool to complement water planning efforts in the Delta & Sacramento River: multi-species effects analysis & ecological flow criteria. Final Report to The Nature Conservancy, Chico, CA. 228 p.

Moyle PB, Baxter RD, Sommer T, Foin TC, Matern SA. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science 2(2): Article 3.

Sommer T, Harrell B, Nobriga M, Brown R, Moyle P, Kimmerer W, Schemel L. 2001. California's Yolo Bypass: evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6-16.

Sommer, T, Conrad L, O'Leary G, Feyrer F, Harrell WC. 2002. Spawning and rearing of splittail in a model floodplain wetland. Transactions of the American Fisheries Society 131:966-974.

Sommer, T., Lead scientist, California Department of Water Resources . 2011. Personal Communication.