FINAL REPORT ◦ APRIL 2014

Lower Tuolumne River Instream Flow Study—Pacific Lamprey and Sacramento Splittail 1-D PHABSIM Habitat Assessment

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Cover photo: Habitat suitability criteria site-specific survey on the lower Tuolumne River, May 2012.

Table of Contents

1 BACKGROUND 1

2 METHODS 2

2.1 Habitat Suitability Criteria Availability 2
2.2 Species Occurrences in the Tuolumne River 3
2.3 Habitat Suitability Criteria Selection 3
2.4 Habitat Time Series 11

3 RESULTS 12

3.1 Weighted Usable Area 12
3.2 Habitat Time Series 16

4 DISCUSSION 23

4.1 Pacific Lamprey in the Lower Tuolumne River 23
4.2 Sacramento Splittail in the Lower Tuolumne River 23

5 REFERENCES 24

Tables

Table 1. Habitat suitability criteria summary for target species and life stages. 3
Table 2. Pacific lamprey ammocoete suitability criteria. 5
Table 3. Pacific lamprey spawning suitability criteria. 7
Table 4. Sacramento splittail juvenile suitability criteria. 9
Table 5. Sacramento splittail spawning suitability criteria. 11
Table 6. San Joaquin Basin 60-20-20 Index, corresponding water year types, and representative water years used for habitat time series analysis in the lower Tuolumne River instream flow study. 11
Table 7. Species/life stage periodicity for the lower Tuolumne River. 12
Table 8. Pacific lamprey WUA results for the lower Tuolumne River. 14
Table 9. Sacramento splittail WUA results for the lower Tuolumne River. 16

Figures

Figure 1. Pacific lamprey ammocoete velocity suitability criteria for the lower Tuolumne River. 4
Figure 2. Pacific lamprey ammocoete depth suitability criteria for the lower Tuolumne River. 4
Figure 3. Pacific lamprey ammocoete dominant substrate suitability criteria for the lower Tuolumne River. 5
Figure 4. Pacific lamprey spawning velocity suitability criteria for the lower Tuolumne River. 6
Figure 5. Pacific lamprey spawning depth suitability criteria for the lower Tuolumne River. 6
Figure 6. Pacific lamprey spawning dominant substrate suitability criteria for the lower Tuolumne River. 7
Figure 7. Sacramento splittail juvenile velocity suitability criteria for the lower Tuolumne River. 8

Figure 8. Sacramento splittail juvenile depth suitability criteria for the lower Tuolumne River. 8
Figure 9. Sacramento splittail spawning velocity suitability criteria for the lower Tuolumne River. 9
Figure 10. Sacramento splittail spawning depth suitability criteria for the lower Tuolumne River. 10
Figure 11. Sacramento splittail spawning dominant substrate suitability criteria for the lower Tuolumne River. 10
Figure 12. Pacific lamprey WUA resultsfor the lower Tuolumne River. 13
Figure 13. Pacific lamprey WUA results for the lower Tuolumne River. 13
Figure 14. Sacramento splittail WUA results for the lower Tuolumne River. 15
Figure 15. Sacramento splittail WUA results for the lower Tuolumne River. 15
Figure 16. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Critical water year. 17
Figure 17. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Critical water year. 18
Figure 18. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Dry water year. 18
Figure 19. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Dry water year. 19
Figure 20. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Below Normal water year. 19
Figure 21. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Below Normal water year. 20
Figure 22. Habitat Time Series results for lower Tuolumne River Pacific lamprey in an Above Normal water year 20
Figure 23. Habitat Time Series results for lower Tuolumne River Sacramento splittail in an Above Normal water year. 21
Figure 24. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Wet water year. 21
Figure 25. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Wet water year. 22
Figure 26. Habitat Time Series results for lower Tuolumne River Pacific lamprey across all water year types. 22
Figure 27. Habitat Time Series results for lower Tuolumne River Sacramento splittail across all water year types. 23

1 BACKGROUND

The *Lower Tuolumne River Instream Flow Studies – Final Study Plan* (Stillwater Sciences 2009a) was filed with the Federal Energy Regulatory Commission (Commission) on October 14, 2009. The Study Plan was approved, pursuant to Ordering paragraphs (A) through (E) of the Commission's May 12, 2010 order. In order to examine the broad flow ranges identified in the Commission's July 16, 2009 Order, the Study Plan separated the study into two separate investigations: (1) A conventional 1-D PHABSIM model ("Instream flow Study"), which examines in-channel habitat conditions at flows from approximately 100–1,000 cfs, and (2) a 2-D hydraulic model of overbank areas, as well as adjacent in-channel locations, for flows of 1,000–5,000 cfs, developed as part of the Pulse Flow Study. The *Lower Tuolumne River Instream Flow Study–Final Report* was filed with the Commission on April 26, 2013 (Stillwater Sciences 2013). The *Pulse Flow Study Report* was submitted to the Commission on June 18, 2012 (Stillwater Sciences 2012).

Subsequent to the original Study Plan approval, the Commission, in their December 22, 2011 Study Plan Determination for the Don Pedro Hydroelectric Project relicensing studies, required the scope of the Lower Tuolumne Instream Flow Study be expanded to include Pacific lamprey (*Entosphenus tridentatus*) and Sacramento splittail (*Pogonichthys macrolepidotus*), if existing habitat suitability criteria (HSC) were available. Within their April 8, 2013 comments on the *Draft Instream Flow Study Report*, the USFWS provided references to existing criteria, developed for the Lower Merced River. More recently, in the Commission's May 21, 2013 Determination on Requests for Study Modifications and New Studies for the Don Pedro Hydroelectric Project, the Commission required the scope of the Lower Tuolumne Instream Flow Study be expanded to assess habitat for non-native predatory fish, including smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and striped bass (*Moronide saxatilis*) using existing habitat suitability criteria data, where available. The Districts compiled existing suitability criteria for the above species and distributed the draft criteria for relicensing participant review on October 30, 2013. No comments were received on the proposed HSC for splittail and lamprey, and the Draft *Pacific lamprey and Sacramento splittail 1-D PHABSIM habitat assessment* was circulated for 30-day review on January 16, 2014. Also, in their November 21, 2013 letter to the Districts, the USFWS requested that the scope of the bass analyses be expanded to include temperature criteria and early life stages (e.g., spawning/incubation, juvenile) of striped bass, largemouth bass, and smallmouth bass. Additional bass HSC were included in the Districts' Updated Study Report filed with FERC on January 6, 2014.

This Report includes the final suitability criteria and habitat assessment for Pacific lamprey and Sacramento splittail. Comments on the draft habitat assessment were received from the U.S. Fish and Wildlife Service in its Updated Study Report comment letter dated February 26, 2014. Comments included: a request for an additional study to evaluate temperature effects on lamprey ammocoetes; a correction to Kern brook lamprey references; a comment on the applicability of the study results for splittail; requested modifications to the previously published HSC; and a request for clarification on substrate data collected in the field. The Kern brook lamprey HSC references were corrected and clarification was added regarding the substrate data collected in the field. All comment responses were included in the *Districts' Response to Relicensing Participants' Comments on the Updated Study Report*, filed March 28, 2014.

The habitat assessment for bass is scheduled for completion in conjunction with the Districts' Predation Study, scheduled for March 2016.[1] A remaining component of the *Lower Tuolumne River Instream Flow Studies* 1-D PHABSIM investigation includes an effective habitat analysis for *O. mykiss*, which is now underway following completion of the *Lower Tuolumne River Temperature Model* (relicensing study W&AR-16). The effective habitat analysis relates to summertime water temperature suitability for *O. mykiss*, and integrates both micro- and macro-habitat considerations, and is expected to be completed (including a 30-day resource agency review period) by August 2014.

2 METHODS

2.1 Habitat Suitability Criteria Availability

Use of the PHABSIM model requires application of HSC to the results of the hydraulic model in order to generate an index of habitat suitability (weighted usable area, or WUA) versus flow. Pursuant to the Commission-approved Study Plan, HSC screening criteria included the following, although no single criterion would qualify or disqualify a curve from further consideration.

- Minimum of 150 observations
- Clear identification of fish size classes
- Depth and velocity HSC
- Category II or III data (Bovee 1986)
- Comparable stream size and morphology (e.g., hydrology, stream width and depth, gradient, geomorphology, etc.)
- Source data from the lower Tuolumne River (or other Central Valley streams)
- Habitat availability data collected
- Data collected at high enough flow that depths and velocities are not biased by flow availability
- Availability of presence/absence data

The target species and life stages include:

- Pacific lamprey*:* spawning and ammocoete
- Sacramento splittail: juvenile and spawning

The available HSC for Pacific lamprey and Sacramento splittail are very limited. Available HSC for Pacific lamprey and Sacramento splittail, referenced by the USFWS, were developed for the Merced Hydroelectric Project relicensing (Merced ID 2011 and 2013) (Table 1). The Merced Category I (binary consensus curves) data were applied to both Pacific lamprey and Kern brook lamprey (*Lampetra hubbsi*) in the Merced River, based on Pacific lamprey habitat descriptions from literature (Close et al. [2002], Gard [2009], and Gunckel et al. [2009]) and not from site-specific surveys. These HSC were used on the Tuolumne River and are presented in Figures 1–6. The splittail HSC were derived from habitat descriptions from Feyrer et al. (2005), Moyle et al. (2004, 2007), Sommer et al. (2002, 2008), and Young and Cech (1996) (Figures 7–11).

[1] Pursuant to FERC's February 12, 2014 letter, the FERC-approved Predation Study Plan was granted a one-year extension to March 2016.

Table 1. Habitat suitability criteria summary for target species and life stages.

Species	Life stage	Depth	Velocity	Substrate	Cover	Source
Pacific lamprey	Ammocoete	Yes	Yes	Yes	No	Merced ID 2011
Pacific lamprey	Spawning	Yes	Yes	Yes	No	Merced ID 2011
Sacramento splittail	Juvenile	Yes	Yes	No	No	Merced ID 2013
Sacramento splittail	Spawning	Yes	Yes	Yes	Yes	Merced ID 2013

2.2 Species Occurrences in the Tuolumne River

As part of salmonid HSC development for the lower Tuolumne River instream flow study, site-specific HSC validation surveys were conducted in the lower Tuolumne River from just below La Grange Dam (RM 52) downstream to Waterford (RM 31). Neither Pacific lamprey nor Sacramento splittail were observed during those surveys, which were conducted across a range of seasons (winter, spring, and summer) and a range of flow conditions (100 cfs, 350 cfs, and 2,000 cfs) (Stillwater Sciences 2013). However, Pacific lamprey have been observed during snorkel surveys conducted between La Grange Dam (RM 52) and Waterford (RM 31) (Stillwater Sciences 2009b, 2010), and Sacramento splittail have been reported to spawn in the lower 6.8 miles of the Tuolumne River during wet years (Moyle et al. 1995).

2.3 Habitat Suitability Criteria Selection

The lamprey and splittail depth, velocity, and substrate HSC developed for Merced ID were applicable for the Lower Tuolumne PHABSIM model. However, the cover criteria used by Merced ID for splittail spawning was based on a coding system that was incompatible with the cover data collected for the lower Tuolumne River. Therefore, cover criteria were not applied for this species/life stage. Selected HSC for Pacific lamprey and Sacramento splittail are shown below in Figures 1–11 and listed in Tables 2–7.

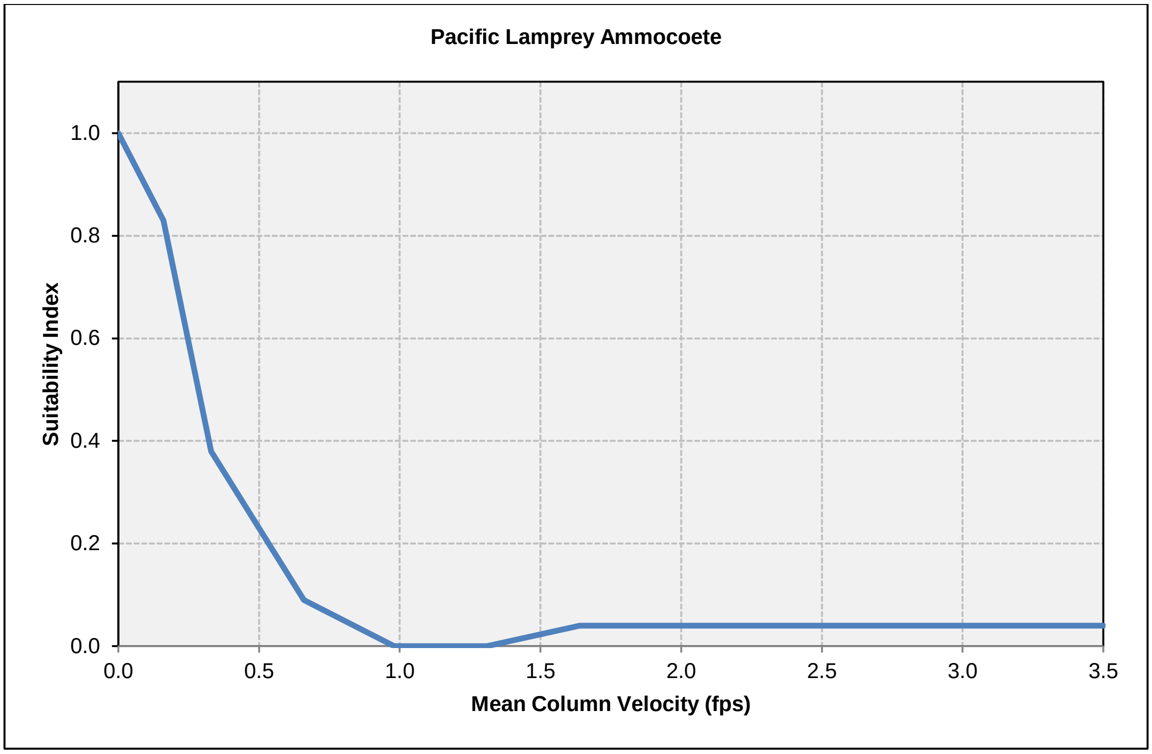

Figure 1. Pacific lamprey ammocoete velocity suitability criteria for the lower Tuolumne River.

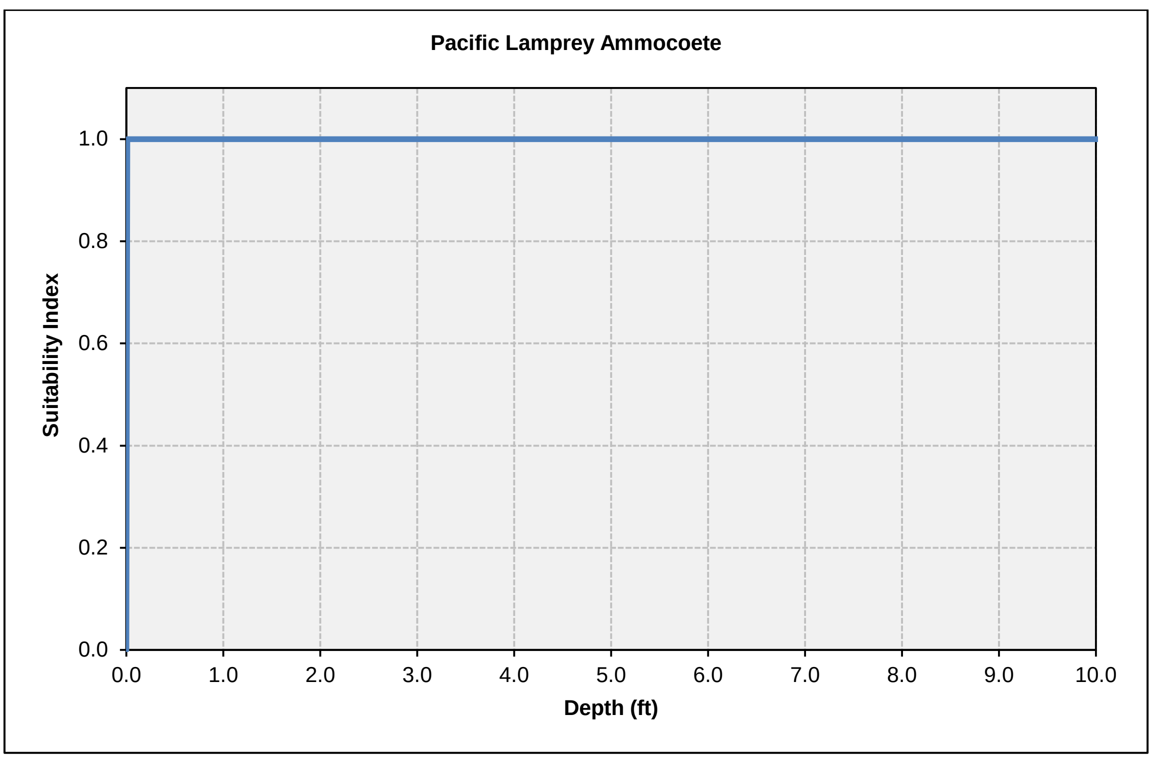

Figure 2. Pacific lamprey ammocoete depth suitability criteria for the lower Tuolumne River.

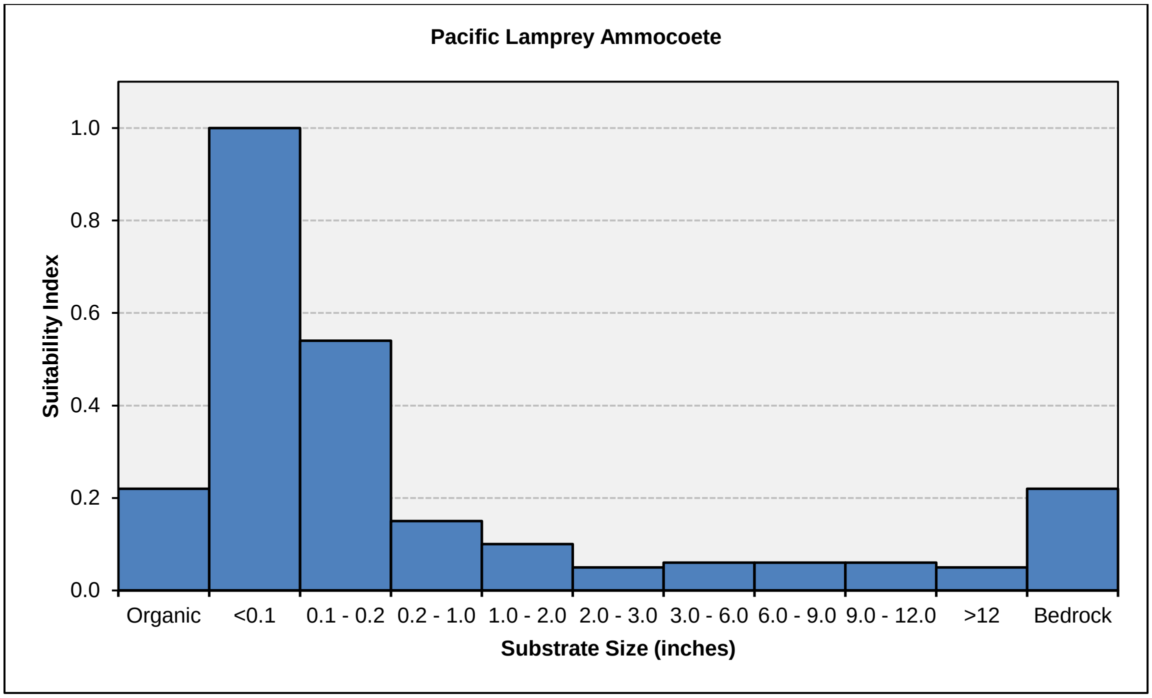

Figure 3. Pacific lamprey ammocoete dominant substrate suitability criteria for the lower Tuolumne River.

Table 2. Pacific lamprey ammocoete suitability criteria.

Velocity		Depth		Substrate		
(fps)	**Index[1]**	**(ft)**	**Index[1]**	**Type**	**Size (inches)**	**Index[1]**
0.00	1.00	0.00	0.00	Organic	N/A	0.22
0.16	0.83	0.01	1.00	Silt	0-0.1	1.00
0.33	0.38	--	--	Sand	0.1-0.2	0.54
0.66	0.09	--	--	Small gravel	0.2-1	0.15
0.98	0.00	--	--	Gravel	1-2	0.10
1.31	0.00	--	--	Large gravel	2-3	0.05
1.64	0.04	--	--	Small cobble	3-6	0.06
--	--	--	--	cobble	6-9	0.06
--	--	--	--	Large cobble	9-12	0.06
--	--	--	--	Boulder	>12	0.05
--	--	--	--	Bedrock	N/A	0.22

[1] Merced ID 2011

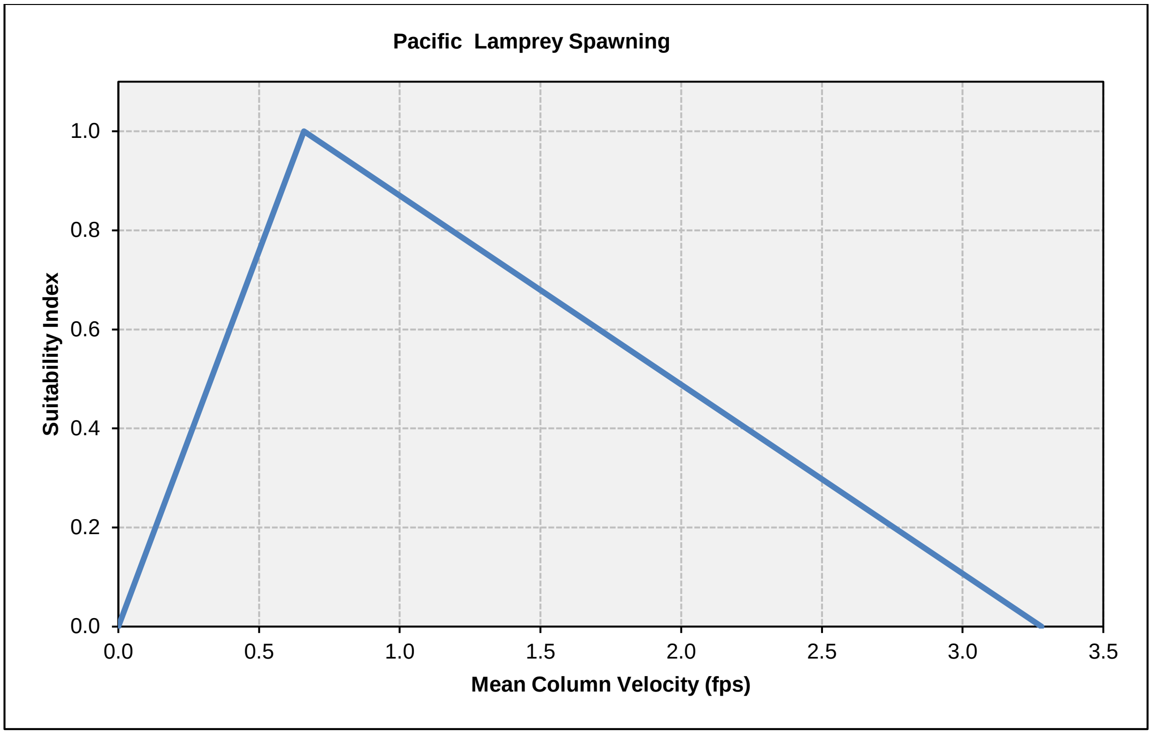

Figure 4. Pacific lamprey spawning velocity suitability criteria for the lower Tuolumne River.

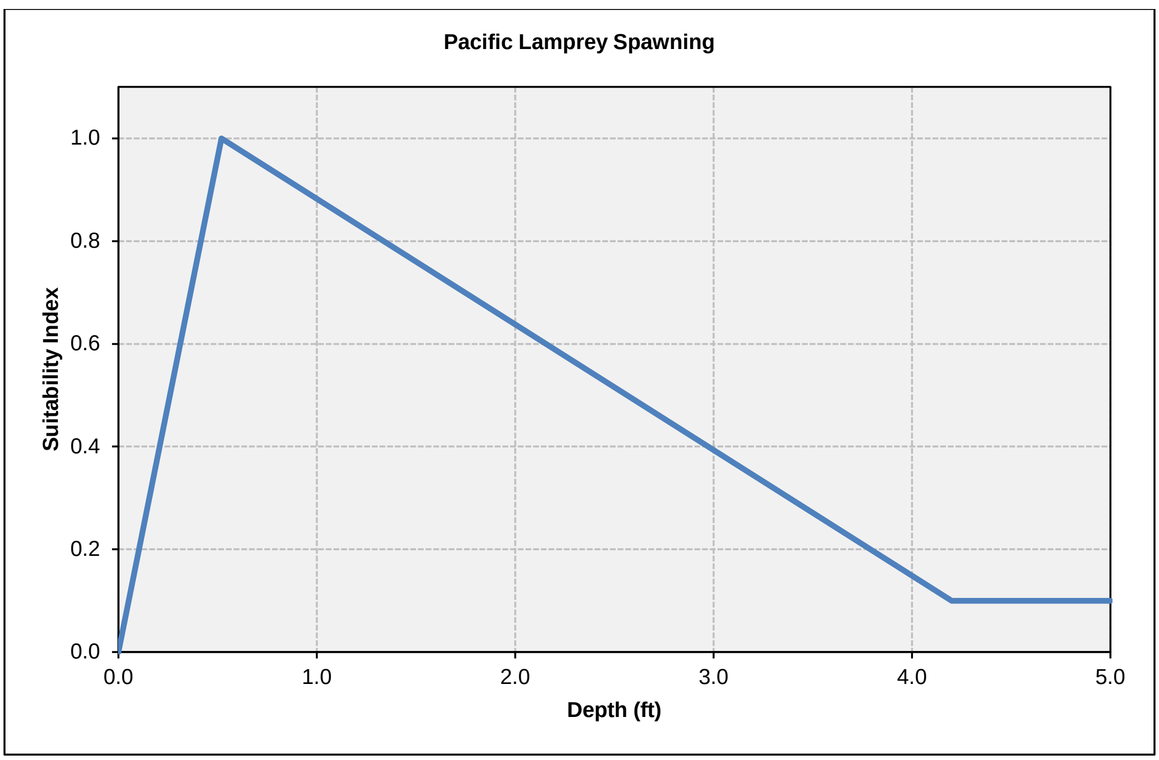

Figure 5. Pacific lamprey spawning depth suitability criteria for the lower Tuolumne River.

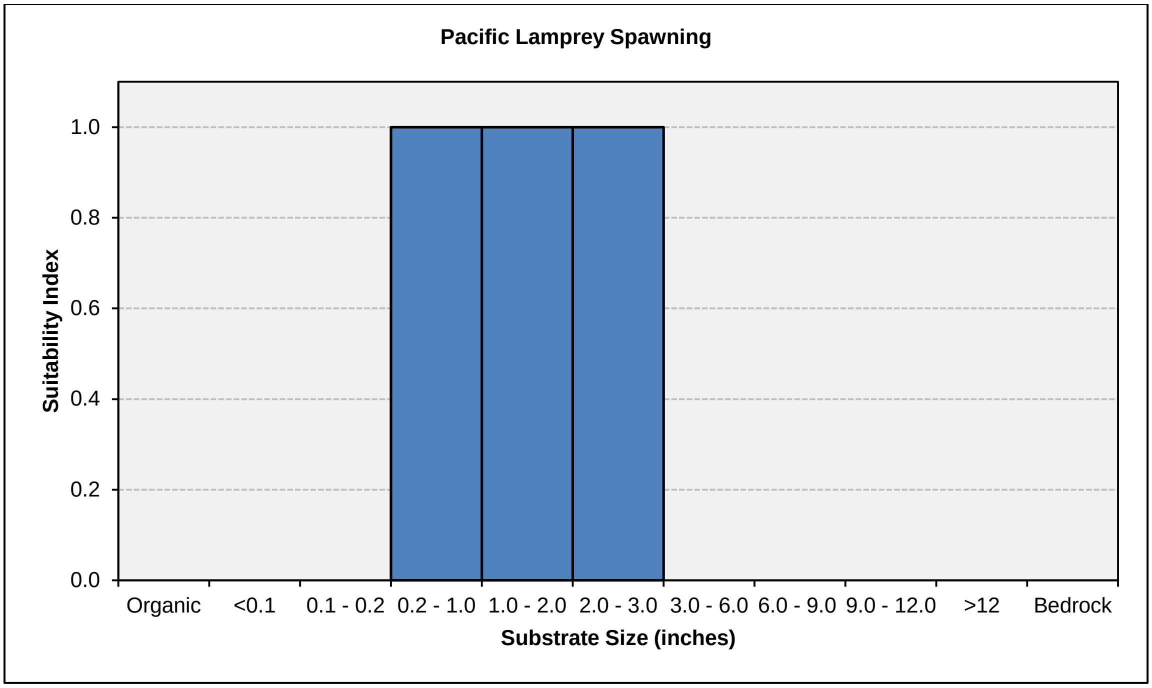

Figure 6. Pacific lamprey spawning dominant substrate suitability criteria for the lower Tuolumne River.

Table 3. Pacific lamprey spawning suitability criteria.

Velocity		Depth		Substrate		
(fps)	**Index[1]**	**(ft)**	**Index[1]**	**Type**	**Size (inches)**	**Index[1]**
0.00	0.00	0.00	0.00	Organic	N/A	0.00
0.66	1.00	0.52	1.00	Silt	<0.1	0.00
3.28	0.00	4.20	0.10	Sand	0.1–0.2	0.00
--	--	--	--	Small gravel	0.2–1	1.00
--	--	--	--	Gravel	1–2	1.00
--	--	--	--	Large gravel	2–3	1.00
--	--	--	--	Small cobble	3–6	0.00
--	--	--	--	cobble	6–9	0.00
--	--	--	--	Large cobble	9–12	0.00
--	--	--	--	Boulder	>12	0.00
--	--	--	--	Bedrock	N/A	0.00

[1] Merced ID 2011

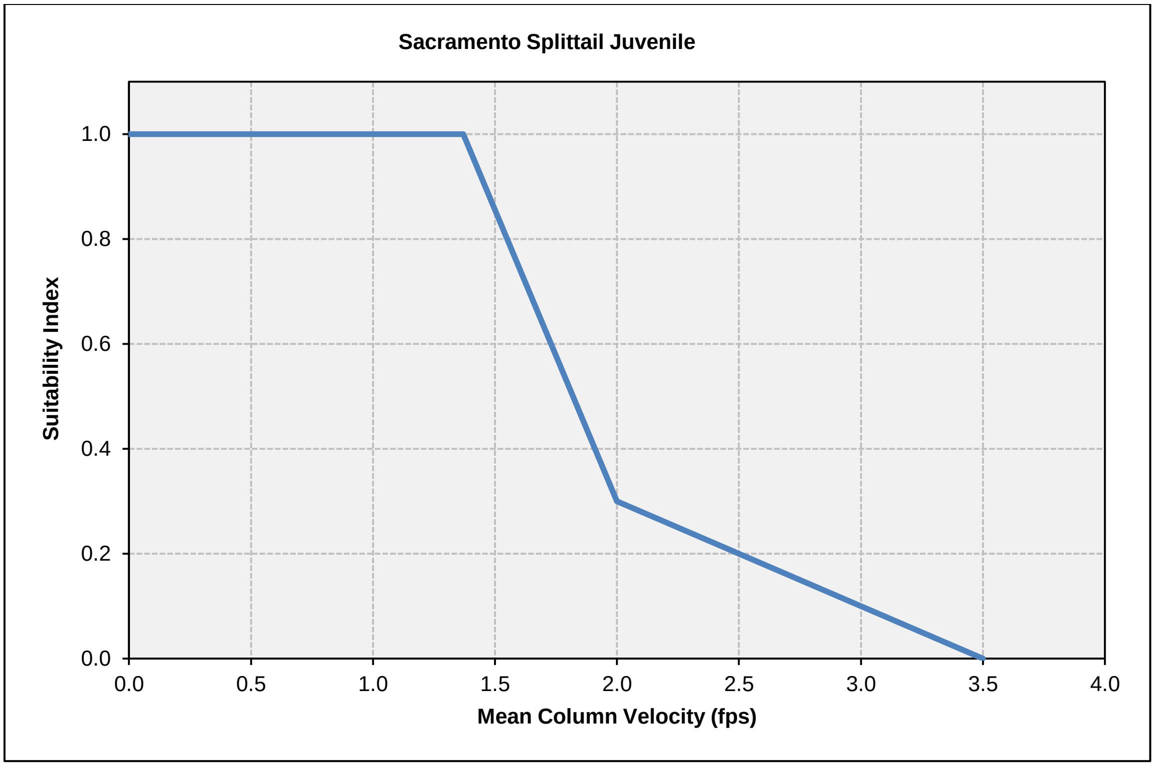

Figure 7. Sacramento splittail juvenile velocity suitability criteria for the lower Tuolumne River.

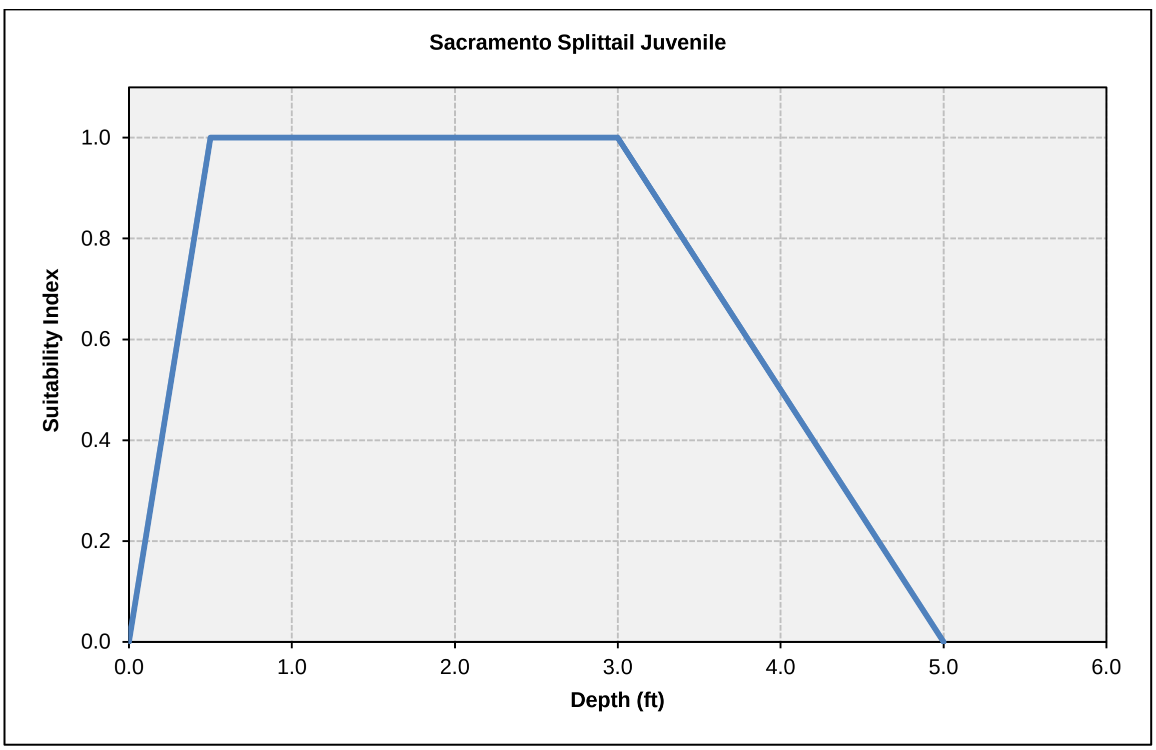

Figure 8. Sacramento splittail juvenile depth suitability criteria for the lower Tuolumne River.

Table 4. Sacramento splittail juvenile suitability criteria.

Velocity		Depth	
(fps)	**Index1**	**(ft)**	**Index[1]**
0.00	1.00	0.00	0.00
0.40	1.00	0.50	1.00
1.37	1.00	1.30	1.00
2.00	0.30	3.00	1.00
3.50	0.00	5.00	0.00

[1] Merced ID 2013

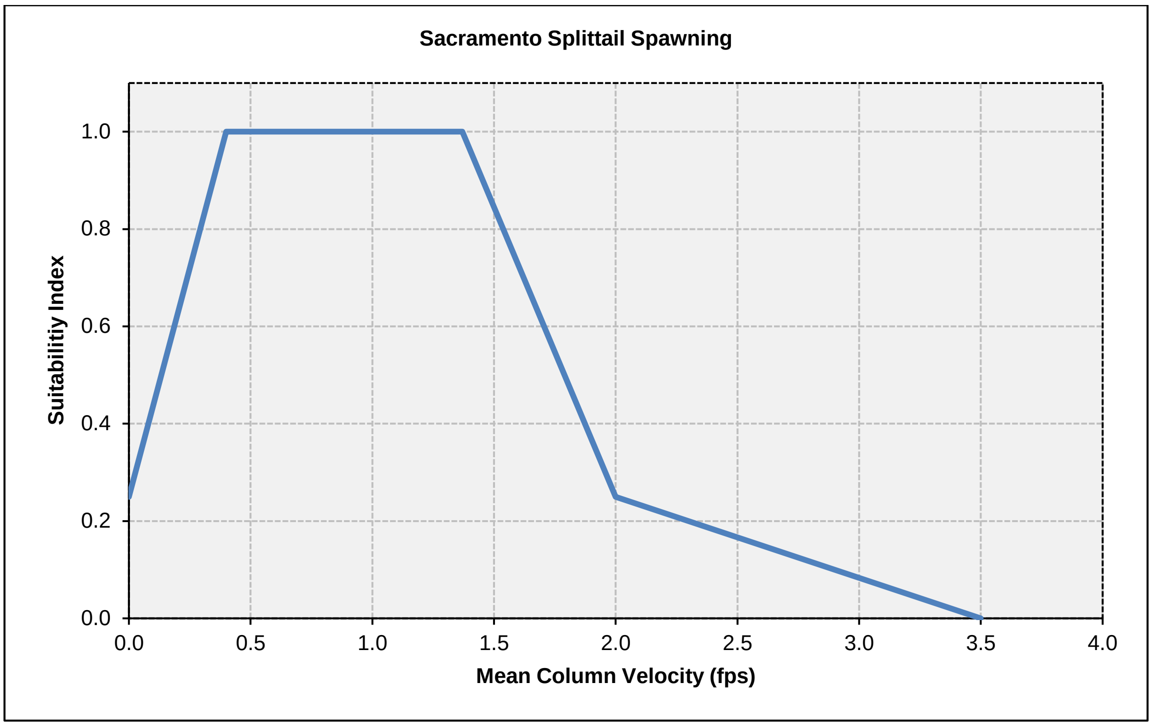

Figure 9. Sacramento splittail spawning velocity suitability criteria for the lower Tuolumne River.

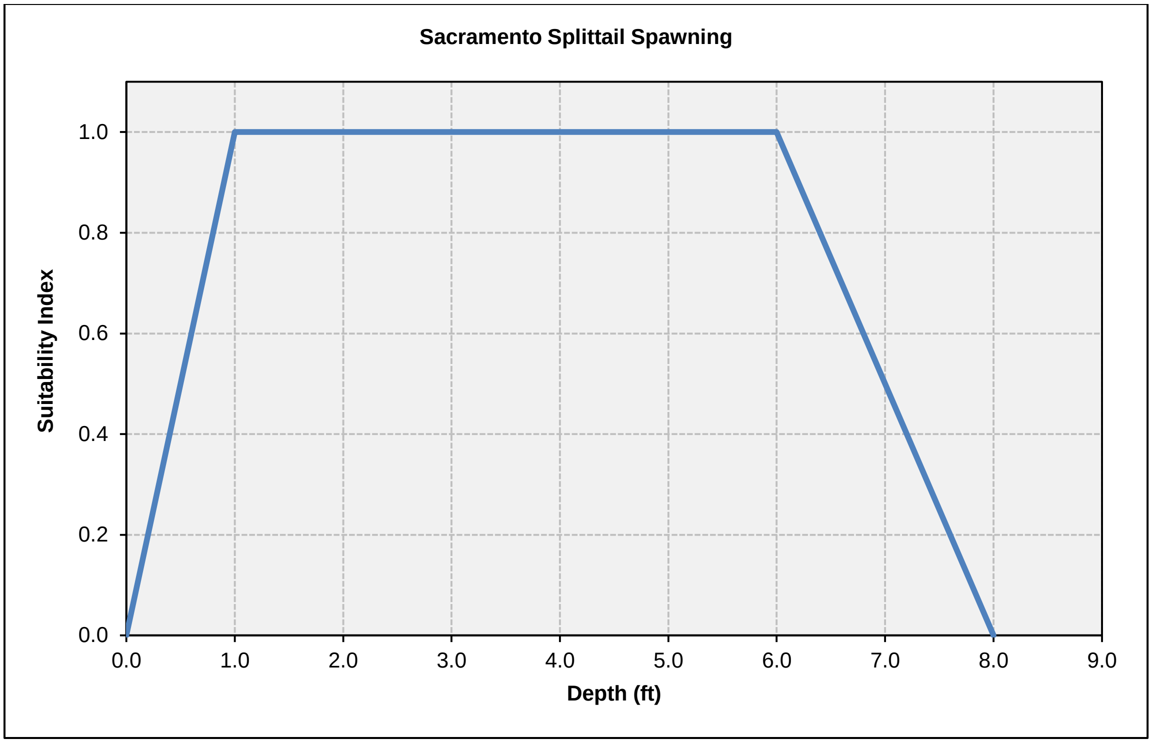

Figure 10. Sacramento splittail spawning depth suitability criteria for the lower Tuolumne River.

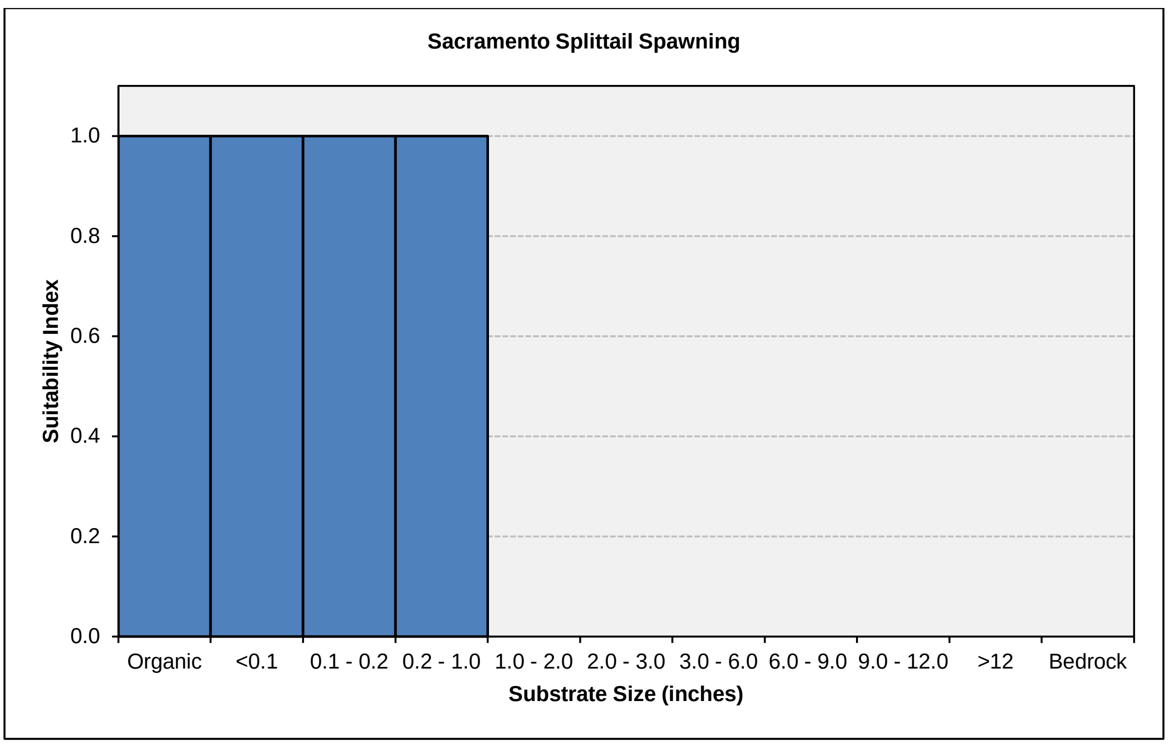

Figure 11. Sacramento splittail spawning dominant substrate suitability criteria for the lower Tuolumne River.

Table 5. Sacramento splittail spawning suitability criteria.

Velocity		Depth		Substrate		
(fps)	Index[1]	(ft)	Index[1]	Type	Size (inches)	Index[1]
0.00	0.25	0.00	0.00	Organic[2]	N/A	1.00
0.40	1.00	1.00	1.00	Silt	<0.1	1.00
1.37	1.00	6.00	1.00	Sand	0.1–0.2	1.00
2.00	0.25	8.00	0.00	Small gravel	0.2–1	1.00
3.50	0.00	--	--	Gravel	1–2	0.00
--	--	--	--	Large gravel	2–3	0.00
--	--	--	--	Small cobble	3–6	0.00
--	--	--	--	Cobble	6–9	0.00
--	--	--	--	Large cobble	9–12	0.00
--	--	--	--	Boulder	>12	0.00
--	--	--	--	Bedrock	N/A	0.00

1 Merced ID 2013
2 Organic substrate includes detritus as well as flooded terrestrial vegetation

2.4 Habitat Time Series

A Habitat Time Series (HTS) analysis was conducted to assess how habitat values for each species and life stage vary over time, under different water year type scenarios. Water year types selected for analysis are the five San Joaquin Basin 60-20-20 Index types: Critical, Dry, Below Normal, Above Normal, and Wet, as represented by Water Years 2008-2012 (the most recent years of these index types) and presented in Table 6.

Table 6. San Joaquin Basin 60-20-20 Index, corresponding water year types, and representative water years used for habitat time series analysis in the lower Tuolumne River instream flow study.

San Joaquin Basin 60-20-20 Index[1]	Water Year Type	Representative Water Year
2.06	Critical	2008
2.18	Dry	2012
2.73	Below Normal	2009
3.55	Above Normal	2010
5.59	Wet	2011

1 DWR Bulletin 132 calculated index

Daily flow values for the lower Tuolumne River were obtained from the USGS gaging station at La Grange Dam (No. 11289560) and were compiled for all Water Year types. No downstream adjustments for accretion or depletion are required in the PHABSIM assessment reach (RM 51.7

to RM 29.0).[2] The associated WUA values were assigned based on the daily flows using a lookup table of WUA values from the PHABSIM results, interpolated to 5 cfs intervals.

The periodicity of Pacific lamprey and Sacramento splittail was adapted from the Merced River hydroelectric relicensing project due to its close proximity to the lower Tuolumne River (Merced ID 2011, 2013) (Table 7); the Sacramento splittail spawning periodicity was modified to indicate the spawning period for the lower Tuolumne River (Moyle et al. 2004).

Table 7. Species/life stage periodicity for the lower Tuolumne River.

Species	Life stage	Fall			Winter			Spring			Summer		
		O	N	D	J	F	M	A	M	J	J	A	S
Pacific lamprey	Ammocoete	■	■	■	■	■	■	■	■	■	■	■	■
	Spawning						■	■	■	■			
Sacramento splittail	Juvenile						■	■	■	■	■	■	■
	Spawning					■	■	■	■				

3 RESULTS

3.1 Weighted Usable Area

Results of the PHABSIM analysis of WUA versus flow relationships for each species and life stage are presented in Figures 12–15 and Tables 8–9. In order to facilitate comparison and analysis, the results are presented and discussed based on a normalized y-axis scale representing "percent of maximum" WUA (Figures 12 and 14).

Results for Pacific lamprey ammocoetes show that their potential habitat is maximized at low flows, with peak WUA values (≥95% of maximum) at flows less than approximately 150 cfs, followed by a slight decline, but still relatively high WUA values (≥80% of maximum) near 450 cfs and then remaining stable over the remaining range of simulated flows (Figures 12 and 13). Results for Pacific lamprey spawning show peak WUA values at approximately 75–150 cfs, with a steady decline, but still relatively high WUA values up to near 250 cfs, followed by a more gradual decline over the remaining range of simulated flows (Figures 12 and 13).

Results for Sacramento splittail juveniles show peak WUA values at approximately 50–175 cfs, with relatively high WUA values below 300 cfs (Figures 14 and 15). Results for Sacramento splittail spawning show high WUA values at about 300-400 cfs, with relatively small increases in WUA values over the remaining simulation range (Figures 14 and 15).

[2] The reach represented in the PHABSIM assessment includes RM 51.7 to RM 29.0. Accretion/depletion studies performed by the Districts suggest that flow changes along the study reach (which is upstream of Dry Creek and does not contain major tributaries) are relatively small compared to the scale of most HTS flows and the associated WUA reporting increments, and therefore the HTS results are not adjusted for these changes.

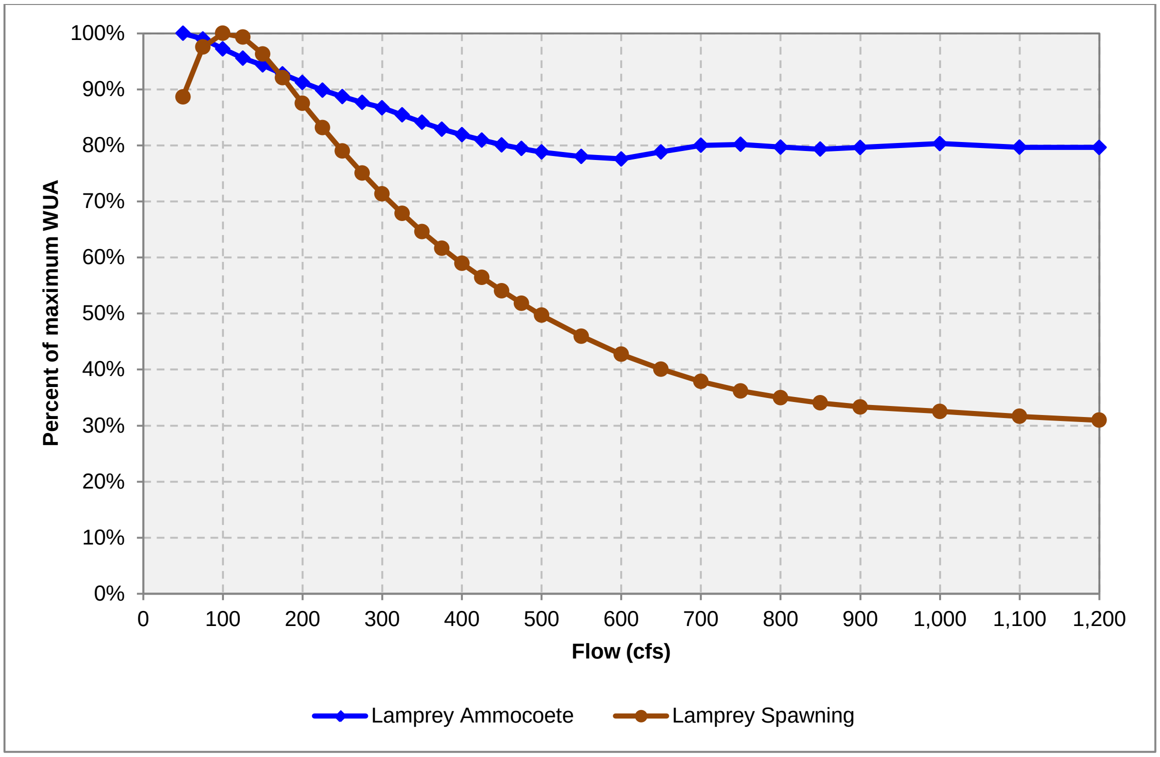

Figure 12. Pacific lamprey WUA results (percent of maximum) for the lower Tuolumne River.

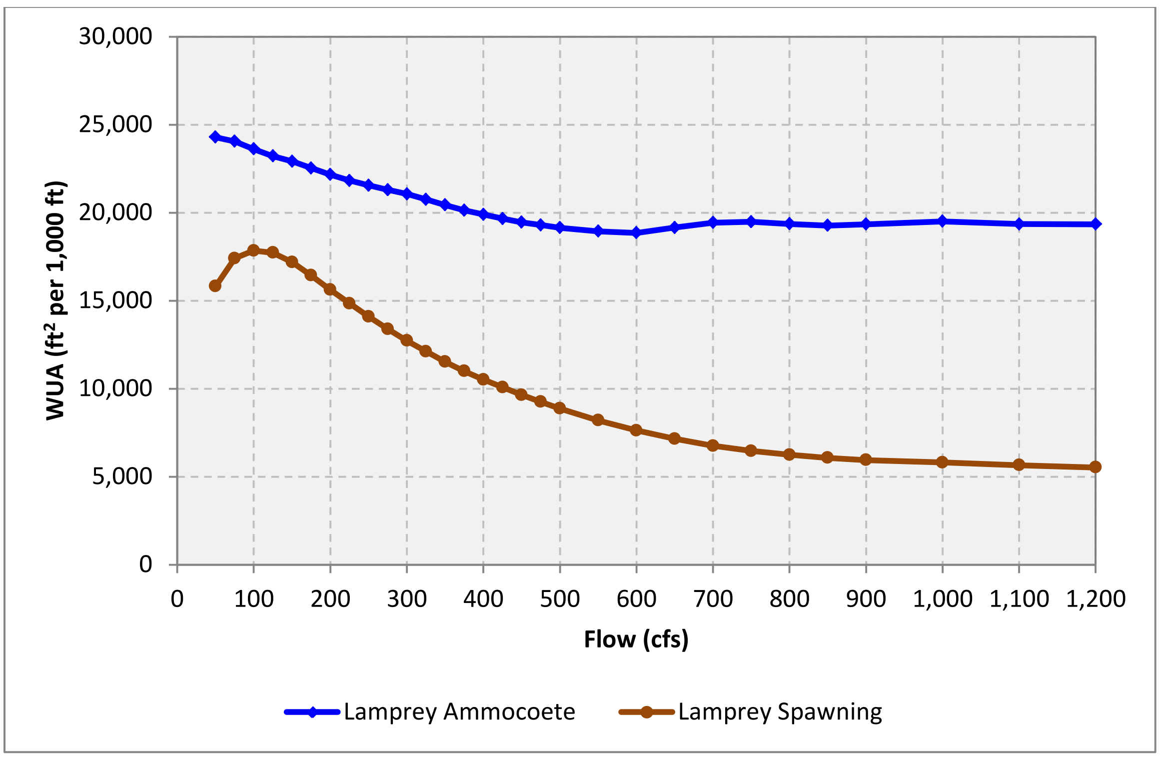

Figure 13. Pacific lamprey WUA results for the lower Tuolumne River.

Table 8. Pacific lamprey WUA results for the lower Tuolumne River.

Simulated discharge (cfs)	Pacific lamprey ammocoete (ft^2 per 1,000 ft)	Pacific lamprey spawning (ft^2 per 1,000 ft)
50	24288.57	15818.00
75	24047.28	17404.11
100	23614.99	17842.49
125	23210.65	17720.25
150	22913.44	17186.22
175	22529.14	16429.56
200	22157.69	15611.94
225	21826.53	14841.16
250	21547.09	14095.15
275	21294.25	13388.09
300	21064.09	12725.28
325	20748.99	12111.84
350	20431.54	11525.86
375	20135.56	10999.58
400	19894.20	10517.03
425	19659.51	10075.10
450	19453.41	9646.10
475	19296.72	9248.33
500	19141.19	8867.14
550	18946.11	8196.07
600	18846.54	7623.26
650	19147.85	7148.60
700	19435.35	6755.09
750	19474.64	6457.57
800	19355.70	6244.06
850	19267.14	6072.78
900	19343.99	5945.62
1000	19508.92	5803.41
1100	19351.98	5646.98
1200	19342.67	5522.68

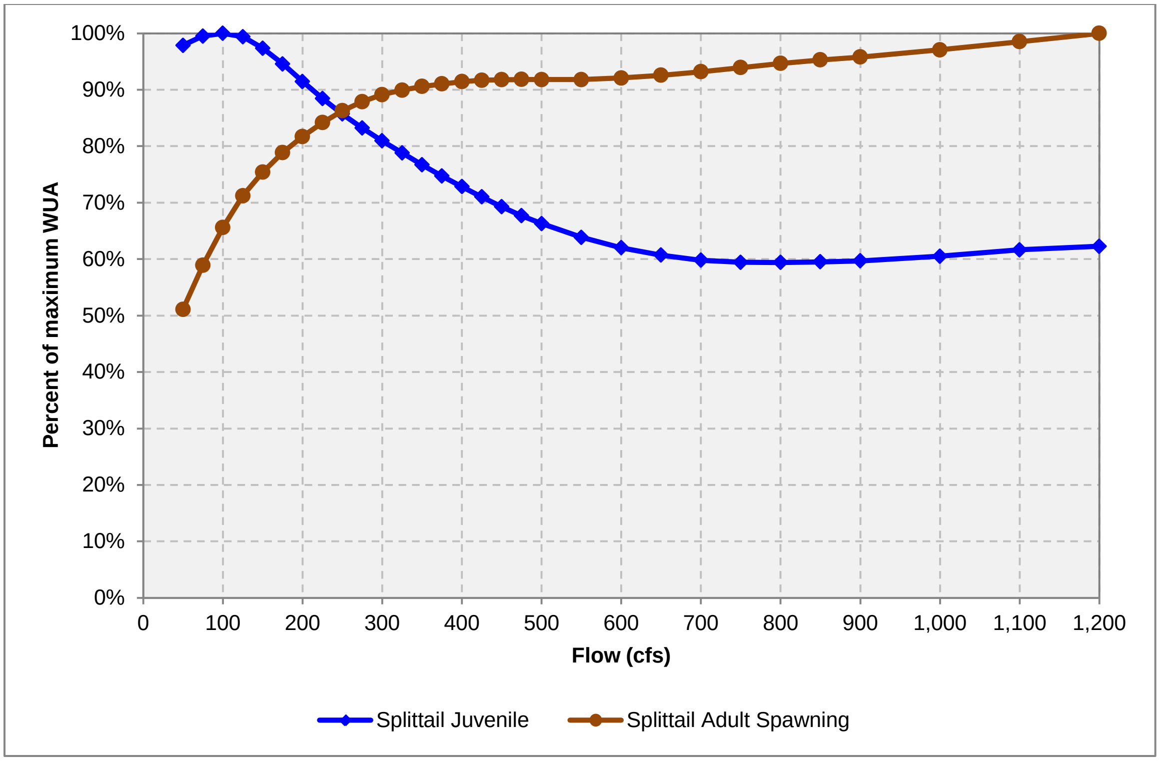

Figure 14. Sacramento splittail WUA results (percent of maximum) for the lower Tuolumne River.

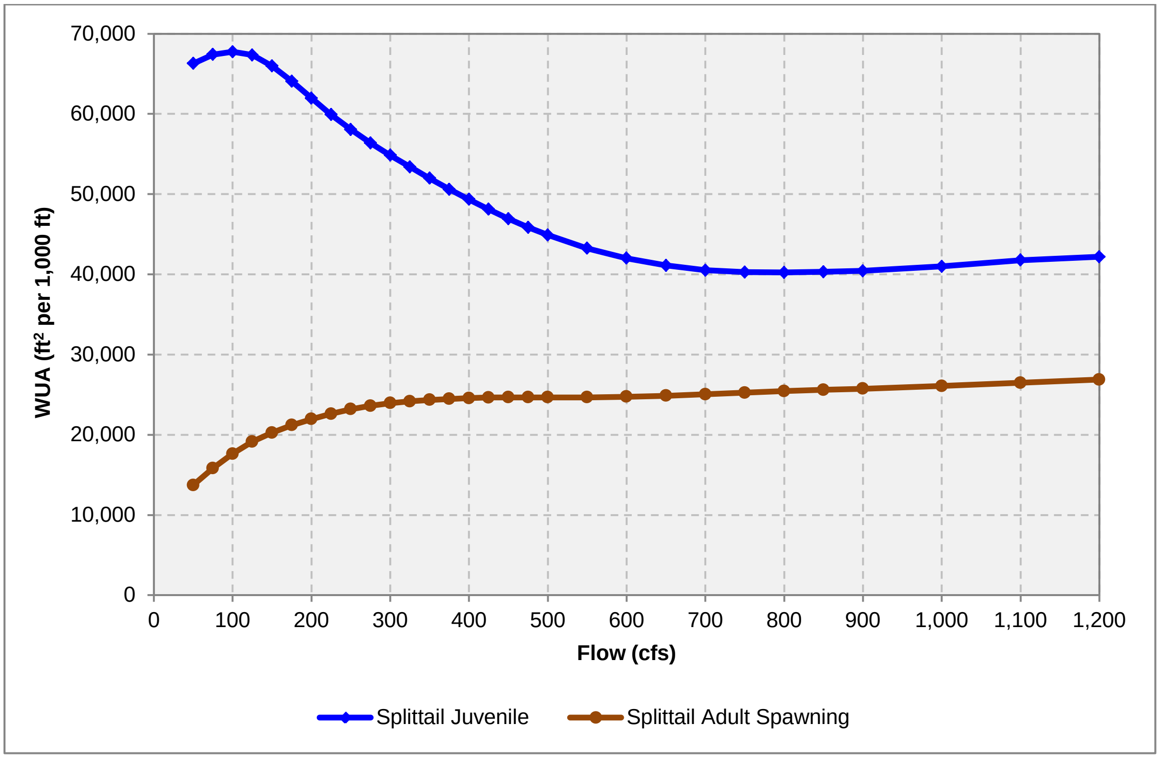

Figure 15. Sacramento splittail WUA results for the lower Tuolumne River.

Table 9. Sacramento splittail WUA results for the lower Tuolumne River.

Simulated discharge (cfs)	Sacramento splittail spawning (ft^2 per 1,000 ft)	Sacramento splittail juvenile (ft^2 per 1,000 ft)
50	13730.95	66296.36
75	15830.43	67407.02
100	17629.23	67745.97
125	19141.98	67343.51
150	20259.21	65966.16
175	21198.40	64075.29
200	21959.39	61966.49
225	22619.46	59919.42
250	23187.14	58058.00
275	23615.71	56379.65
300	23953.35	54844.25
325	24168.83	53399.74
350	24343.61	51967.60
375	24460.33	50607.40
400	24569.94	49339.50
425	24640.72	48118.83
450	24660.87	46937.17
475	24674.46	45858.11
500	24668.73	44906.92
550	24670.27	43254.15
600	24743.66	42006.93
650	24875.21	41122.02
700	25040.35	40507.25
750	25242.78	40266.80
800	25434.96	40244.34
850	25609.38	40315.27
900	25744.88	40437.44
1000	26087.91	40987.27
1100	26474.78	41768.93
1200	26871.41	42183.33

3.2 Habitat Time Series

Habitat Time Series (HTS) results for each of five water year types (using the San Joaquin River 60-20-20 Index) and four species and life stage combinations are presented in Figures 16–25. The time periods used in the habitat time series analysis are when individual life stages are most typically observed, or could theoretically be present, within the study reach based on the periodicity shown in Table 7.

Consistent with the HTS analysis of Chinook salmon and *O. mykiss* (Stillwater Sciences 2013), WUA values were maintained at the 1,200 cfs level for flows over the WUA extrapolation limit of 1,200 cfs. This approach assumes that in-channel WUA will not get significantly higher (or will get higher, then descend again) or lower (or go lower and rise again or level off) than where it was at 1,200 cfs. This is a more conservative approach, but it does have the drawback that all flows above 1,200 cfs will return the same WUA value (e.g "flatline") and a depiction of potential variability at higher flows is lost. Figures 26 and 27 present HTS results across all water year types for Pacific lamprey and Sacramento splittail, respectively, and facilitate comparisons of patterns between water year types.

Under Critical, Dry, and Below Normal year scenarios, Pacific lamprey ammocoete WUA remains relatively stable. Pacific lamprey spawning WUA fluctuates with flow until flow nears 1,200 cfs, where WUA is minimized. Sacramento splittail juvenile WUA is maximized during periods of low flow and quickly drops when flow increases. In contrast, Sacramento splittail spawning WUA is minimized at lower flows and increases as flows increase above 1,000 cfs.

Under Above Normal and Wet year scenarios, Pacific lamprey ammocoete WUA remains relatively stable. Pacific lamprey spawning WUA decreases with increased flow, until flow nears 1,200 cfs where WUA is minimized. Sacramento splittail juvenile WUA are minimized when flow increases above approximately 600 cfs. Sacramento splittail spawning WUA is maximized as flow increases up to 1,200 cfs.

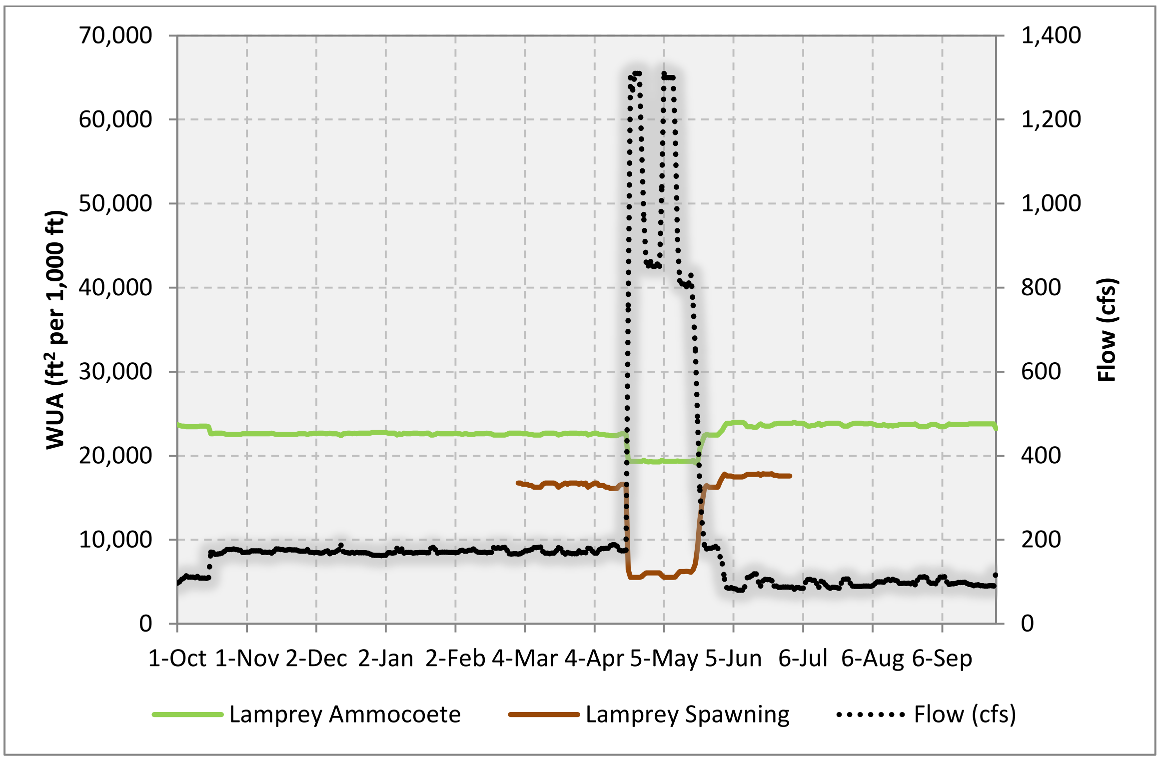

Figure 16. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Critical water year (2008).

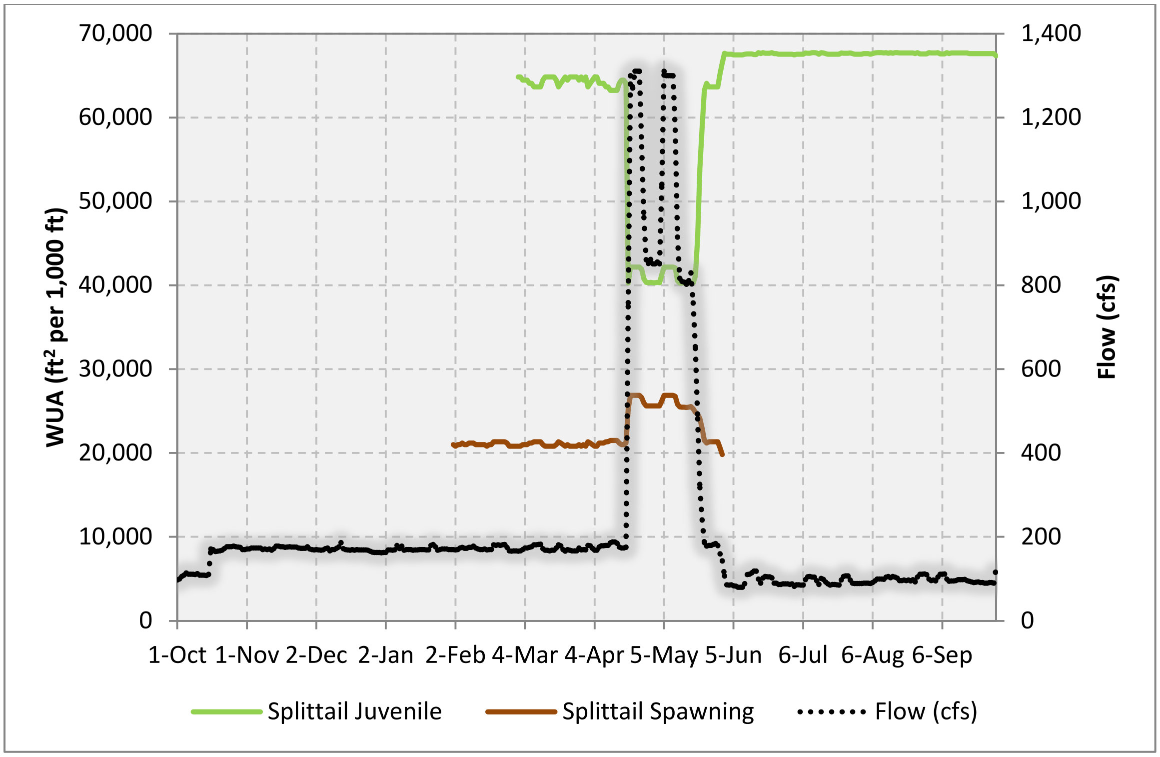

Figure 17. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Critical water year (2008).

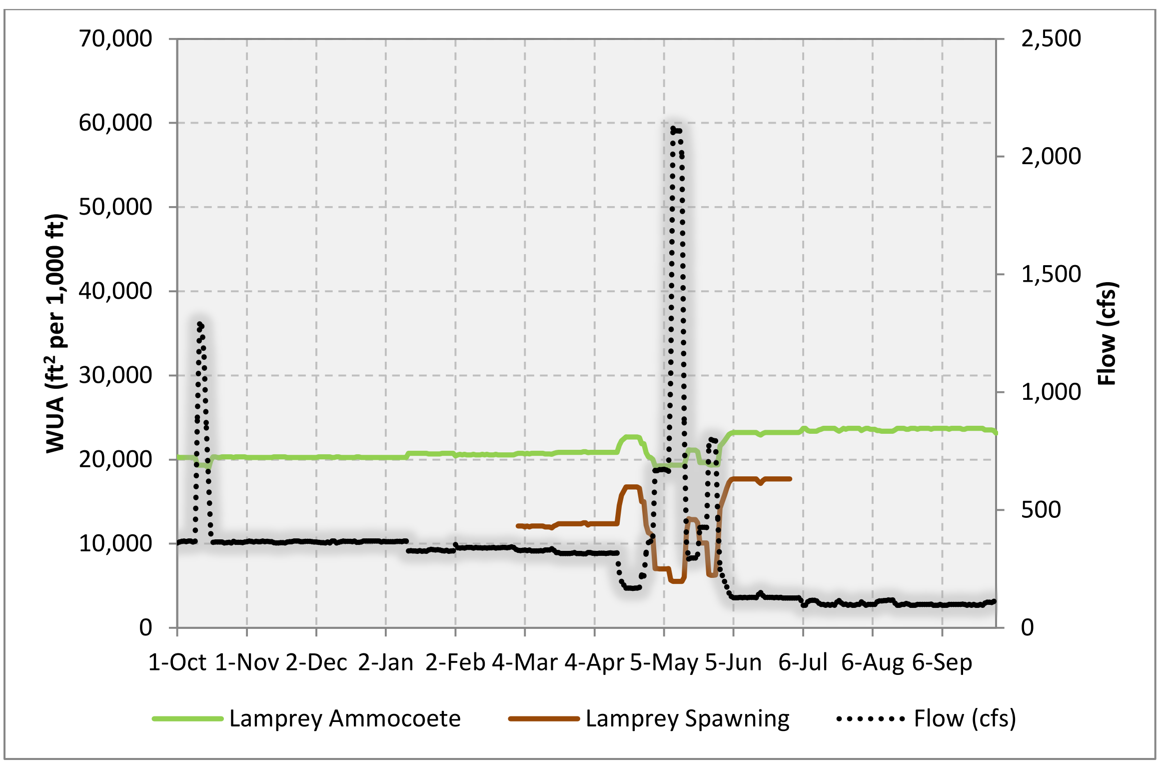

Figure 18. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Dry water year (2012).

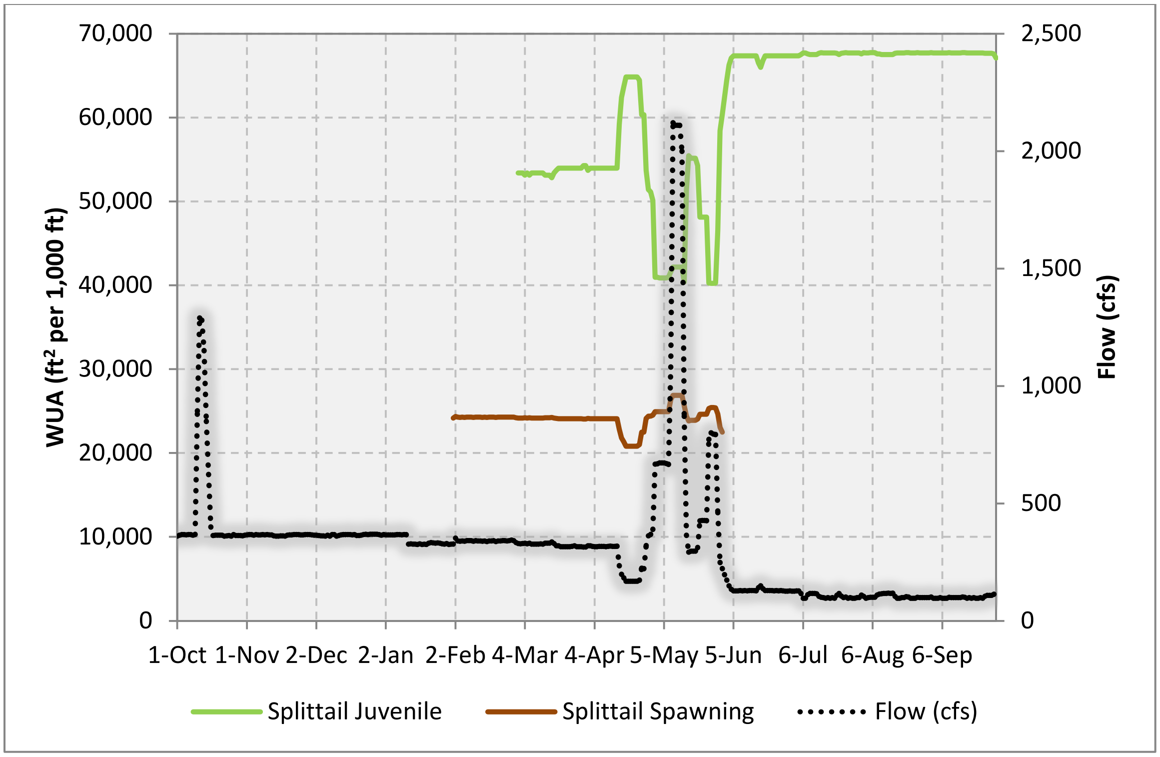

Figure 19. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Dry water year (2012).

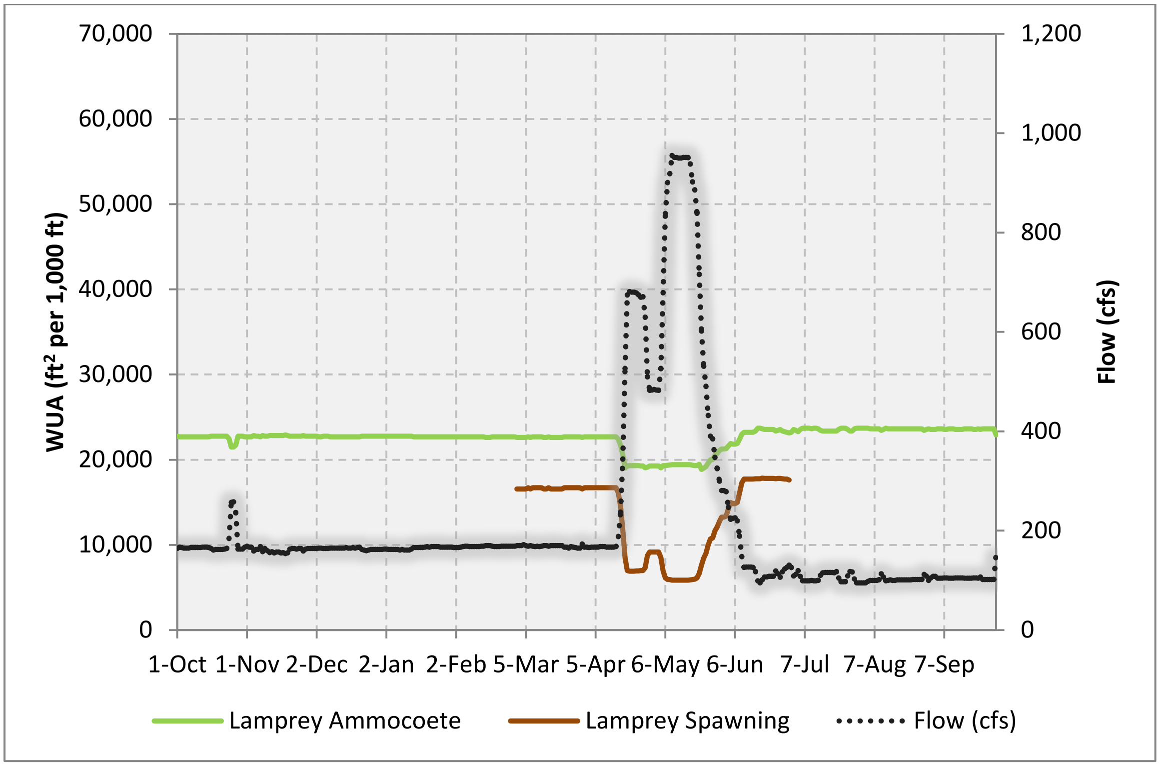

Figure 20. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Below Normal water year (2009).

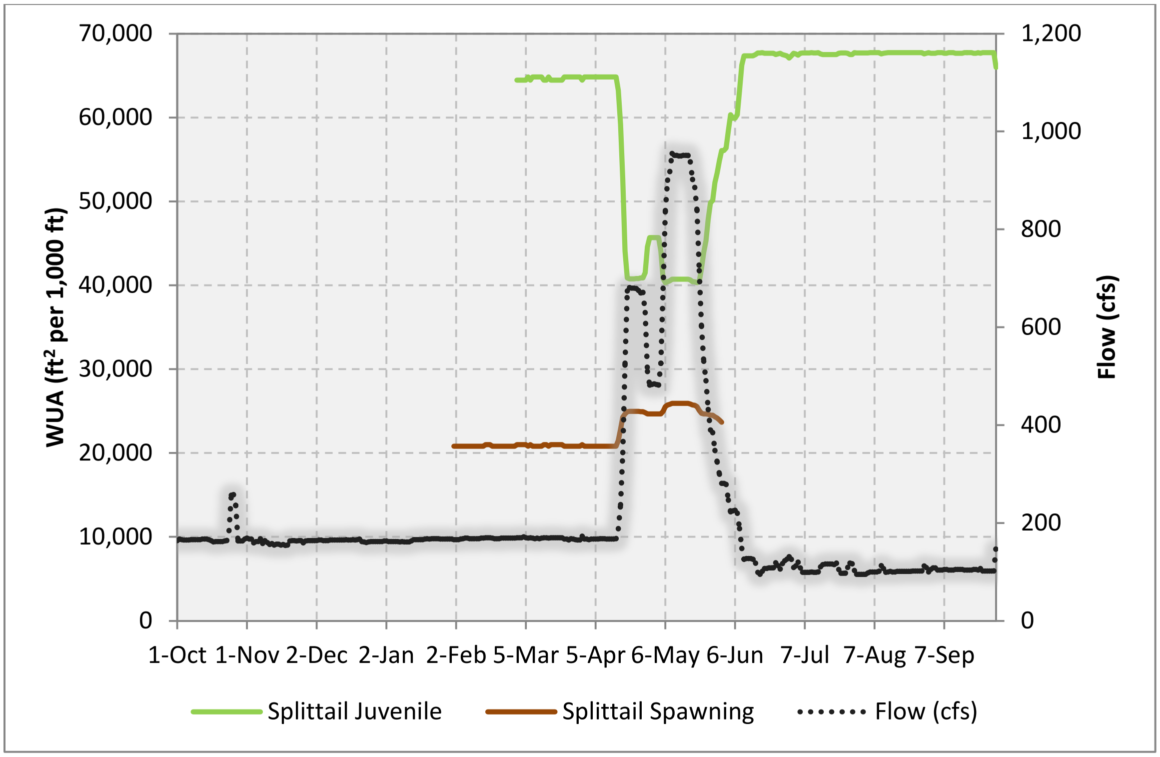

Figure 21. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Below Normal water year (2009).

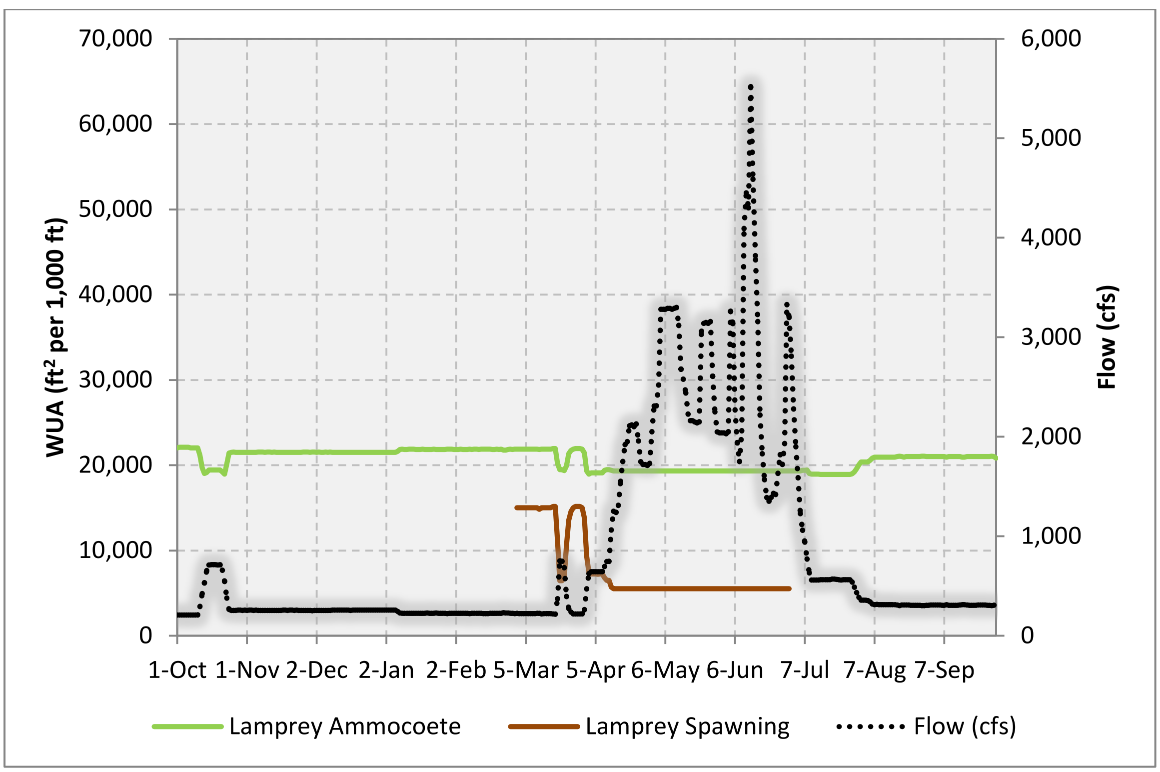

Figure 22. Habitat Time Series results for lower Tuolumne River Pacific lamprey in an Above Normal water year (2010).

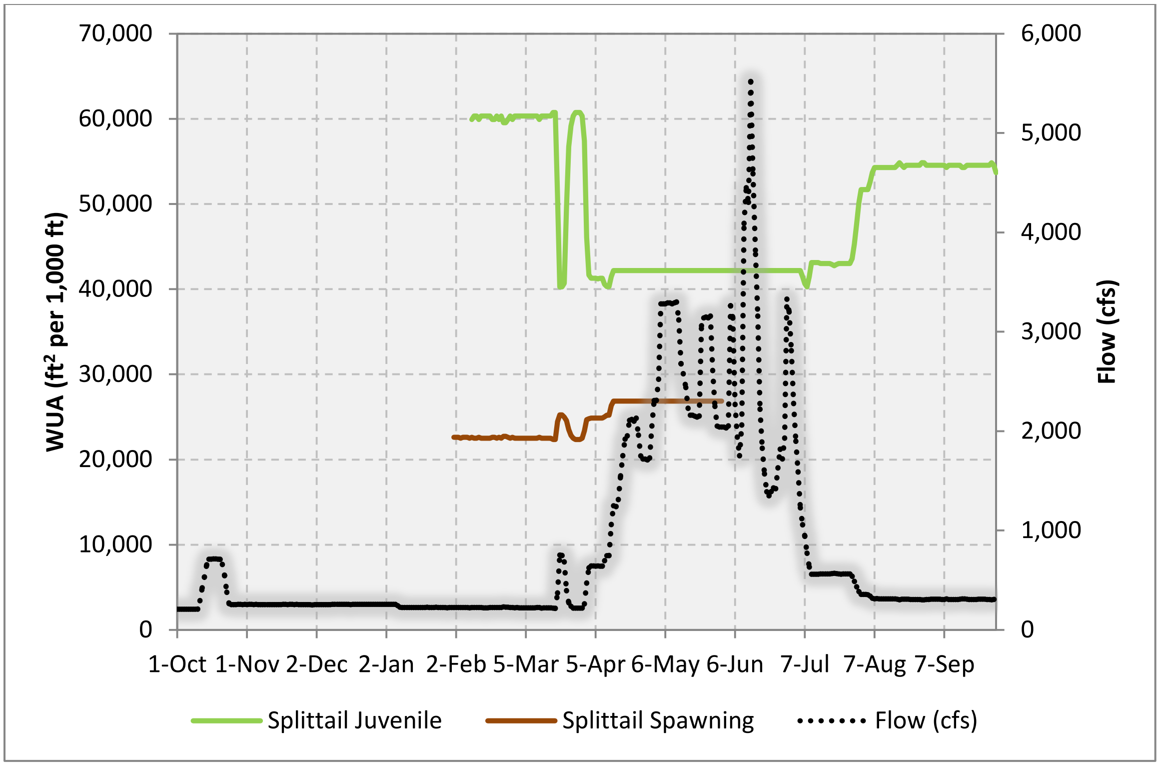

Figure 23. Habitat Time Series results for lower Tuolumne River Sacramento splittail in an Above Normal water year (2010).

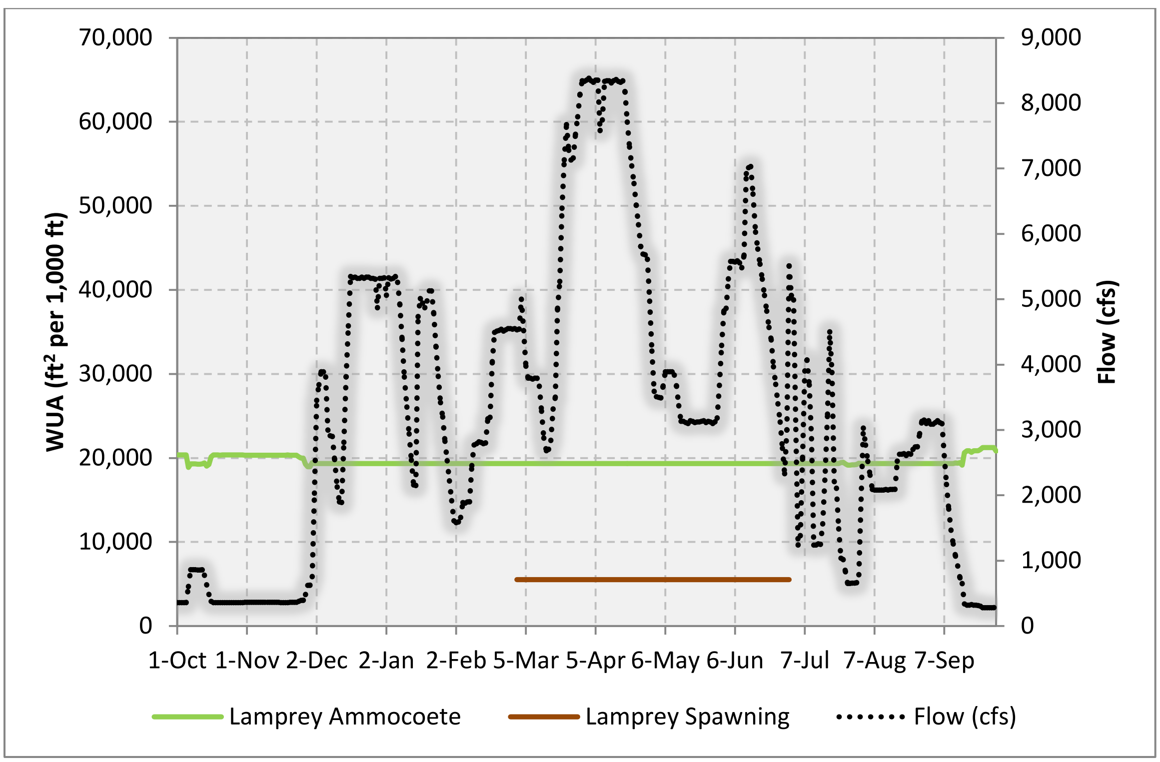

Figure 24. Habitat Time Series results for lower Tuolumne River Pacific lamprey in a Wet water year (2011).

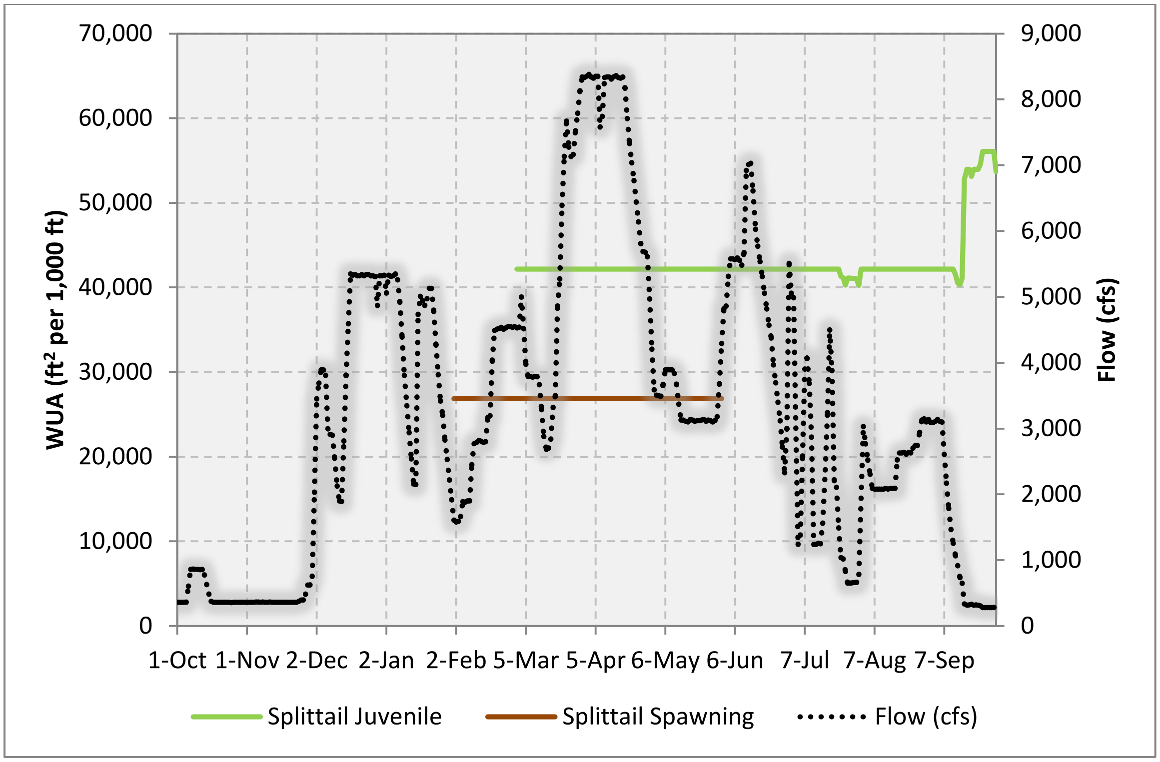

Figure 25. Habitat Time Series results for lower Tuolumne River Sacramento splittail in a Wet water year (2011).

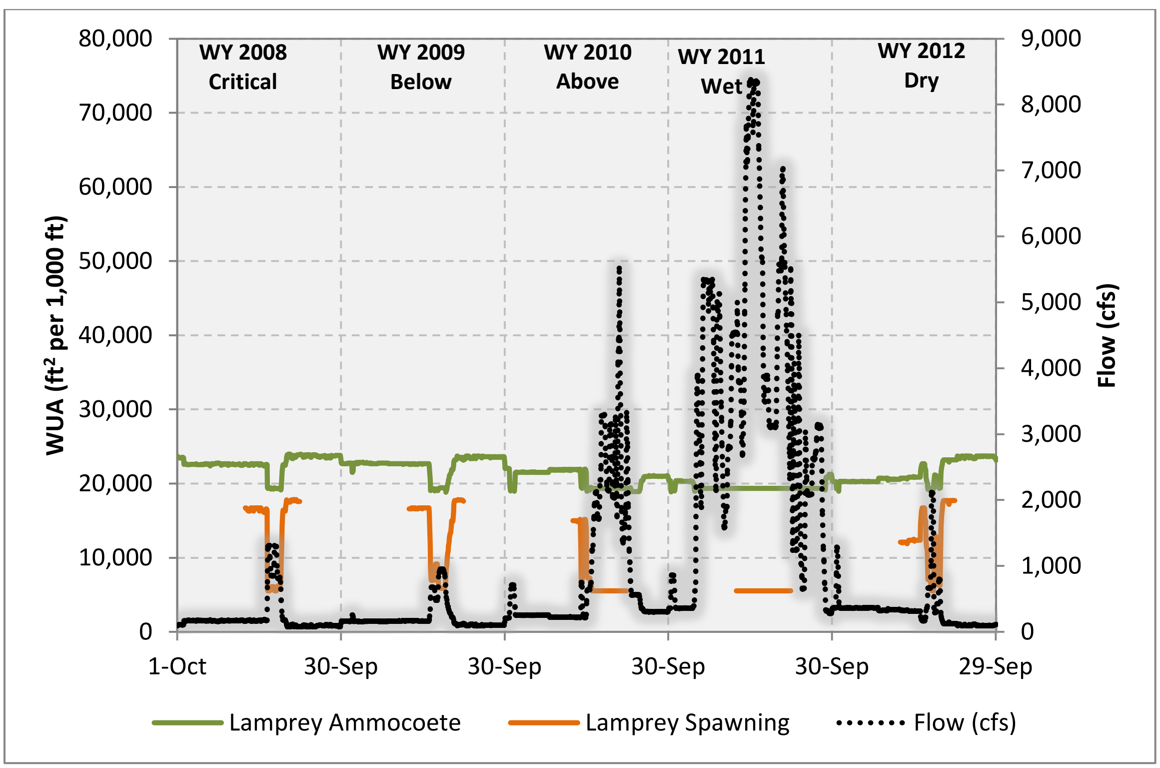

Figure 26. Habitat Time Series results for lower Tuolumne River Pacific lamprey across all water year types.

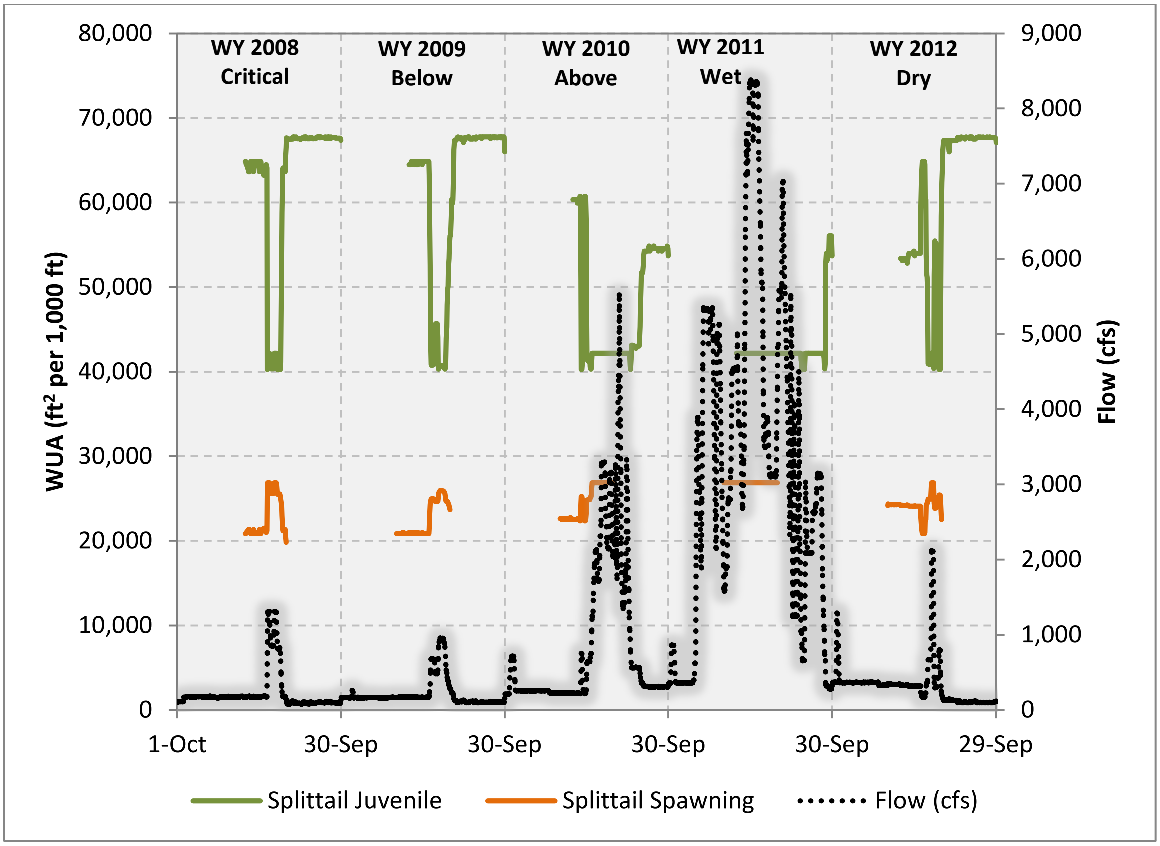

Figure 27. Habitat Time Series results for lower Tuolumne River Sacramento splittail across all water year types.

4 DISCUSSION

4.1 Pacific Lamprey in the Lower Tuolumne River

Pacific lamprey are present in the study reach between La Grange Dam (RM 52) and below Waterford (RM 29). Lamprey ammocoetes are present year-round and typically prefer slow backwater or edgewater habitat, which is available in the study reach across all of the modeled flows. Subsequently, habitat availability (as measured by WUA) for ammocoetes is consistent across a range of flows. In contrast, lamprey spawning may be limited by higher flows in the late winter and spring, as habitat availability decreases with increases in flow. As a result, lamprey spawning habitat declines during flood control or other high flow releases in the spring.

4.2 Sacramento Splittail in the Lower Tuolumne River

Sacramento splittail have not been observed in the study reach between La Grange Dam (RM 52) and below Waterford (RM 29). Splittail inhabit low gradient valley-floor estuaries and streams, and can tolerate a broad range of salinities and temperatures. They have been observed in the lower Tuolumne River as far up as the City of Modesto during wet years, and have been reported to spawn in the lower 6.8 miles of the river (Moyle et al. 1995). Adults are expected to gradually move into the lower Tuolumne in the winter and spring but may migrate more rapidly during flood periods. Adult splittail will forage and opportunistically spawn in flooded areas, after which the young-of-year/juveniles migrate downstream into the estuary by summer (Moyle 2002).

The section of the Tuolumne River where splittail have been observed is within the slow-moving, low-gradient, sand-bedded reach. Water temperatures in this reach are generally influenced by ambient air temperatures, as opposed to releases from Don Pedro Dam. The instream flow study reach (RM 29–52) is within the higher-gradient, gravel-bedded reach further upstream, and generally contains cooler stream temperatures.

The WUA results were extrapolated to the study reach only (RM 29–52). As a result, shallow depths and low velocities preferred by juvenile splittail are maximized at lower flows in this higher gradient reach. However, the WUA results are not directly applicable to the portion of the river (RM 0.0–6.8) where the species is known to occur.

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