TECHNICAL MEMORANDUM ◦ NOVEMBER 2018

Upper Tuolumne River Ecosystem Program 2015 and 2016 Fisheries Monitoring

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Cover photo: Snorkelers in the Hetch Hetchy Reach, fall 2015.

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1 INTRODUCTION AND PURPOSE

Annual monitoring of fish populations in the upper Tuolumne River Watershed serves as a basis for evaluating aquatic habitat conditions and assists in understanding how releases from the San Francisco Public Utilities Commission (SFPUC) Hetch Hetchy Project facilities affect fish habitat and fish populations over time.

The SFPUC conducted annual monitoring of fish populations for the reach between O'Shaughnessy Dam and Kirkwood Powerhouse (the Hetch Hetchy Reach) from 2007 to 2012; no data was collected in 2013 due to the Rim Fire. In 2014, the sampling approach for this reach was refined to be more efficient and effective (see Stillwater Sciences 2016), and sampling was continued in 2015 and 2016. In 2016, reconnaissance level fisheries monitoring began in the reach immediately upstream of Hetch Hetchy Reservoir (the Above Hetch Hetchy Reservoir Reach). The SFPUC conducted an initial fish population monitoring effort in Cherry Creek from Cherry Valley Dam to Holm Powerhouse in 2012 (the Cherry Creek Reach). In 2016, the SFPUC reinitiated fish population monitoring in the Cherry Creek Reach using an approach and methods consistent with those used in the Hetch Hetchy Reach since 2014.

Given the management emphasis of state and federal regulatory agencies on salmonids and sport fishing values, fish population monitoring is focused on evaluating long-term changes in native Rainbow Trout (*Oncorhnychus mykiss*) and non-native Brown Trout (*Salmo trutta*) populations. Other native fish species known to occur in the upper Tuolumne River include Riffle Sculpin (*Cottus gulosus*), California Roach (*Lavinia symmetricus*), and Sacramento Sucker (*Catostomus occidentalis*). These non-salmonid species are observed infrequently upstream of Preston Falls (SFPUC 2008, unpublished data).

This technical memorandum summarizes the fish population monitoring methods and results for surveys in the Hetch Hetchy Reach during 2015 and 2016, in the Above Hetch Hetchy Reservoir Reach during 2016, and in the Cherry Creek Reach during 2012 and 2016. Fisheries monitoring results from previous years are also presented for comparison where appropriate (i.e., 2007–2012 in the Hetch Hetchy Reach and 2012 in the Cherry Creek Reach).

2 SAMPLING APPROACH

The sampling approach was designed to monitor Rainbow Trout and Brown Trout populations in sufficient detail to detect meaningful differences over time. The approach focused on locations likely to provide "good" habitat conditions for trout. In this context, "good" habitat refers to habitats having numerous locations where trout would be expected to use and defend bioenergetically profitable feeding locations and where a variety of trout age- and size-classes would be present. The results are intended to provide an estimate of trout abundance at the sample locations and a reasonable metric of trout abundance within each sub-reach for tracking population trends.

The sampling framework for the Hetch Hetchy Reach used habitat typing by the U.S. Fish and Wildlife Service (USFWS) to describe the distribution and abundance of aquatic habitat in the reach (USFWS 1992). Monitoring sites were selected from within this framework based on criteria developed to meet sampling objectives and key sampling considerations. The primary sampling objective of the revised approach was to incorporate methods that control for statistical bias and allow sample variance and confidence intervals (CI) to be calculated for abundance estimates. These methods improve the ability to detect differences among sites and (sampled) sub-reaches, and changes over time that are statistically significant. Key sampling site considerations included access, efficiency, effectiveness, and repeatability. See Stillwater Sciences (2016) for a detailed discussion.

In 2016, fish population monitoring sites were added in the Above Hetch Hetchy Reservoir Reach to aid in understanding annual variation and long-term trends for a population subject to "natural" unregulated flow conditions. The Above Hetch Hetchy Reservoir Reach differs from the lower three sub-reaches in that habitat quantity and quality are governed by the natural flow regime. Annual monitoring of trout populations in the Above Hetch Hetchy Reservoir Reach will serve as a "control" and increase the ability to understand whether changes in trout populations in reaches downstream from the reservoir are the result of management actions. Although the Above Hetch Hetchy Reservoir Reach is subject to natural flow conditions, fish populations may be influenced by access to Hetch Hetchy Reservoir. In addition, the reach upstream of the reservoir is at a higher elevation compared with reaches downstream, and therefore may be influenced by slightly different climactic conditions.

In Cherry Creek, the sampling framework was based on mesohabitat mapping conducted in summer 2016 by McBain Associates (see Section 3). Sample sites were selected using similar criteria to those used to select sites in the Hetch Hetchy Reach, with the intent of achieving similar sampling objectives. Sites were selected based on their ease of access, the ability to sample accurately and efficiently with high repeatability, and their representativeness of the monitoring reach.

3 CHERRY CREEK MESOHABITAT MAPPING

Mesohabitat mapping was conducted by McBain Associates in Cherry Creek from Cherry Valley Dam to above Holm Powerhouse in summer 2016. The purpose of mesohabitat mapping was to quantify the amount, location, and type of mesohabitats available to salmonids. Mesohabitat mapping also provides a framework for sample site selection where specific mesohabitat units can be identified for sampling based on habitat-specific attributes as defined by the site selection criteria. 2016 snorkel survey sites in Cherry Creek were selected using similar site selection criteria to those used for the Hetch Hetchy Reach.

Mesohabitat mapping for Cherry Creek was done first by orthorectified aerial photography, then verified using ground-based surveys. The first delineation of mesohabitat units was conducted in the office with a geographic information system (GIS) using polygon coverage, orthorectified aerial photography, and Cherry Creek "center line" stationing (provided by McBain Associates). Mesohabitat types and boundaries were visually estimated for each unit based on California Department of Fish and Wildlife (CDFW) predetermined mesohabitat classifications (Table 1) and numbered continuously from downstream to upstream. Length, area, and average width of each mesohabitat unit were calculated with GIS using the polygon coverage.

Table 1. Mesohabitat types and descriptions used to characterize the Cherry Creek monitoring reach. Types and descriptions were based on CDFW Level III habitat typing methodology (Flosi et al. 2010), and not all mesohabitat types were observed in the monitoring reach.

Mesohabitat type	Description
Cascade	>10% gradient and boulder
Chute	>10% gradient and bedrock
Deep pool	>6 feet maximum depth
Shallow pool	<6 feet maximum depth
Glide/pool tail	Typically, in the downstream portion of a pool with negative bed slope where converging flow approaches the riffle crest. Wide, shallow, flat bottom with little to no surface agitation. Substrate type is typically smaller than riffle, but coarser than pool, and often provides best salmonid spawning habitat.
Run	Long, smoothly flowing reaches, flat or concave bottom, and deeper than riffles with less surface agitation. Higher velocities than pools.
Boulder garden	Moderate to low gradient riffles, runs, and glides with numerous large boulders/obstructions that create scour pockets and eddies with near zero velocity. Often no clear thalweg present due to multiple flow paths.
High-gradient riffle	>4% and <10% gradient. Substrate is usually large boulder and bedrock (>24 inches).
Low-gradient riffle	<4% gradient. Substrate is usually small boulder and large cobble (6–24 inches).
Side channel	Contains <20% of total flow. Connected at top and bottom to main channel at low flow.
Backwater	Low to zero velocity; only connected to main channel from one end.
Sand-filled pool	Was a pool in 2007 photo, now filled with sand from hillslope erosion (unique to Rim Fire impacts)
Island	In between a split channel (used to enable mesohabitat unit area and width to be adjusted).
Medial bar	Medial gravel bar (used to enable mesohabitat unit area and width to be adjusted).

After office-based surveys were completed, verification was done by an on-ground, reconnaissance-level mesohabitat mapping survey. Survey data included characterization of habitat availability for rearing salmonids including large woody debris counts by size class (Table 2), identification of spawning gravels, and maximum and average depths of pool mesohabitat types. Ground-based mapping was conducted at the same streamflow (cubic feet per second [cfs]) at which aerial photos were taken (43 cfs at United States Geological Survey [USGS] gage 11278300 above Holm Powerhouse) so that water surface elevations and wetted channel widths would be similar, and verification of office-based mapping would be easier.

Table 2. Large woody debris sizes classes used for tallying wood found in mesohabitat units during reconnaissance-level mesohabitat mapping. Size classes were based on CDFW Level III habitat typing methodology (Flosi et al. 2010), and not all categories were observed in the monitoring reach.

Diameter (inches)	Length (feet)
6–12	3–10
12–24	10–25
24–36	25–50
>36	50–75
	>75

All 14 habitat types were represented in the monitoring reach. The most dominant habitat types identified were deep pool, shallow pool, boulder garden, cascade, and high-gradient riffle, which cumulatively made up 76 percent of total reach length (Table 3). The average depth among deep pools was 8.4 feet and was 4.6 feet among shallow pools when the daily average streamflow at the time of the survey was 43 cfs (USGS gage 11278300 above Holm Powerhouse).

Table 3. Characterization of habitat types found in Cherry Creek.

Mesohabitat type	Count of habitat units	Percent of habitat units	Average length (feet)	Average width (feet)	Total area (square feet)	Average maximum depths (feet)
Cascade	60	12%	70.5	40.5	178,933	n/a
Chute	26	5%	116.8	23.9	85,692	n/a
Deep pool	94	19%	153.6	51.6	756,862	8.4
Shallow pool	87	18%	105.0	42.9	405,546	4.6
Glide/pool tail	8	2%	115.2	39.0	35,588	n/a
Run	30	6%	106.2	36.1	110,228	n/a
Boulder garden	68	14%	274.1	56.5	1,064,733	n/a
High-gradient riffle	60	12%	108.1	42.0	356,403	n/a
Low-gradient riffle	25	5%	66.4	38.8	70,139	n/a
Side channel	6	1%	146.9	14.1	13,383	n/a
Backwater	8	2%	71.0	15.8	9,104	n/a
Sand-filled pool	1	>1%	193.3	32.6	6,297	n/a
Island	9	2%	129.1	25.0	53,814	n/a
Medial bar	4	1%	302.9	55.2	87,366	n/a

n/a = not applicable. Water depths were not measured in these habitat types.

4 MONITORING SITES

Fish population monitoring sites in the Hetch Hetchy Reach of the upper Tuolumne River were established and surveyed in 2014. Monitoring surveys in the Hetch Hetchy Reach were performed again in 2015 and 2016 with minor modifications to the specific sites surveyed. Fish population monitoring sites were established and surveyed in Cherry Creek and in the Tuolumne River above Hetch Hetchy Reservoir in 2016. Monitoring sites within each surveyed reach include the dominant habitat types by length in the reach and are distributed to capture longitudinal variability.

4.1 Site Selection

Monitoring sites sampled in the Hetch Hetchy Reach during 2015 were the same as those sampled in 2014 with minor modifications, which included the addition of a pocketwater (site 229-PW) and removal of a deep pool (site 223-DP) in the O'Shaughnessy sub-reach. Modifications were based on criteria developed to meet the sampling objectives and were intended to focus effort on sites that can be efficiently and effectively sampled with high repeatability, that likely support a range of trout age- and size-classes, and to reflect the habitat composition within each sub-reach. In 2016, monitoring site adjustments included the addition of a deep pool (site 223-DP) and removal of one shallow pool (site 249-SP), both in the O'Shaughnessy sub-reach.

Four monitoring sites were sampled in the Above Hetch Hetchy Reservoir Reach in 2016. Sample sites in the Above Hetch Hetchy Reservoir Reach were selected based on similar criteria to those used to select sites in the Hetch Hetchy Reach, with access being a strong consideration.

In Cherry Creek, 2016 sites were selected from 2016 mesohabitat mapping data, prioritizing those sites surveyed in 2012. Thirteen sites were selected based on the ability to efficiently and effectively perform snorkel surveys, access to sites, ability to be repeated, and likelihood to support trout (i.e., the monitoring approach focuses on sampling locations that are likely to provide "good" habitat conditions for trout, referring to habitats with numerous locations where trout would be expected to use and defend bioenergetically profitable feeding locations and where a variety of trout age- and size-classes would be present). Sites were selected in three sub-reaches: Upper Cherry, Lower Cherry, and Holm Powerhouse (see Section 4.3 for more detail).

4.2 Surveyed Sites

4.2.1 Hetch Hetchy Reach

A total of 16 monitoring sites in the Hetch Hetchy Reach were sampled in 2015: six in the Early Intake sub-reach, six in the Preston Falls sub-reach, and four in the O'Shaughnessy sub-reach (Table 4, Figure 1). In 2016, all the previous year's sites were monitored with the following exceptions: the upstream half of a pocketwater (site 229-PW) was not surveyed due to high flows, site 249-SP was dropped due to low fish numbers and non-representative habitat composition, and site 38-DP was sampled inadvertently. Sites included deep pool, shallow pool, and pocketwater habitat types. These three habitat types comprise 75 to 90 percent of habitats in the sub-reaches sampled (Table 5). Run, riffle, cascade, and chute habitat types were not included because (1) they did not meet site selection criteria, and/or (2) there was very little representation of these habitat types within the sub-reaches sampled.

The length of each monitoring site was estimated with GIS using a polygon coverage (.kmz) defining upstream and downstream boundaries (provided by the SFPUC), orthorectified aerial photography, and Tuolumne River "center line" stationing. Estimates of surveyed length were used to calculate linear fish density (fish/1,000 feet). Minor changes (<5 feet) in site length reported between 2015 and 2016 reflect updates to the position of the GIS center line. Larger changes in site-specific surveyed length between years were due to differences in sampling condition (e.g., flow) and the feasibility of effectively surveying a site each year. Differences in stationing from 2014–2015 to 2016 reflect an updated downstream boundary (i.e., station 000+00) at the Wards Ferry Bridge, approximately 2,525 feet upstream of the previous starting point (Table 6).

In 2016, sampling coverage by length was 10 percent, 11 percent, and 8 percent for the Early Intake, Preston Falls, and O'Shaughnessy sub-reaches, respectively (Table 7). Within the sub-reaches, 2016 sampling coverages by length for deep pool, shallow pool, and pocketwater habitat types were 7 to 14 percent, 23 to 33 percent, and 5 to 10 percent, respectively (Table 7).

Table 4. 2014–2016 fish population monitoring sites.

Site ID[1]	Habitat type[2]	Surveyed length (feet)		
		2014	2015	2016
Early Intake sub-reach				
11-SP	shallow pool	153	153	153
13-DP	deep pool	194	194	194
18-PW	pocketwater	147	147	196
27-SP	shallow pool	273	273	275
34-DP	deep pool	172	172	171
37-PW	pocketwater	118	118	133
38-DP	deep pool	--	--	120
Preston Falls sub-reach				
44-PW	pocketwater	167	167	169
46-DP	deep pool	179	179	129
49-SP	shallow pool	153	153	172
56-DP	deep pool	244	244	246
74-DP	deep pool	250	250	249
76-SP	shallow pool	146	146	145
O'Shaughnessy sub-reach				
223-DP	deep pool	231	--	236
227-DP	deep pool	146	146	149
229-PW	pocketwater	--	175	122
249-SP[2]	shallow pool	175	175	--
267-SP	shallow pool	254	254	255

[1] Based on USFWS habitat typing data. Monitoring site numbers refer to sequential habitat unit numbers from Kirkwood Powerhouse to O'Shaughnessy Dam (data provided to Stillwater Sciences by McBain Associates).
[2] Site 249-SP is a shallow pool complex comprising habitat units 249/250/251. Sampling at SP-249 was discontinued in 2016.

Table 5. Composition of study sub-reaches by habitat type.

Study sub-reach	Habitat type composition by length (percent)						
	Deep pool	Shallow pool	Run	Riffle	Cascade	Pocketwater[1]	Chute
Early Intake	23	12	5	0	0	60	0
Preston Falls	66	12	2	1	2	16	1
O'Shaughnessy	55	11	<1	7	4	16	6

[1] Includes habitats classified as PW (pocketwater) and PW/CA (pocketwater/cascade).

Table 6. 2016 fish population monitoring sites in the Hetch Hetchy Reach with GIS stationing.

Site ID[1]	Habitat type[1]	Longitudinal stationing[2] (feet)		Surveyed length (feet)
		Downstream	Upstream	
Early Intake sub-reach				
11-SP	shallow pool	1483+36	1484+89	153
13-DP	deep pool	1485+86	1487+80	194
18-PW	pocketwater	1512+35	1514+31	147
27-SP	shallow pool	1533+71	1536+47	273
34-DP	deep pool	1556+83	1558+54	172
37-PW	pocketwater	1565+79	1567+12	118
38-DP	deep pool	1567+42	1568+63	120
Preston Falls sub-reach				
44-PW	pocketwater	1578+51	1580+20	167
46-DP	deep pool	1580+53	1581+82	179
49-SP	shallow pool	1584+39	1586+11	153
56-DP	deep pool	1593+58	1596+04	244
74-DP	deep pool	1652+05	1654+54	250
76-SP	shallow pool	1656+16	1657+61	146
O'Shaughnessy sub-reach				
223-DP	deep pool	2004+33	2006+69	231
227-DP	deep pool	2009+25	2010+74	146
229-PW	pocketwater	2011+96	2013+18	175
267-SP	shallow pool	2076+77	2079+32	254

[1] Based on USFWS habitat typing data. Monitoring site numbers refer to sequential habitat unit numbers from Kirkwood Powerhouse to O'Shaughnessy Dam (data provided to Stillwater Sciences by McBain Associates).

[2] Stationing is based on the GIS center line for the Tuolumne River from the Wards Ferry Bridge upstream of Don Pedro Reservoir (RM 0) upstream to O'Shaughnessy Dam.

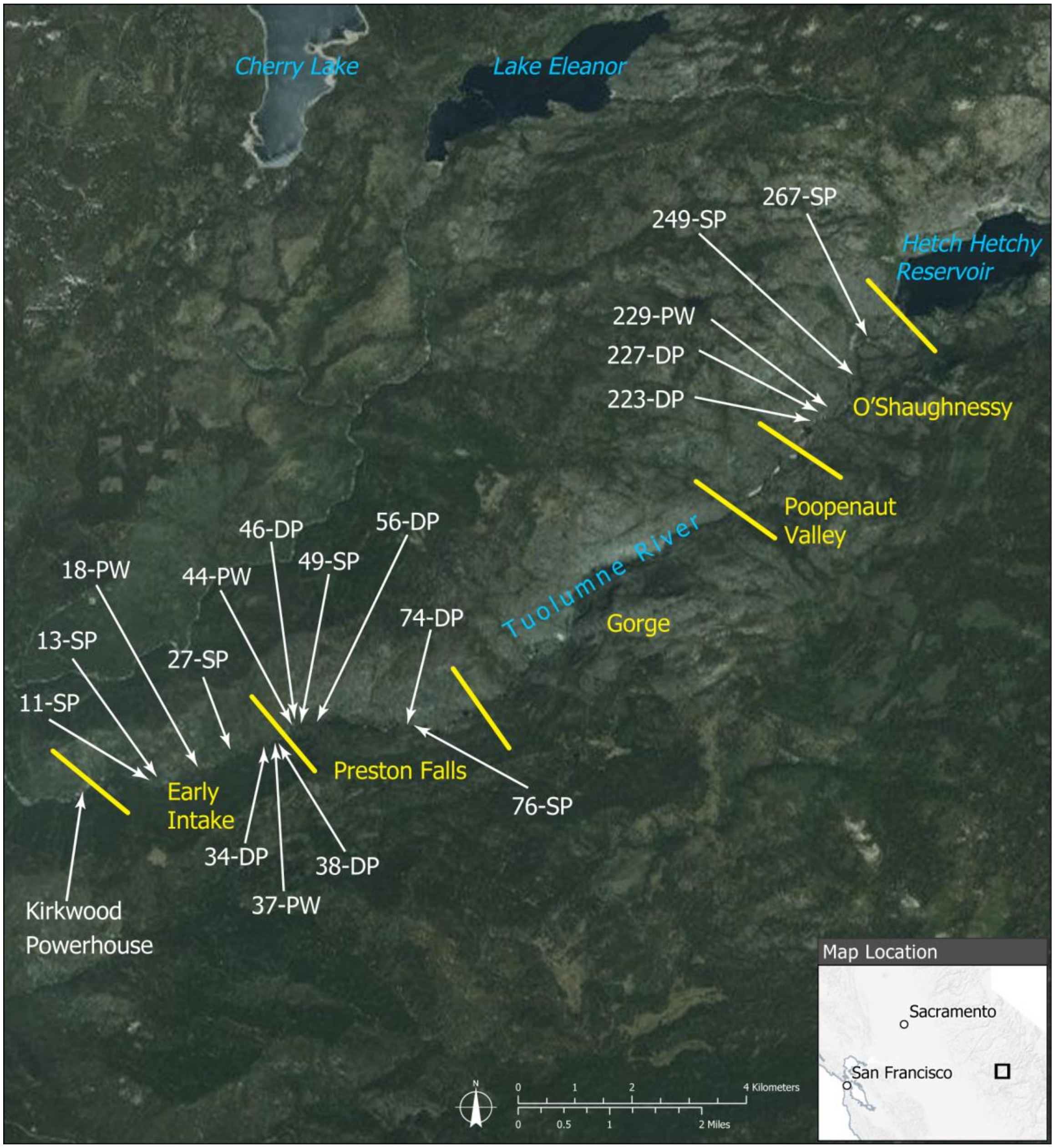

Figure 1. 2015 and 2016 fish population monitoring site locations in the Hetch Hetchy Reach.

Table 7. Sampling coverage of habitat types in study sub-reaches in 2015 and 2016.

Study sub-reach	Habitat type (percent of length sampled)			
	Deep pool	Shallow pool	Pocketwater	All types
2015				
Early Intake	14	33	4	10
Preston Falls	10	24	10	11
O'Shaughnessy	3	38	13	8
2016				
Early Intake	14	33	5	10
Preston Falls	9	26	10	11
O'Shaughnessy	7	23	7	8

4.2.2 Above Hetch Hetchy Reservoir Reach

Four monitoring sites were surveyed in the Above Hetch Hetchy Reservoir Reach during 2016: one pocketwater (510-PW), two shallow pools (sites 507-SP and 511-SP), and one deep pool (514-DP) (Table 8, Figure 2). Site 507-SP is not expected to be sampled in future years, since site 511-SP was considered a better shallow pool habitat for meeting site selection criteria and long-term objectives.

Table 8. 2016 fish population monitoring sites in the Above Hetch Hetchy Reservoir Reach with GIS stationing.

Site ID[1]	Habitat type[1]	Longitudinal stationing[2] (feet)		Surveyed length (feet)
		Downstream	Upstream	
507-SP	Shallow pool	2546+79	2548+11	132
510-PW	pocketwater	2548+99	2550+04	105
511-SP	shallow pool	2550+04	2551+42	138
514-DP	deep pool	2555+63	2557+49	185

1 Based on USFWS habitat typing data. Monitoring site numbers refer to sequential habitat unit numbers from Kirkwood Powerhouse to O'Shaughnessy Dam (data provided to Stillwater Sciences by McBain Associates).
2 Stationing is based on the GIS center line for the Tuolumne River from the Wards Ferry Bridge upstream of Don Pedro Reservoir (RM 0) upstream to O'Shaughnessy Dam.

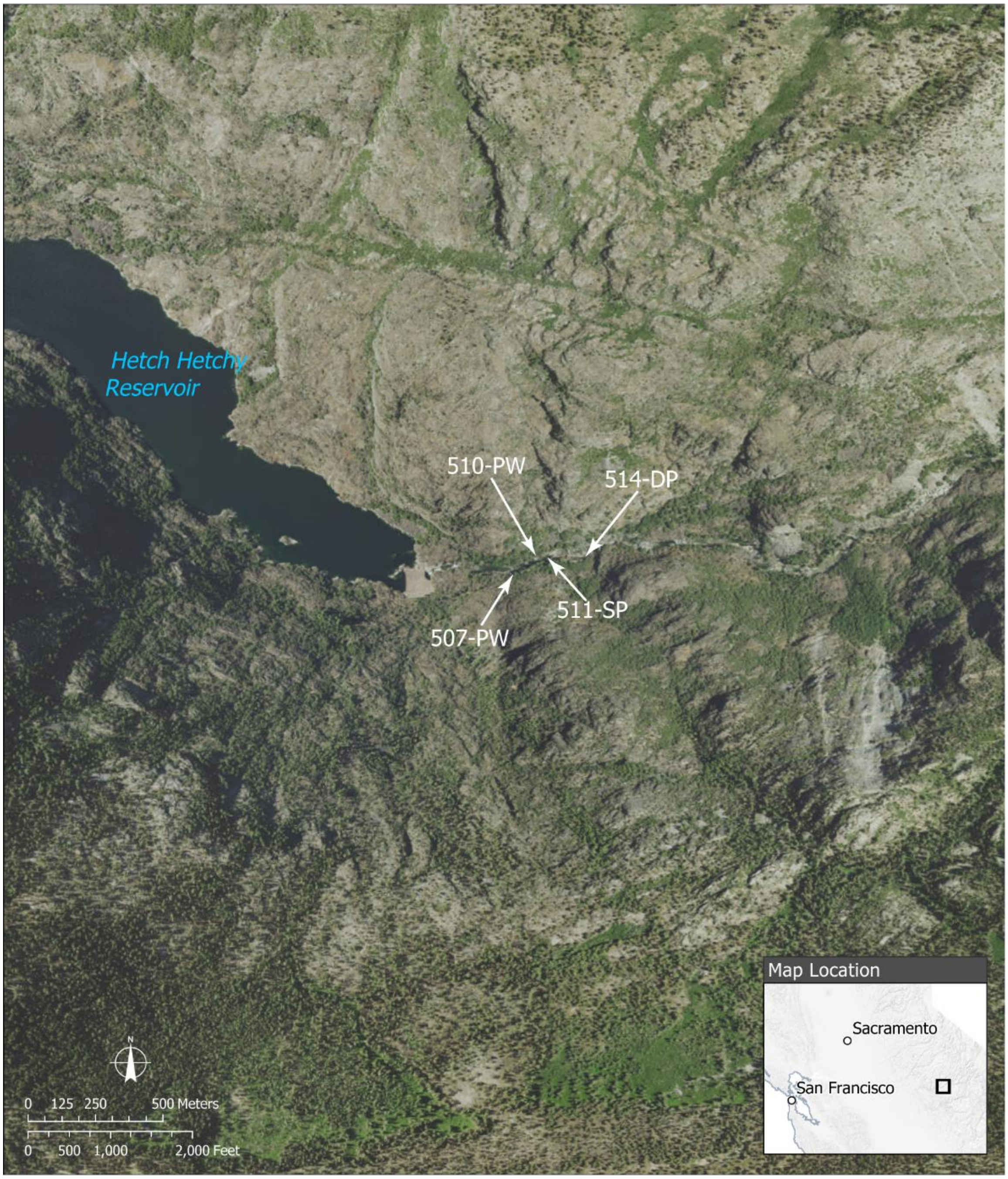

Figure 2. 2016 fish population monitoring site locations in the Above Hetch Hetchy Reservoir Reach.

4.2.3 Cherry Creek

Snorkel surveys in the Cherry Creek Reach were performed from Cherry Valley Dam to above Holm Powerhouse in fall 2016. The Cherry Creek Reach was divided into three sub-reaches: Upper Cherry sub-reach, Lower Cherry sub-reach and Holm Powerhouse sub-reach (Figure 3). Monitoring sites were selected based on the same criteria used for the Upper Tuolumne River snorkeling efforts (Stillwater Sciences 2016). A total of 13 monitoring sites were sampled: five in the Upper Cherry sub-reach and eight in the Lower Cherry sub-reach (Table 9, Figure 3). No monitoring sites were selected in the Holm Powerhouse sub-reach because flow releases below Holm Powerhouse were too high to safely survey. Monitoring sites included shallow pool, deep pool, boulder garden, and run habitat types. These four habitat types represented 71 percent of the total length of the Upper Cherry sub-reach and 77 percent of the Lower Cherry sub-reach (Table 10). Riffle, cascade, and chute habitat types were not included because (1) they did not meet site selection criteria, and/or (2) there was very little representation of these habitat types within the reaches sampled.

The length of each monitoring site was estimated with GIS using polygon coverage (.kmz), orthorectified aerial photography, and Cherry Creek GIS “center line” stationing (Table 9). The total length surveyed in each sub-reach was 731 feet in the Upper Cherry sub-reach and 1,365 feet in the Lower Cherry sub-reach, which was 3 percent and 4 percent of the total length of each reach, respectively. For the Upper Cherry and Lower Cherry sub-reaches, 5 percent and 9 percent of deep pool habitat, 11 percent and 4 percent of shallow pool habitat, 0 percent and 2 percent of boulder garden habitat, and 0 percent and 7 percent of run habitat was surveyed, respectively (Table 11).

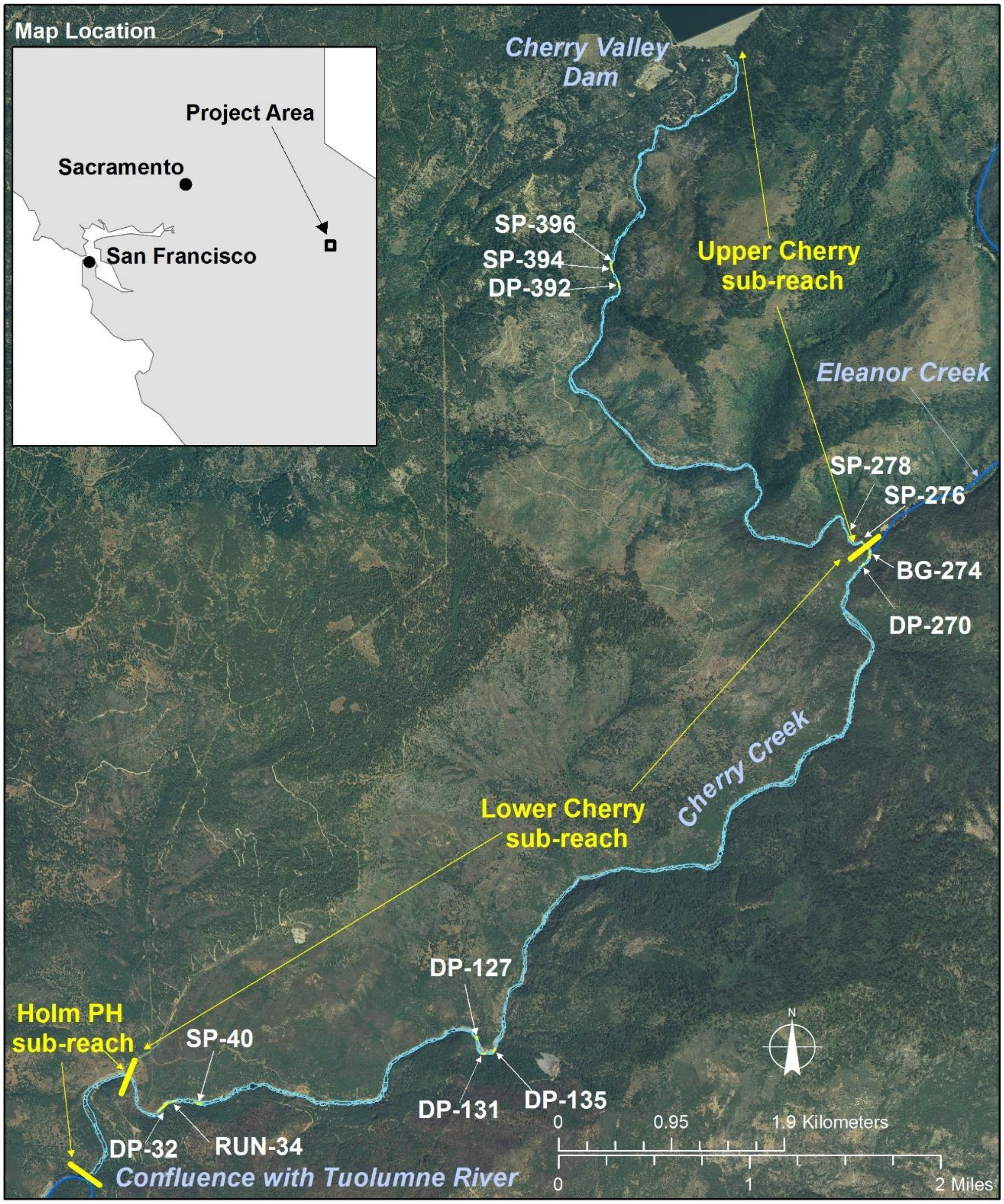

Figure 3. 2016 and 2012 fish population monitoring site locations in the Cherry Creek Reach.

Table 9. 2016 Fish population monitoring sites on Cherry Creek from Cherry Valley Dam to upstream of Holm Powerhouse.

Site ID[1]	Habitat type[1]	Stationing[2]		Surveyed length (feet)
		Downstream	Upstream	
Upper Cherry sub-reach				
SP-396[3]	shallow pool	550+82	551+34	52
SP-394[3]	shallow pool	547+90	550+55	265
DP-392	deep pool	543+17	545+36	219
SP-278[3]	shallow pool	384+30	385+66	136
SP-276[3]	shallow pool	383+45	384+03	58
Lower Cherry sub-reach				
BG-274[3]	boulder garden	379+72	382+05	233
DP-270[3]	deep pool	377+00	378+05	100
DP-135	deep pool	169+12	170+72	160
DP-131[3]	deep pool	165+83	167+32	149
DP-127	deep pool	160+07	161+52	145
SP-40[3]	shallow pool	67+70	69+51	181
RN-34	run	61+06	62+17	111
DP-32	deep pool	57+60	60+46	286

1 Monitoring site numbers refer to sequential habitat unit numbers from the Tuolumne River confluence to Cherry Valley Dam.
2 Stationing is based on the GIS center line for Cherry Creek from the Tuolumne River confluence (RM 0) upstream of Cherry Valley Dam (RM 11).
3 Monitoring sites also surveyed in 2012.

Table 10. Percent length of habitat types in the Cherry Creek Reach. Excludes islands, medial bars, and sand-filled pools (<1 percent in Cherry Creek).

Sub-reach	Habitat type (percent length)										
	Cascade	Chute	Deep pool[1]	Shallow pool[1]	Glide/ Pool tail	Run[1]	Boulder garden[1]	High-gradient riffle	Low-gradient riffle	Side channel	Backwater
Upper Cherry	2	8	16	19	3	7	29	8	5	3	1
Lower Cherry	10	3	27	13	1	4	33	8	0	0	1

1 Habitat types selected for monitoring in Cherry Creek.

Table 11. Percent length of sub-reaches surveyed in 2016 by habitat type in the Cherry Creek Reach.

Sub-reach	Percent length of monitoring sites in sub-reaches by habitat type				Percent of total length of sub-reach surveyed[1]
	Deep pool	Shallow pool	Boulder garden	Run	
Upper Cherry	5	11	0	0	3
Lower Cherry	9	4	2	7	4

[1] Excludes islands, medial bars, and sand filled pools (<1 percent in Cherry Creek).

5 METHODS

The three-pass snorkel survey method (Routledge 1982) was used to estimate fish population abundance in all reaches and years except on Cherry Creek in 2012. The standardization of snorkel survey methods across reaches and years allows for comparable results and trend assessments. Employing multi-pass snorkel methods allows for variance to be estimated and confidence interval to be calculated, which improves the ability to determine whether changes to fish populations over time are meaningful.

The three-pass method allows abundance estimates and confidence intervals to be computed using a bounded counts estimator (Routledge 1982). This method assumes that each fish is observable, that there is a reasonable chance of seeing all fish during a single pass, and that no fish are counted twice during a single pass. There are various ways of deriving the estimator. For this application, the following formula was used:

$$\tilde{y}_B = d_{[m]} + (d_{[m]} - d_{[m-1]})$$

where $d_{[m]}$ is the maximum number of fish counted during any of the passes, and $d_{[m-1]}$ is the second highest count; counts are arranged in ascending order as:

$$d_{[1]} \le d_{[2]} \le d_{[3]} \le \cdots \le d_{[m-1]} \le d_{[m]}.$$

Confidence intervals (95 percent) were calculated based on Robson and Whitlock (1964). The lower bound (N_L) was calculated as:

$$N_L = d_{[m]}$$

The upper bound (N_U) was calculated as:

$$N_U = d_{[m]} + [(1-\alpha)/\alpha] \cdot [d_{[m]} - d_{[m-1]}]$$

where α is the level of significance (i.e., α=0.05 for calculation of a 95 percent confidence interval), unless $d_{[m]} = d_{[m-1]}$. When the maximum dive count is equal to the second highest dive count ($d_{[m]} = d_{[m-1]}$), the upper bound for the confidence interval is equivalent to the abundance estimate, and therefore the coverage probability for the confidence interval tends to be poor.

Abundance estimates were used to calculate linear fish density (i.e., fish/1,000 feet) to normalize for length and allow comparisons of abundance between individual monitoring sites and reaches. Linear density was calculated for each monitoring site by dividing site abundance by site length (resulting in fish abundance per foot of stream), and then multiplying by 1,000 to calculate linear fish density (fish/1,000 feet) for the site. A weighted mean was used for calculating linear density at the reach level.

5.1 Hetch Hetchy Reach

Fish population monitoring surveys in the Hetch Hetchy Reach were performed from August 23 through August 28, 2015, and August 20, 21, and 23 through 26, 2016. Average daily streamflow during 2015 monitoring surveys was 77 cfs at the upstream end of the reach (USGS gage 11276500 near Hetch Hetchy) and 93 cfs at the downstream end of the reach (USGS gage 11276600 above Early Intake). In 2016, average daily streamflow during monitoring surveys was 138–143 cfs at the upstream end of the reach and 138–146 cfs at the downstream end of the reach. Sixteen monitoring sites were surveyed in 2015 and 17 monitoring sites were surveyed in 2016. Three-pass, bounded count snorkel surveys were conducted at all monitoring sites in 2015 and 2016 except for one site (34-DP) in 2016 when one snorkel pass was used. Field crews generally consisted of five snorkelers and one shore-based safety/data recorder. For each of the three snorkel passes, snorkelers entered the site from downstream and snorkeled in an upstream direction, each within a designated lane. Snorkelers identified, counted, and visually estimated total length (TL) of trout in their own lane while moving upstream at a slow and uniform pace. Dive slates were used to tally fish observed by species and length class, and fish observation data were recorded with a field computer at the end of each pass. General site habitat characteristics and water quality observations were also recorded for each site.

5.2 Above Hetch Hetchy Reservoir Reach

Fish population monitoring surveys in the Above Hetch Hetchy Reservoir Reach were performed on August 22, 2016 when average daily streamflow was 36 cfs (USGS gage 11274790 above Hetch Hetchy). Snorkel surveys were conducted at each of the 4 monitoring sites using similar methods to those described above for the Hetch Hetchy Reach. Three-pass methods were used at 3 monitoring sites (510-PW, 511-SP, 514-DP) and one-pass methods were used at one monitoring site (507-SP).

5.3 Cherry Creek Reach

Fish population monitoring surveys in the Cherry Creek Reach were performed from September 13 through September 16, 2016 when daily average streamflow was 43 cfs (USGS gage 11278300 above Holm Powerhouse). Snorkel surveys employed the three-pass method using a similar sampling approach with two to three snorkelers and one shore-based safety/data recorder. It is important to note that the 2012 Cherry Creek snorkel surveys only employed a one-pass method, and reported abundances are based on direct enumeration. As a result, confidence intervals could not be calculated for the 2012 survey data.

Habitat characteristics were recorded for each monitoring site and included weather, visibility (feet), dominant and subdominant substrate types (silt, sand, gravel, cobble, and boulder), percent instream cover type (boulder, bubble curtain, undercut bank, large woody debris, instream vegetation, bedrock ledge), water temperature (degrees Celsius [^{o}C]), and maximum depth. In addition, photos and Global Positioning System (GPS) points at the upstream and downstream end of each reach were taken to document the extent of each site.

6 RESULTS AND DISCUSSION

Length-frequency data were used to determine a length threshold for differentiating between age-0 and age-1 and older trout in the Hetch Hetchy, Above Hetch Hetchy Reservoir, and Cherry Creek reaches to inform the interpretation of results. Differentiating between these two age classes improves the ability to understand how habitat conditions (e.g., flow and water temperature) influence fish populations in the monitoring reaches, since different environmental pressures influence fish abundance and survival for these age classes. Abundance and linear density were estimated to assess fish populations at the habitat unit, sub-reach, and reach scales, and to evaluate changes and trends in populations over time. Streamflow and water temperature at gages in each of the monitoring reaches provide information on habitat conditions and their influence on trout populations in the monitoring reaches.

6.1 Length and Age

6.1.1 Hetch Hetchy Reach

The length-frequency distributions for Rainbow and Brown Trout in 2015 generally show similar patterns to 2014. In both years there were a large number of fish in the 75- to 100-millimeter (mm) length category, an absence of fish in the 0- to 50-mm length category, and the general downward trend in the number of larger fish (Figure 4). For 2016, length-frequency distributions show somewhat different patterns compared with 2014 and 2015, with relatively fewer fish in the 75- to 100-mm length category compared with some other length categories (e.g., 175 to 200 mm). These data also indicate that age-0 Rainbow and Brown Trout recruitment in 2016 was relatively low compared with 2015.

Length-frequency distributions for Rainbow and Brown Trout in 2015 do not clearly differentiate between age-0 and age-1 trout (Figure 4). This is likely the result of variable growth and strongly overlapping length distributions between age classes, which is common with length-frequency data because fish emerge at different times and grow at different rates based on competition and environmental conditions. The length-frequency distributions for 2016 support using the 125-mm length threshold for differentiating between age-0 and age-1 trout (Figure 4).

Based on the following reasons, and to allow comparison with conditions during the 2007–2012 monitoring period, the 125-mm threshold was used to differentiate between age-0 and age-1 and older trout for results presented in this document:

1. Similarities in length-frequency distribution patterns in 2014 and 2015;
2. Similarities in the apparent length threshold to differentiate between age-0 and age-1 and older trout for 2014 and 2016;
3. The potential for environmental stochasticity to affect individual growth rates and length-frequency data, and strongly overlapped length distributions.

During the 2007–2010 monitoring period, the threshold between age-0 and age-1 fish was estimated to be approximately 85 mm and 105 mm for Rainbow and Brown Trout, respectively (Stillwater Sciences 2016). It is possible that apparent differences in size-at-age between 2007–2010 and 2014–2016 are due to differences in methods and/or crews. However, the SFPUC employs procedures to ensure consistency, and reduce method and/or crew differences as a potential source of error or bias. Other potential reasons include the hypothesis that post-fire drought conditions may have resulted in increased growth rates compared with conditions during the 2007–2010 monitoring period.

Results of sampling in 2015 and 2016 showed no clear differences in the size and age between Rainbow and Brown Trout (Figure 4). Age-0 Brown Trout are expected to be slightly larger than Rainbow Trout at the same time of year because Brown Trout spawn and emerge earlier. Minor differences in lengths between the two species may be masked by using 25-mm length categories to track field observations. By age-1, length differences between the trout species may or may not be evident due to variable growth rates and strongly overlapping length distributions.

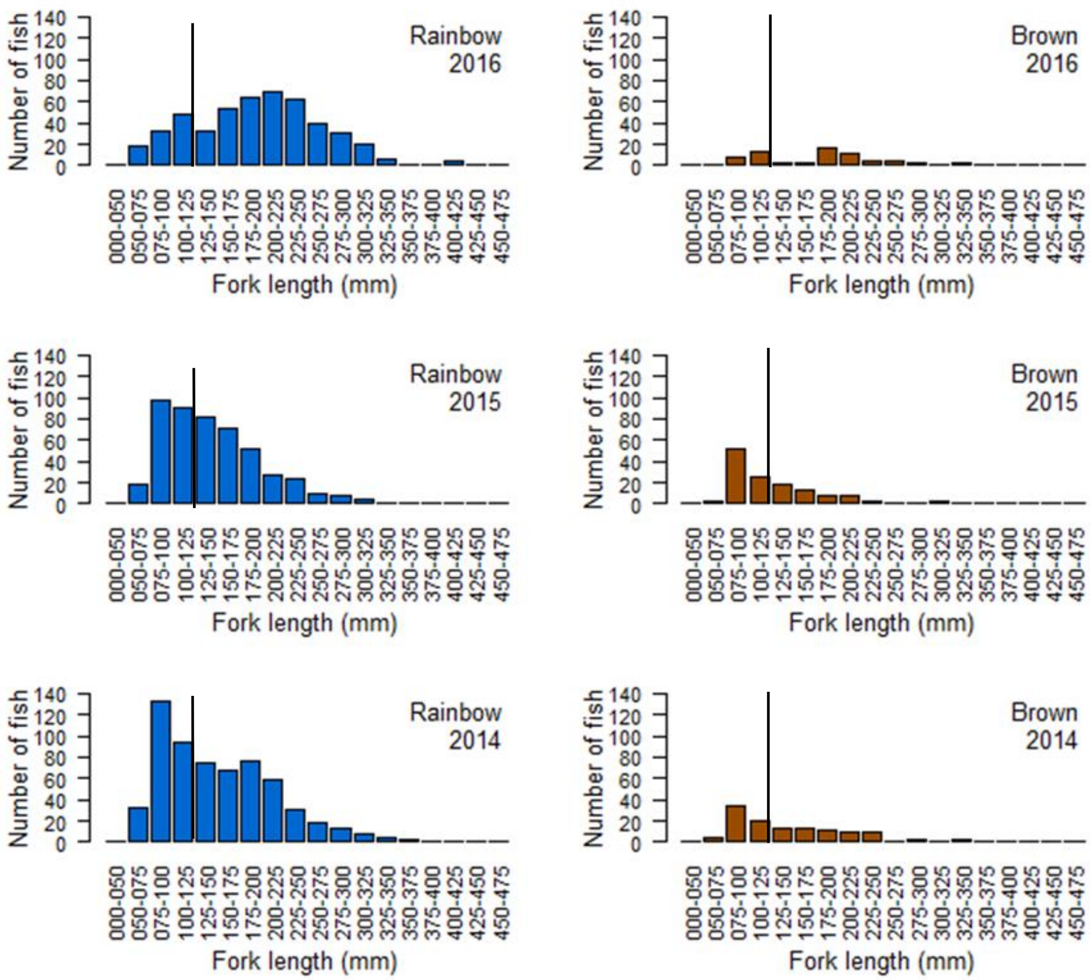

Figure 4. Length-frequency distributions for Rainbow Trout and Brown Trout observed at surveyed sites in the Hetch Hetchy Reach (first pass only). The vertical black line indicates the 125-mm size threshold used to differentiate between age-0 and age-1 and older trout.

6.1.2 Above Hetch Hetchy Reservoir Reach

Sample sizes of fish length observations in the Above Hetch Hetchy Reservoir Reach were too small to develop meaningful length-frequency distributions to assess trout length at age specific to this reach.

6.1.3 Cherry Creek Reach

Rainbow Trout were the only trout species observed during 2016 and 2012 snorkel survey efforts in Cherry Creek. Rainbow Trout length-frequency data for Cherry Creek in both 2016 and 2012 support a 125-mm length threshold for differentiating age-0 from age-1 and older trout (Figures 5 and 6). The 125-mm length threshold is consistent with length-frequency data for Rainbow Trout in the Hetch Hetchy Reach for 2014–2016.

In both 2016 and 2012, most Rainbow Trout observed in Cherry Creek were in the 76- to 100-mm size range (approximately 23 percent for both years). In 2016, very few trout (3) <50 mm were observed compared with 2012 (47), which may be explained by the earlier timing of snorkel surveys in 2012 (i.e., September 2016 vs. August 2012); it is likely that the majority of young-of-the-year Rainbow Trout had grown to >50 mm by September. During 2016, more trout >125 mm were observed than were observed during 2012, while 2012 had more trout ≤125 mm observed than trout >125 mm overall (Figures 5 and 6). The increase in frequency of Rainbow Trout >125 mm in 2016 compared with 2012 supports the hypothesis that post-Rim Fire drought conditions increased survival and relative abundance of age-1 and older trout in the Hetch Hetchy and Cherry Creek reaches (see Section 6.1.1).

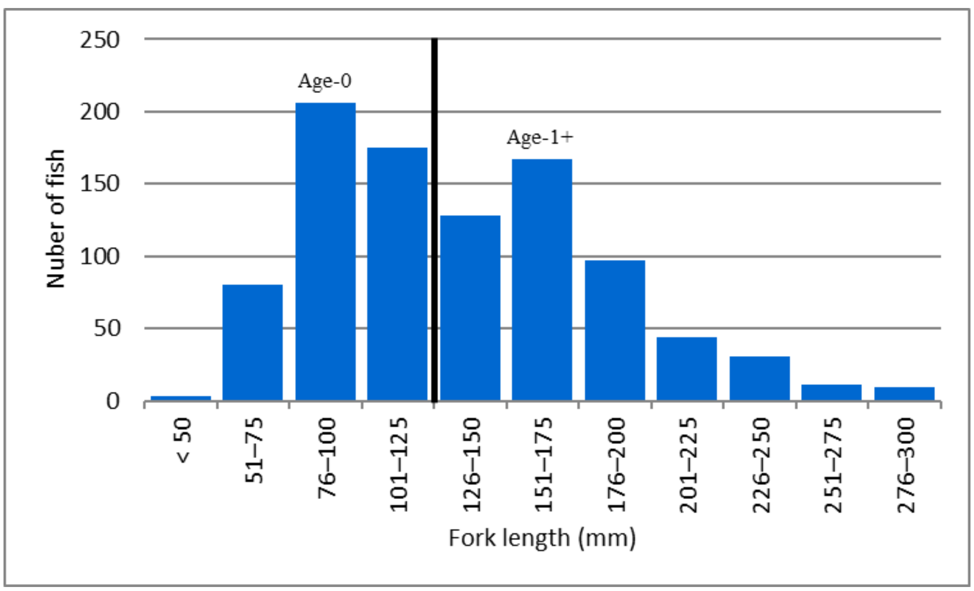

Figure 5. Length-frequency distribution for Rainbow Trout observed at surveyed sites in the Cherry Creek Reach during 2016 (first pass only). The vertical black line indicates the 125 mm size threshold used to differentiate between age-0 and age-1 and older trout.

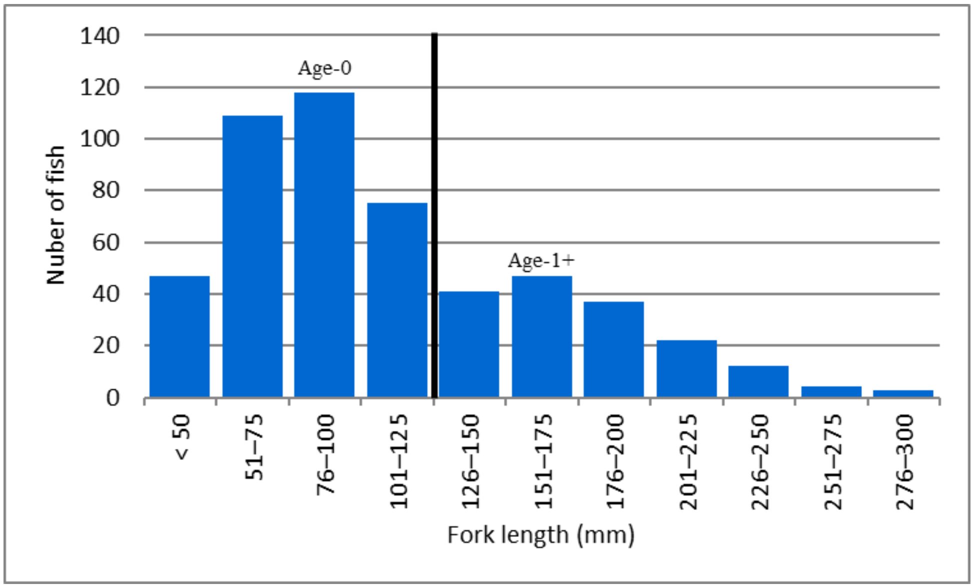

Figure 6. Length-frequency distribution for Rainbow Trout observed at surveyed sites in the Cherry Creek Reach during 2012 (first pass only). The vertical black line indicates the 125 mm size threshold used to differentiate between age-0 and age-1 and older trout.

6.2 Abundance and Linear Density Estimates

Fry abundance commonly fluctuates from year to year based on spawning and incubation success as well as environmental conditions (e.g., flows) soon after emergence. Age-0 trout (≤125 mm total length) abundance can be a useful indication of potential recruitment to older age classes and can aid in understanding how environmental conditions affect year class success. However, large variations in annual fry numbers can reduce the ability to detect meaningful trends in trout populations, therefore, annual fish population abundance results presented in this document focus on age-1 and older trout (>125 mm total length). In addition, age-1 and older trout have survived through at least one winter and are more likely to contribute to the adult population and reproduce. Within this document, when the length class is not specified, it is referring to trout >125 mm.

6.2.1 Hetch Hetchy Reach

6.2.1.1 2015 Monitoring in Hetch Hetchy Reach

Trout >125 mm

The 2015 fish population monitoring results for trout abundance, relative abundance, and density in the Hetch Hetchy Reach are presented below for trout >125 mm (Tables 12–14, Figures 7–9). Total trout abundance estimates for all sites combined were 380, 109, and 452 for Rainbow, Brown, and all trout, respectively (Table 12). Estimates for “all trout” include unidentified trout that are not included in the species-specific estimates. The ratio of Rainbow Trout to Brown Trout was 3.5:1 for all sites combined and ranged from 2.6:1 in the Preston Falls sub-reach to 17:1 in the O’Shaughnessy sub-reach. No Brown Trout >125 mm were observed at four of the fifteen monitoring sites (sites 11-SP, 34-DP, 227-DP, and 249-SP). Overall, trout abundance and density were highest in the Preston Falls sub-reach and lowest in the O’Shaughnessy sub-reach (Table 13, Figure 9). Site-specific density estimates for all trout >125 mm were variable, ranging from 0 fish/1,000 feet at site 249-SP to 527 fish/1,000 feet at site 76-SP. Sites 44-PW, 74-DP, and 76-SP stood out as having relatively high densities, and sites 249-SP and 267-SP as having relatively low densities. Otherwise, trout densities at monitoring sites generally were within the range of about 50 to 175 fish/1,000 feet (Figures 7–9).

Table 12. Abundance estimates for Rainbow and Brown Trout >125 mm by site in the Hetch Hetchy Reach in 2015 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow	**Brown**	**All trout**
Early Intake sub-reach				
11-SP	shallow pool	9 (±0)	0 (±0)	11 (±2)
13-DP	deep pool	15 (±4)	3 (±0)	19 (±4)
18-PW	pocketwater	14 (±4)	2 (±0)	18 (±6)
27-SP	shallow pool	17 (±2)	3 (±2)	18 (±2)
34-DP	deep pool	15 (±12)	0 (±0)	15 (±12)
37-PW	pocketwater	14 (±2)	4 (±4)	17 (±4)
Preston Falls sub-reach				
44-PW	pocketwater	46 (±14)	13 (±2)	59 (±18)
46-DP	deep pool	19 (±2)	6 (±4)	22 (±2)
49-SP	shallow pool	10 (±6)	5 (±0)	15 (±6)
56-DP	deep pool	39 (±10)	8 (±2)	43 (±2)
74-DP	deep pool	89 (±27)	34 (±18)	90 (±4)
76-SP	shallow pool	42 (±12)	28 (±18)	77 (±35)
O'Shaughnessy sub-reach				
227-DP	deep pool	14 (±4)	0 (±0)	12 (±0)
229-PW	pocketwater	28 (±8)	2 (±2)	28 (±6)
249-SP	shallow pool	0 (±0)	0 (±0)	0 (±0)
267-SP	shallow pool	9 (±4)	1 (±0)	8 (±2)

Table 13. Abundance estimates for Rainbow and Brown Trout >125 mm by sub-reach in the Hetch Hetchy Reach in 2015 (95 percent CI).

Sub-reach	Trout >125 mm (age-1 and older)		
	Rainbow	**Brown**	**All trout**
Early Intake	84 (±13)	12 (±4)	98 (±15)
Preston Falls	245 (±35)	94 (±25)	306 (±40)
O'Shaughnessy	51 (±8)	3 (±2)	48 (±7)
Total	380 (±38)	109 (±26)	452 (±43)

Table 14. Abundance estimates for Rainbow and Brown Trout >125 mm by habitat type in the Hetch Hetchy Reach in 2015 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow	**Brown**	**All trout**
Shallow pool	87 (±14)	37 (±18)	129 (±36)
Deep pool	191 (±32)	51 (±18)	201 (±13)
Pocketwater	102 (±16)	21 (±5)	122 (±20)
Total	380 (±38)	109 (±26)	452 (±43)

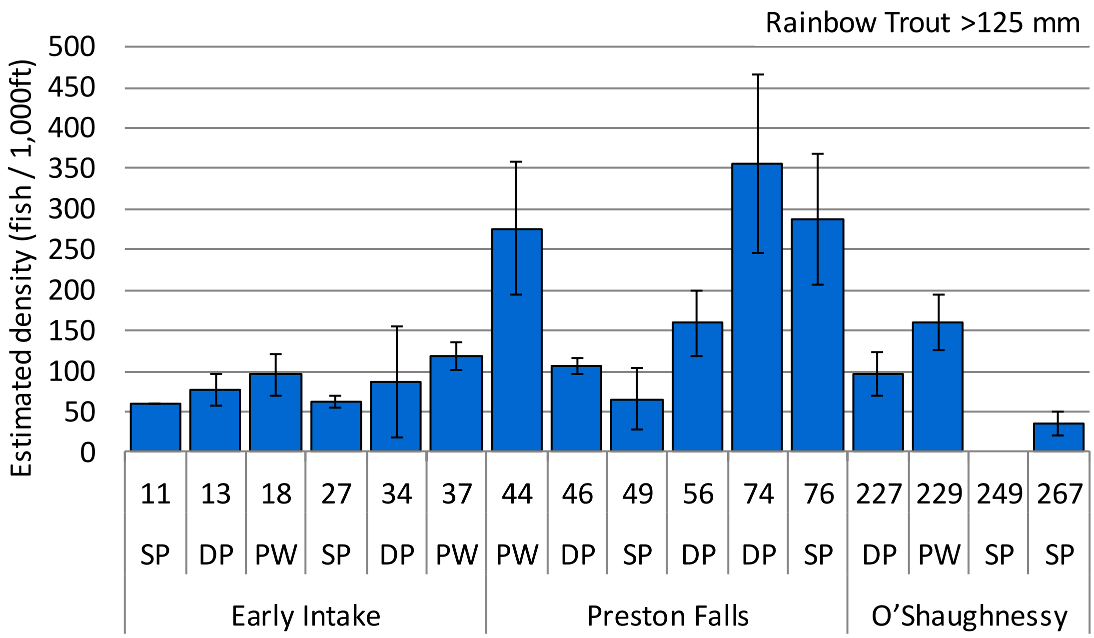

Figure 7. Estimated linear density of Rainbow Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2015. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

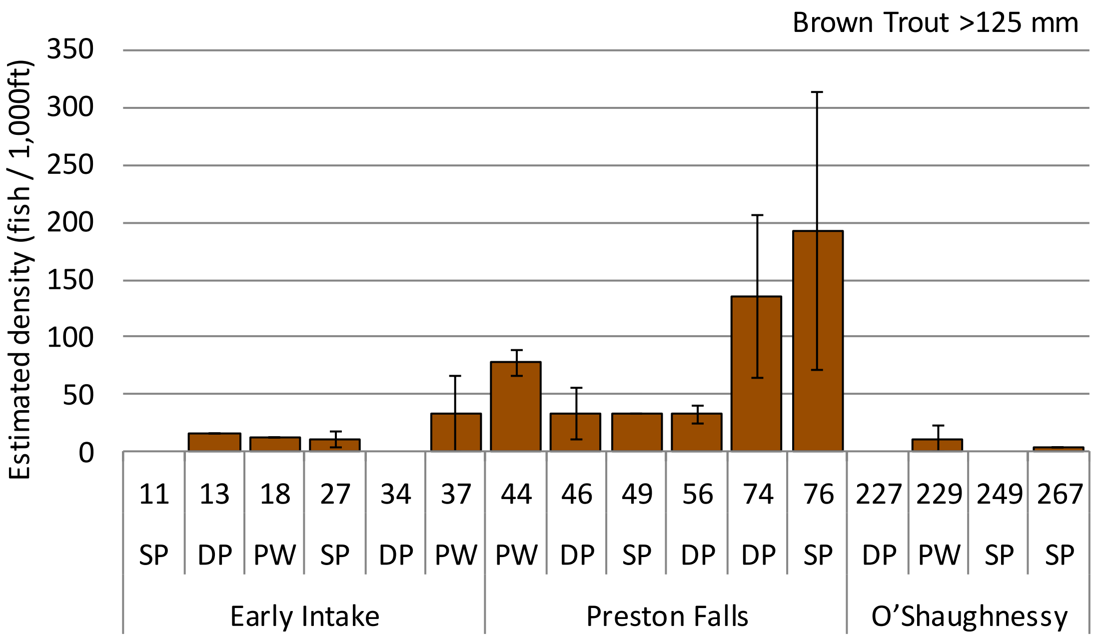

Figure 8. Estimated linear density of Brown Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2015. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

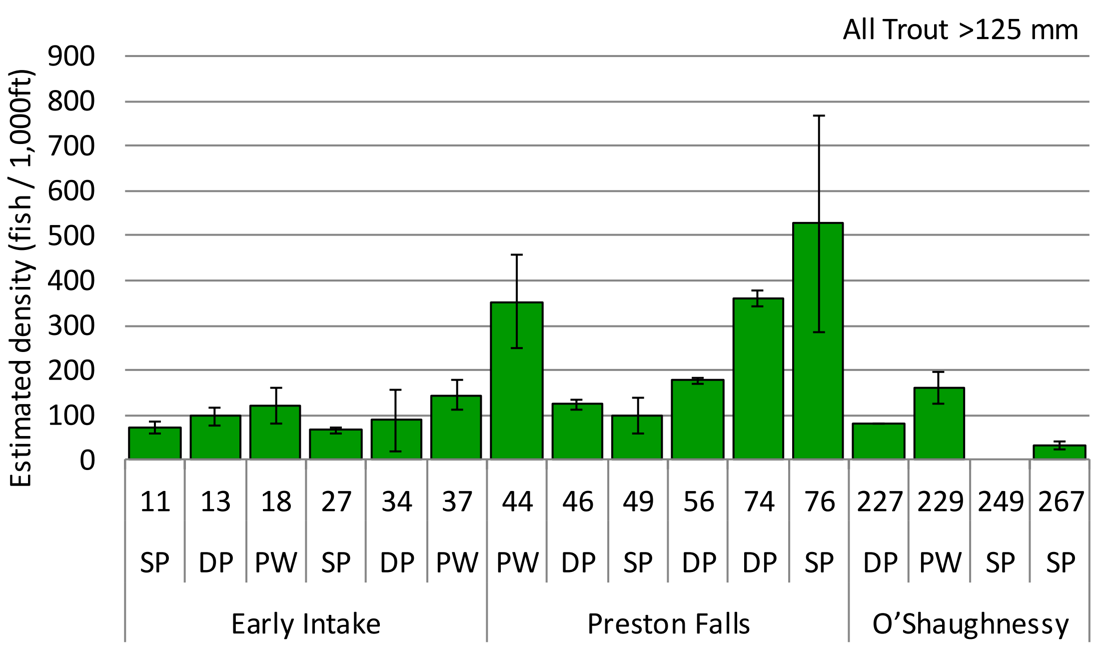

Figure 9. Estimated linear density (fish/1,000 feet) of Rainbow and Brown Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2015. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

Trout ≤125 mm

As described in Section 6.1, trout ≤125 mm are primarily comprised of fish in their first year of life (age-0) and provide an indication of spawning success and age-0 recruitment. The 2015 fish population monitoring results indicate that Rainbow and Brown Trout densities for fish ≤125 mm were greatest in the Preston Falls sub-reach and lowest in the O'Shaughnessy sub-reach (Tables 15–17, Figures 10 and 11). Rainbow Trout ≤125 mm were observed at all monitoring sites except for two sites in the O'Shaughnessy sub-reach. No Brown Trout ≤125 mm were observed in the O'Shaughnessy sub-reach or in two sites in the Early Intake sub-reach in 2015 (Figure 11). Rainbow Trout density was greatest at site 44-PW (461 fish/1,000 feet). Brown Trout density was substantially higher at site 74-DP (368 fish/1,000 feet) compared with the other sites sampled.

Table 15. Abundance estimates for Rainbow and Brown Trout ≤125 mm by site in the Hetch Hetchy Reach in 2015 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)		
		Rainbow	Brown	All trout
Early Intake sub-reach				
11-SP	shallow pool	6 (±4)	0 (±0)	5 (±2)
13-DP	deep pool	4 (±2)	0 (±0)	5 (±2)
18-PW	pocketwater	18 (±8)	6 (±0)	26 (±6)
27-SP	shallow pool	20 (±18)	5 (±2)	19 (±14)
34-DP	deep pool	1 (±0)	2 (±2)	3 (±2)
37-PW	pocketwater	18 (±0)	5 (±2)	25 (±4)
Preston Falls sub-reach				
44-PW	pocketwater	77 (±39)	20 (±12)	83 (±35)
46-DP	deep pool	20 (±2)	9 (±6)	31 (±10)
49-SP	shallow pool	40 (±2)	16 (±8)	57 (±10)
56-DP	deep pool	39 (±25)	16 (±8)	43 (±18)
74-DP	deep pool	81 (±12)	92 (±39)	174 (±61)
76-SP	shallow pool	33 (±12)	13 (±2)	39 (±2)
O'Shaughnessy sub-reach				
227-DP	deep pool	0 (±0)	0 (±0)	0 (±0)
229-PW	pocketwater	3 (±2)	0 (±0)	3 (±2)
249-SP	shallow pool	15 (±14)	0 (±0)	15 (±14)
267-SP	shallow pool	0 (±0)	0 (±0)	0 (±0)

Table 16. Abundance estimates for Rainbow and Brown Trout ≤125 mm by sub-reach in the Hetch Hetchy Reach in 2015 (95 percent CI).

Sub-reach	Trout ≤125 mm (age-0)		
	Rainbow	**Brown**	**All trout**
Early Intake	67 (±20)	18 (±3)	83 (±16)
Preston Falls	290 (±50)	166 (±43)	427 (±74)
O'Shaughnessy	18 (±14)	0 (±0)	18 (±14)
Total	375 (±55)	184 (±43)	528 (±77)

Table 17. Abundance estimates for Rainbow and Brown Trout ≤125 mm by habitat type in the Hetch Hetchy Reach in 2015 (95 percent CI).

Habitat type	Trout ≤125 mm (age-0)		
	Rainbow	**Brown**	**All trout**
Shallow pool	114 (±26)	34 (±8)	135 (±22)
Deep pool	145 (±28)	119 (±40)	256 (±64)
Pocketwater	116 (±40)	31 (±12)	137 (±36)
Total	375 (±55)	184 (±43)	528 (±77)

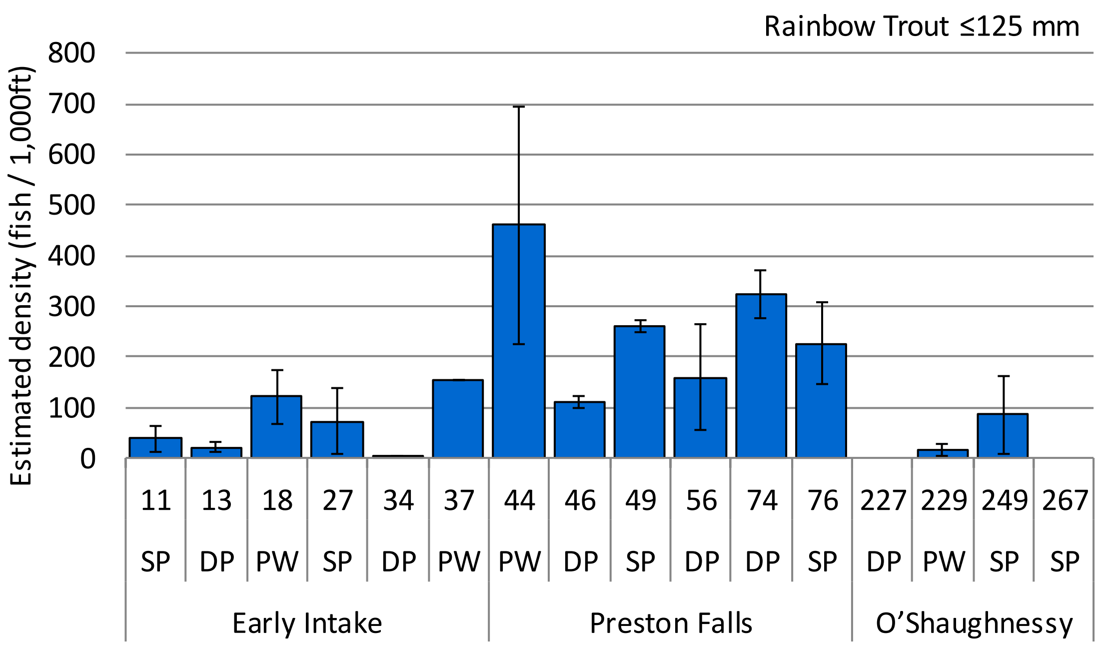

Figure 10. Estimated linear density (fish/1,000 feet) of Rainbow Trout ≤125 mm by sub-reach and site in the Hetch Hetchy Reach in 2015. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

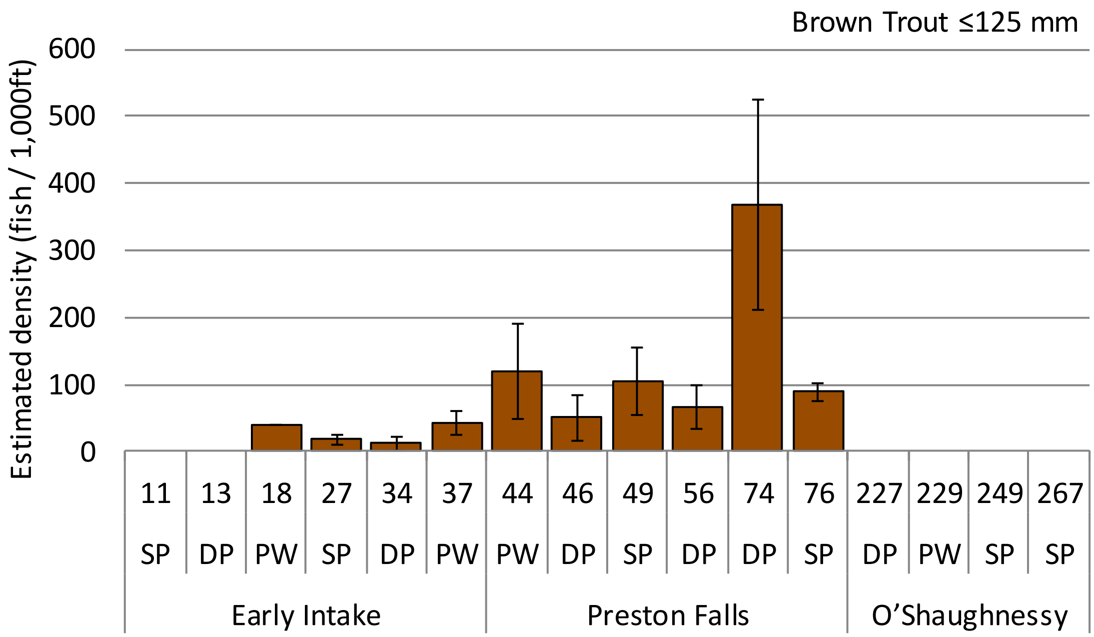

Figure 11. Estimated linear density (fish/1,000 feet) of Brown Trout ≤125 mm by sub-reach and site in the Hetch Hetchy Reach in 2015. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

6.2.1.2 2016 Monitoring in Hetch Hetchy Reach

Trout >125 mm

The 2016 fish population monitoring results for trout abundance, relative abundance, and density are presented below for trout >125 mm (Tables 18–20, Figures 12–14). Monitoring results for sites sampled in the Above Hetch Hetchy Reservoir Reach are reported separately (see Section 6.2.2) from results for sites in the Hetch Hetchy Reach.

Abundance estimates for all Hetch Hetchy Reach sites combined were 440, 85, and 562 for Rainbow, Brown, and all trout, respectively (Table 19). The ratio of Rainbow Trout to Brown Trout was 5.4:1 for all sites combined, ranging from 2:1 to 15:1 at individual monitoring sites. Brown Trout >125 mm were not observed at two monitoring sites in the reach (sites 18-PW and 227-DP). Overall, trout densities were about 185 fish/1,000 feet for the Early Intake and Preston Falls sub-reaches, and 165 fish/1,000 feet for the O'Shaughnessy sub-reach. Density estimates for all trout >125 mm at monitoring sites were variable, ranging from 51 fish/1,000 feet at site 267-SP to 300 fish/1,000 feet at site 38-DP. Site 267-SP stands out as having relatively low trout density compared with the other monitoring sites. Otherwise, the density of trout >125 mm at monitoring sites was generally in the range of 115 to 225 fish/1,000 feet (Figures 12–14). Trout abundance and density at monitoring sites were highest in the Preston Falls sub-reach and lowest in the O'Shaughnessy sub-reach.

Table 18. Abundance estimates for Rainbow and Brown Trout >125 mm by site in the Hetch Hetchy Reach in 2016 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow	Brown	All trout
Early Intake sub-reach				
11-SP	shallow pool	20 (±2)	7 (±2)	27 (±2)
13-DP	deep pool	25 (±2)	6 (±4)	32 (±6)
18-PW	pocketwater	16 (±8)	0 (±0)	20 (±10)
27-SP	shallow pool	36 (±0)	6 (±0)	51 (±12)
34-DP[1]	deep pool	23	6	32
37-PW	pocketwater	18 (±6)	4 (±4)	32 (±14)
38-DP	deep pool	28 (±2)	7 (±4)	36 (±4)
Preston Falls sub-reach				
44-PW	pocketwater	22 (±0)	5 (±2)	27 (±2)
46-DP	deep pool	21 (±2)	10 (±4)	29 (±2)
49-SP	shallow pool	21 (±8)	3 (±2)	20 (±4)
56-DP	deep pool	30 (±12)	6 (±4)	34 (±12)
74-DP	deep pool	58 (±10)	9 (±2)	63 (±6)
76-DP	shallow pool	20 (±0)	4 (±2)	33 (±12)
O’Shaughnessy sub-reach				
223-DP	deep pool	45 (±8)	5 (±2)	65 (±25)
227-DP	deep pool	17 (±10)	0 (±0)	17 (±10)
229-PW	pocketwater	30 (±6)	2 (±2)	31 (±6)
267-SP	shallow pool	10 (±2)	5 (±4)	13 (±2)

[1] Habitats sampled with a single-pass.

Table 19. Abundance estimates for Rainbow and Brown Trout >125 mm by sub-reach in the Hetch Hetchy Reach in 2016 (95 percent CI).

Sub-reach	Trout >125 mm (age-1 and older)		
	Rainbow	Brown	All trout
Early Intake	166 (±10)	36 (±7)	230 (±22)
Preston Falls	172 (±17)	37 (±7)	206 (±18)
O’Shaughnessy	102 (±14)	12 (±5)	126 (±28)
Total	440 (±25)	85 (±11)	562 (±40)

Table 20. Abundance estimates for Rainbow and Brown Trout >125 mm by habitat type in the Hetch Hetchy Reach in 2016 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow	**Brown**	**All trout**
Shallow pool	107 (±8)	25 (±5)	144 (±17)
Deep pool	247 (±20)	49 (±8)	308 (±31)
Pocketwater	86 (±11)	11 (±5)	110 (±18)
Total	440 (±25)	85 (±11)	562 (±40)

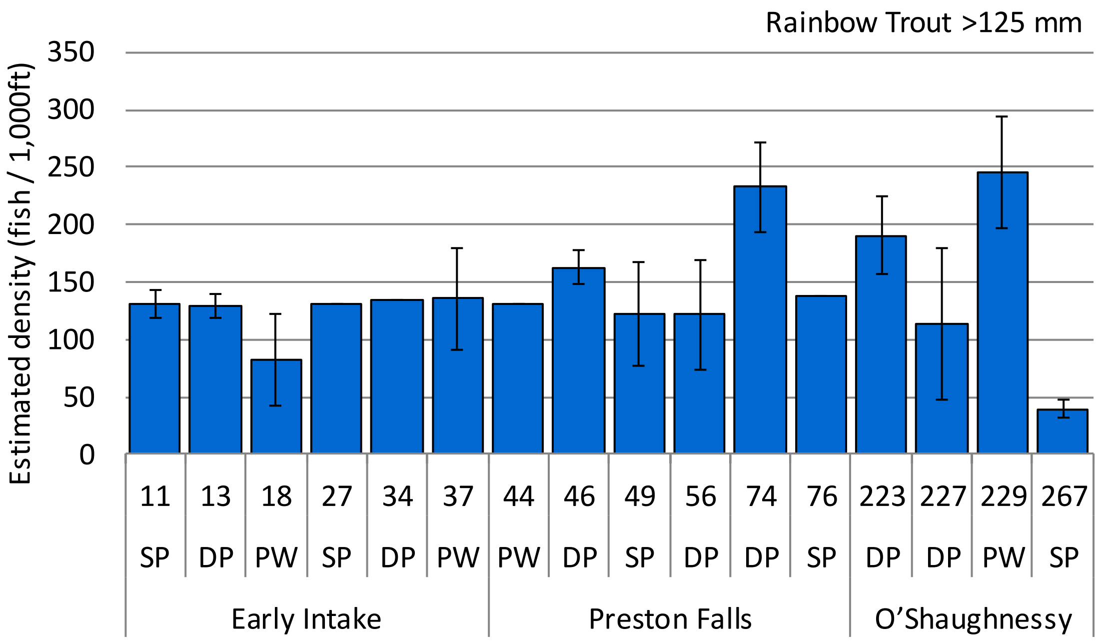

Figure 12. Estimated linear density of Rainbow Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

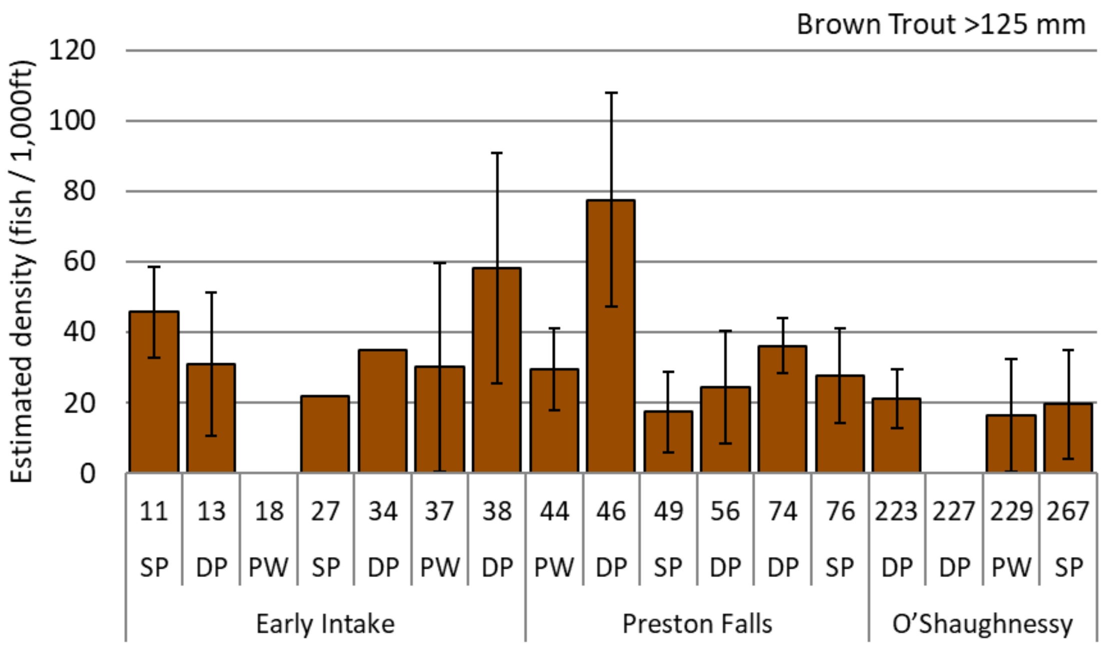

Figure 13. Estimated linear density of Brown Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.) No Brown Trout >125 mm were observed at sites 18-PW and 227-DP in 2016.

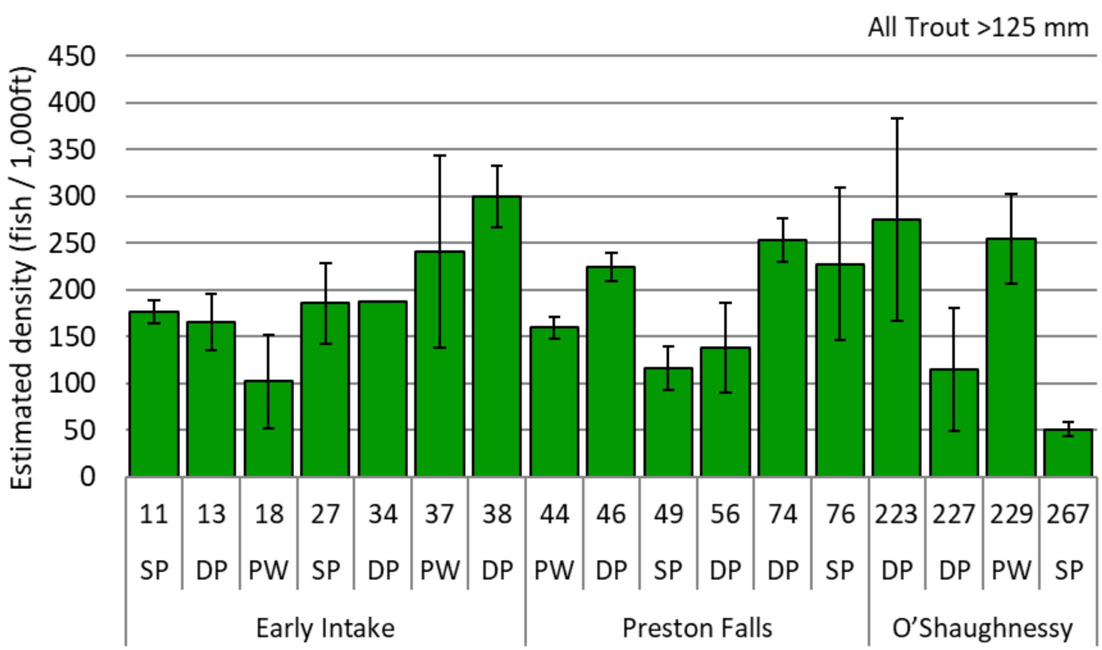

Figure 14. Estimated linear density (fish/1,000 feet) of both Rainbow and Brown Trout >125 mm by sub-reach and site in the Hetch Hetchy Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

Trout ≤125 mm

The 2016 fish population monitoring results for the density of trout ≤125 mm indicate that Rainbow and Brown Trout recruitment was highly variable by site, with greater overall recruitment of Rainbow Trout compared with Brown Trout (Tables 21–23, Figures 15 and 16). Rainbow Trout ≤125 mm were observed at all monitoring sites in 2016. Brown Trout ≤125 mm were observed at all monitoring sites except for two sites in the O'Shaughnessy sub-reach and two sites in the Early Intake sub-reach (Table 21, Figure 16). Densities of Rainbow and Brown Trout ≤125 mm were greatest in the Preston Falls sub-reach and lowest in the O'Shaughnessy sub-reach (Table 22). Rainbow Trout density was greatest at site 229-PW (147 fish/1,000 feet) and Brown Trout density was greatest at site 76-SP (55 fish/1,000 feet).

Table 21. Abundance estimates for Rainbow and Brown Trout ≤125 mm by site in the Hetch Hetchy Reach in 2016 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)		
		Rainbow	Brown	All trout
Early Intake sub-reach				
11-SP	shallow pool	15 (±8)	1 (±0)	16 (±8)
13-DP	deep pool	8 (±6)	4 (±4)	12 (±10)
18-PW	pocketwater	12 (±4)	1 (±0)	13 (±4)
27-SP	shallow pool	10 (±2)	1 (±0)	11 (±2)
34-DP[1]	deep pool	2	5	7
37-PW	pocketwater	11 (±8)	0 (±0)	11 (±8)
38-DP	deep pool	6 (±4)	0 (±0)	7 (±4)
Preston Falls sub-reach				
44-PW	pocketwater	7 (±0)	1 (±0)	10 (±2)
46-DP	deep pool	12 (±6)	3 (±0)	15 (±6)
49-SP	shallow pool	20 (±2)	8 (±4)	29 (±4)
56-DP	deep pool	17 (±12)	4 (±4)	23 (±18)
74-DP	deep pool	19 (±4)	6 (±2)	24 (±4)
76-DP	shallow pool	9 (±4)	8 (±6)	11 (±0)
O'Shaughnessy sub-reach				
223-DP	deep pool	2 (±0)	0 (±0)	2 (±0)
227-DP	deep pool	8 (±2)	0 (±0)	8 (±2)
229-PW	pocketwater	18 (±8)	5 (±4)	17 (±4)
267-SP	shallow pool	4 (±2)	1 (±0)	4 (±0)

[1] Habitats sampled with a single-pass.

Table 22. Abundance estimates for Rainbow and Brown Trout ≤125 mm by sub-reach in the Hetch Hetchy Reach in 2016 (95 percent CI).

Sub-reach	Trout ≤125 mm (age-0)		
	Rainbow	**Brown**	**All trout**
Early Intake	64 (±14)	12 (±4)	77 (±16)
Preston Falls	84 (±14)	30 (±8)	112 (±20)
O'Shaughnessy	32 (±8)	6 (±4)	31 (±4)
Total	180 (±22)	48 (±10)	220 (±26)

Table 23. Abundance estimates for Rainbow and Brown Trout ≤125 mm by habitat type in the Hetch Hetchy Reach in 2016 (95 percent CI).

Habitat type	Trout ≤125 mm (age-0)		
	Rainbow	**Brown**	**All trout**
Shallow pool	58 (±9)	19 (±7)	71 (±9)
Deep pool	74 (±16)	22 (±6)	98 (±22)
Pocketwater	48 (±12)	7 (±4)	51 (±10)
Total	180 (±22)	48 (±10)	220 (±26)

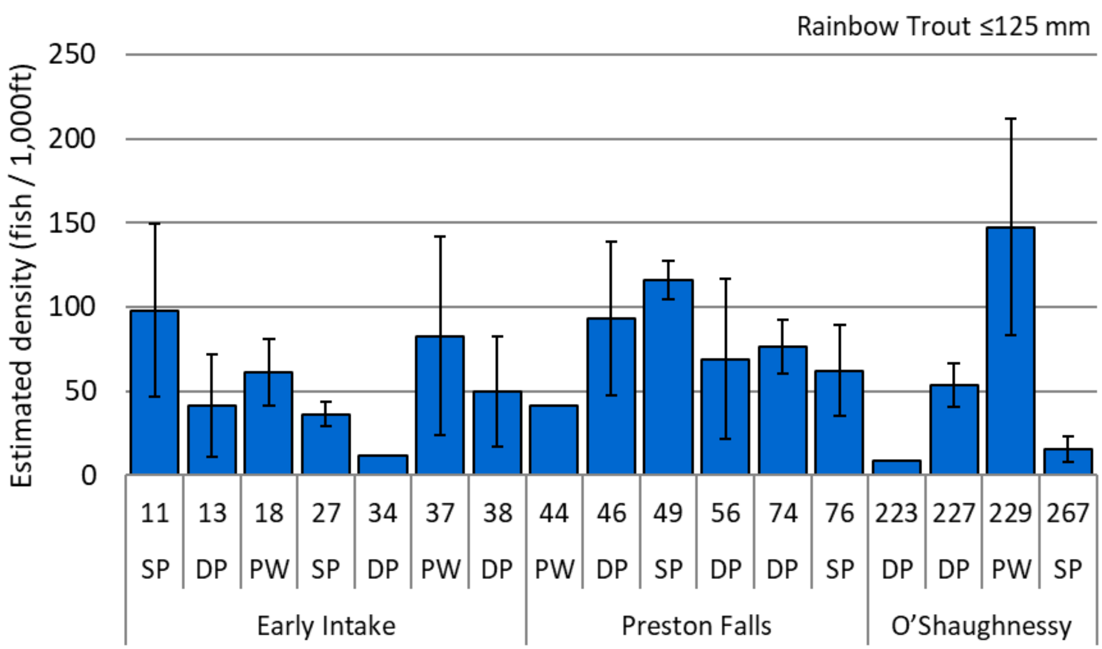

Figure 15. Estimated linear density (fish/1,000 feet) of Rainbow Trout ≤125 mm by sub-reach and site in the Hetch Hetchy Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

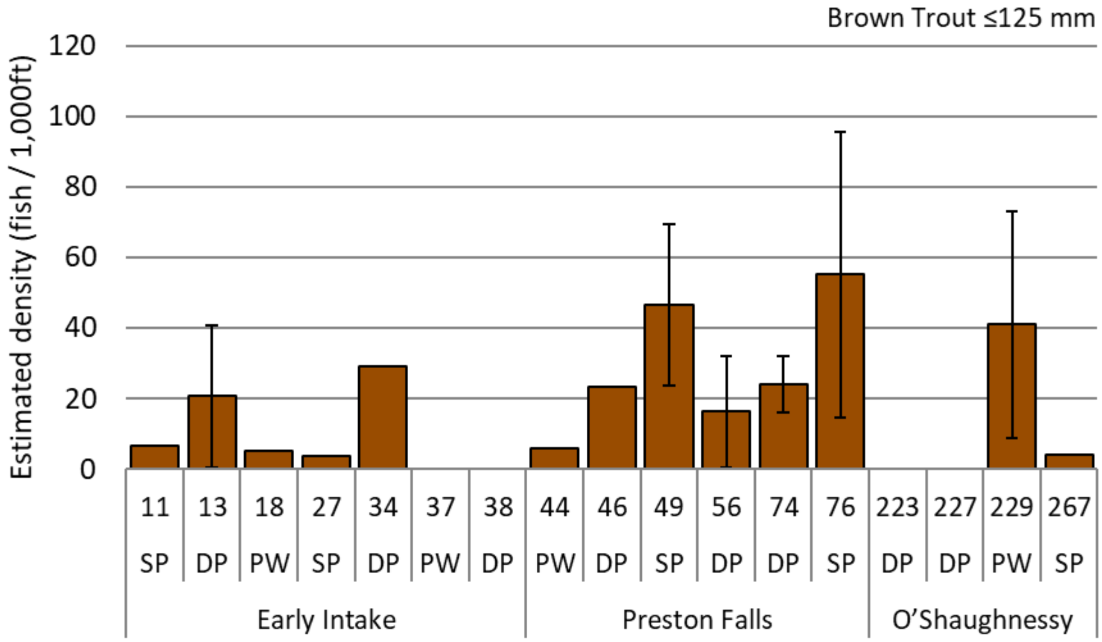

Figure 16. Estimated linear density (fish/1,000 feet) of Brown Trout ≤125 mm by sub-reach and site in the Hetch Hetchy Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

6.2.1.3 Reach-level comparisons of 2014-2016 results in Hetch Hetchy Reach

To assess whether potentially meaningful changes or trends in trout population abundance are evident, comparisons of trout density were evaluated at the sub-reach scale based on 2014–2016 monitoring data. Two-sample t-tests were used to assess whether differences in abundance were statistically significant at a p-value ≤0.05. Site 38-DP was not included in the year-to-year comparisons presented in this section, since it was only surveyed in 2016 and likely will not be monitored in the future.

Trout >125 mm

Rainbow Trout densities in the Early Intake and O'Shaughnessy sub-reaches both show a decrease from 2014 to 2015 and an increase from 2015 to 2016, with 2015 having a significantly lower density compared with 2014 and 2016 (Figure 17). Rainbow Trout densities in the Early Intake and Preston Falls sub-reaches were highest in 2014 and highest in the O'Shaughnessy sub-reaches in 2016. Rainbow Trout density in the Preston Falls sub-reach shows a declining trend from 2014 to 2016, but density in this sub-reach was relatively high compared with the other sub-reaches. Overall, Rainbow Trout density was greatest in 2014, largely due to the influence of high density in the Preston Falls sub-reach.

Brown Trout densities in the Early Intake and O'Shaughnessy sub-reaches show a similar trend to that of Rainbow Trout, with the lowest densities in 2015 (Figure 18). In contrast, Brown Trout density in the Preston Falls sub-reach was greatest in 2015, which was the highest Brown Trout density observed for a sub-reach during the 2014–2016 monitoring period. Total Brown Trout densities show a similar pattern to the Preston Falls sub-reach due to the relatively high density in this sub-reach compared with the other sub-reaches.

Densities for all trout show a similar pattern to those for Rainbow Trout, with similar relationships in the Early Intake and O'Shaughnessy sub-reaches and a declining trend over the three-year monitoring period for the Preston Falls sub-reach (Figure 18).

T-test results indicate numerous year-to-year differences that are statistically significant (Table 24) and suggest that trout populations are highly variable annually. The extent to which differences in abundance may be influenced by differences in annual rainfall, summer water temperature, and recovery from the Rim Fire will be evaluated as more years of monitoring data become available.

In 2014 and 2015, sites 46-DP and 49-SP, and to a lesser degree site 44-PW, were observed to be particularly affected by coarse sediment (i.e., sand and small gravel) supplied to the Preston Falls sub-reach through erosion after the Rim Fire. Pool site 46-DP was filled and could no longer be considered a "deep" pool. Relatively low streamflow resulting from the extended drought did not change sediment conditions substantially from 2014 to 2015. Monitoring in 2016 revealed considerable scour of the sediment-filled site 46-DP, returning it to a deep pool habitat. In shallow pool 49-SP, sediment from a small tributary entering upstream from the north, formed a large alluvial delta fan deposit from 2014 to 2015. The alluvial fan deposit was scoured from high flows during 2016, creating additional depth and improving fish habitat within the site. These sites will continue to be of interest for understanding the effects of the Rim Fire on fish habitat in the reach, the evolution and longevity of the impact, and the effect on fish populations.

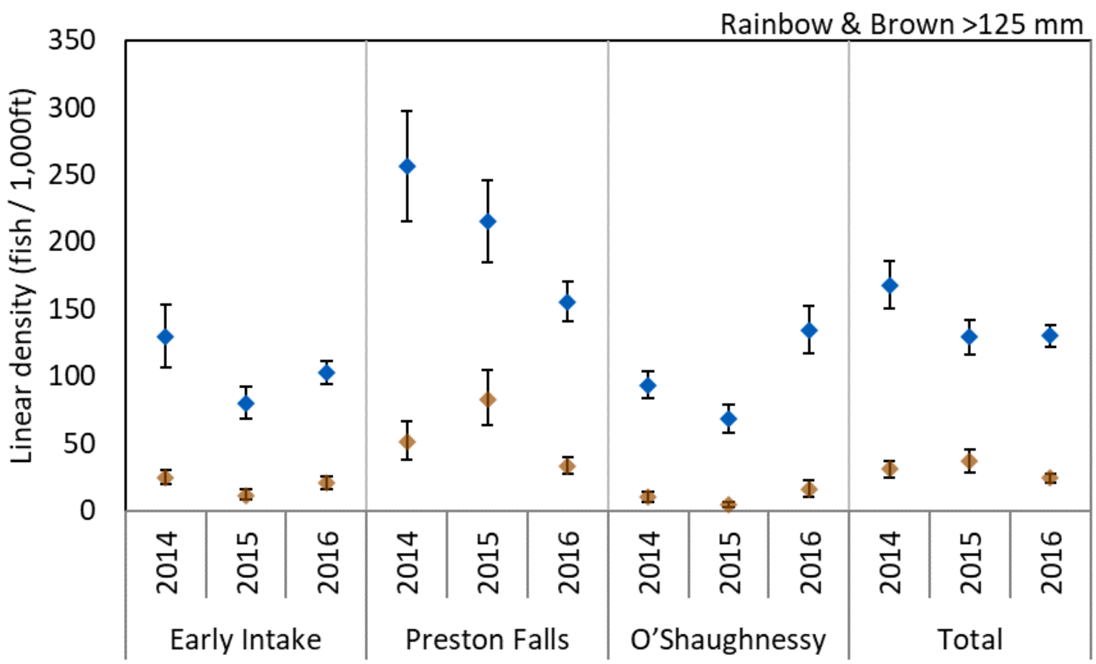

Figure 17. Estimated linear density of Rainbow (blue) and Brown (brown) Trout >125 mm by sub-reach in the Hetch Hetchy Reach for monitoring years 2014–2016. (Error bars indicate 95 percent CI.)

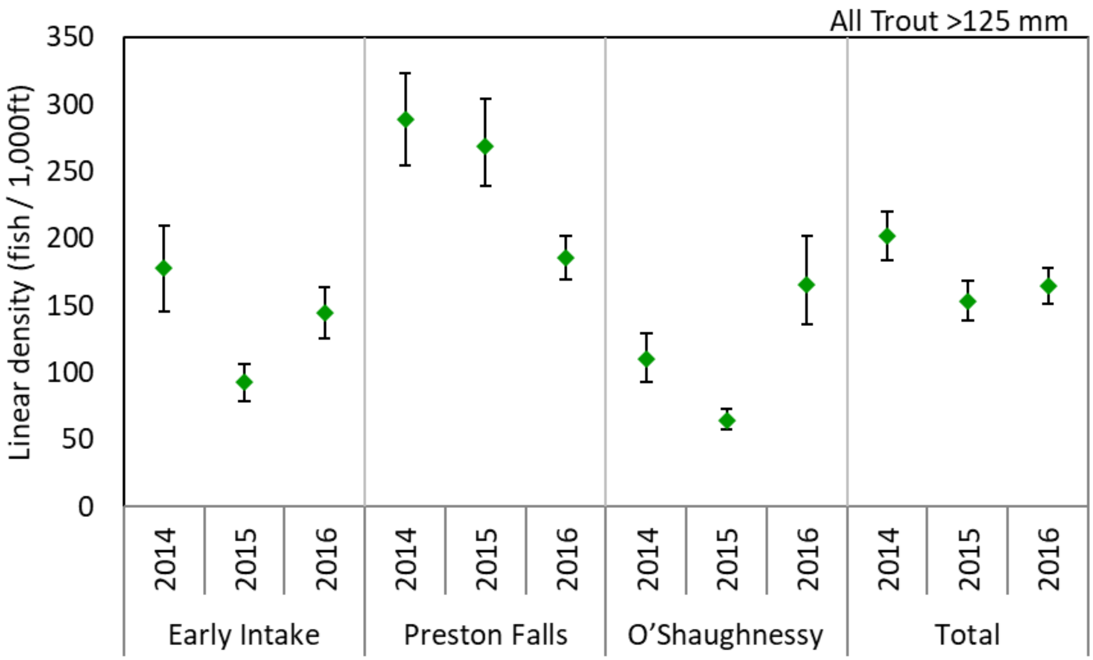

Figure 18. Estimated linear density of Rainbow and Brown Trout >125 mm combined by sub-reach in the Hetch Hetchy Reach for monitoring years 2014–2016. (Error bars indicate 95 percent CI.)

Table 24. T-test results (p-values) comparing 2014-2016 estimated density for Rainbow and Brown Trout >125 mm by sub-reach. Significant values (p-value ≤0.05) are marked with an asterisk (*).

Sub-reach	Comparison	Rainbow	Brown	All trout
Early Intake	2014 vs. 2015	0.0077*	0.0037*	0.0030*
	2014 vs. 2016	0.16	0.49	0.24
	2015 vs. 2016	0.0055*	0.016*	0.0013*
Preston Falls	2014 vs. 2015	0.15	0.053	0.44
	2014 vs. 2016	0.0031*	0.075	<0.001*
	2015 vs. 2016	0.0079*	0.0081*	0.0044*
O'Shaughnessy	2014 vs. 2015	0.0071*	0.067	0.0078*
	2014 vs. 2016	0.031*	0.24	0.084
	2015 vs. 2016	0.0036*	0.042*	0.013*
Total	2014 vs. 2015	<0.001*	0.31	<0.001*
	2014 vs. 2016	<0.001*	0.083	0.0028*
	2015 vs. 2016	0.70	0.017*	0.17

Trout ≤125 mm

The density of trout ≤125 mm provides insight into annual spawning success and recruitment of age-0 Rainbow and Brown Trout (Figure 19). Over the three-year monitoring period (2014–2016), Rainbow and Brown Trout densities in the Early Intake and O'Shaughnessy sub-reaches were highest in 2014, and Rainbow and Brown Trout densities in the Preston Falls sub-reach were highest in 2015. In 2014 and 2015, Rainbow Trout densities in the Preston Falls sub-reach were significantly higher compared with densities the Early Intake and O'Shaughnessy sub-reaches. Rainbow Trout densities were notably low (<25 fish/1,000 feet) in the O'Shaughnessy sub-reach in 2015 (Figure 19). No Brown Trout ≤125 mm were observed in the O'Shaughnessy sub-reach in 2015 (Figure 19).

Within each sub-reach, densities of Rainbow and Brown Trout ≤125 mm generally show similar relative patterns over the three-year monitoring period, indicating Rainbow and Brown Trout ≤125 mm are responding similarly to environmental pressures within each sub-reach. However, relative density patterns are different for each sub-reach, suggesting that there are important differences in habitat quality and/or quantity between the sub-reaches.

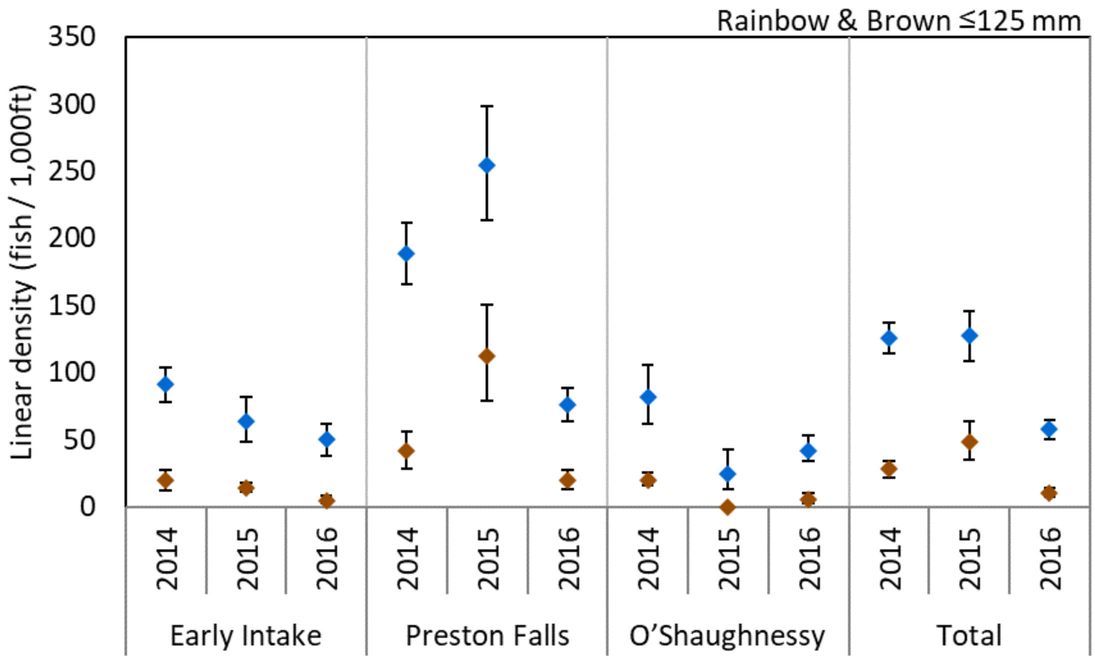

Figure 19. Estimated linear density of Rainbow (blue) and Brown (green) Trout ≤125 mm by sub-reach in the Hetch Hetchy Reach for monitoring years 2014-2016. (Error bars indicate 95 percent CI.)

6.2.1.4 Comparisons with Hetch Hetchy Reach survey data from previous years

Reach-level monitoring results for 2014–2016 were compared with snorkel surveys performed by the SFPUC annually from 2007 to 2012 (SFPUC, unpublished data) in the Hetch Hetchy Reach to assess whether notable differences were evident. It is important to note that sampling locations differed between 2014–2016 and previous (2007–2012) surveys, but snorkel methods were similar. Modifications to the sampling approach that were first applied in 2014 were intended to focus sampling in locations expected to provide "good" habitat conditions for trout and where sampling would be efficient and effective. In application, these modifications resulted in selecting habitats with relatively high complexity compared with previous survey sites and that are expected to have higher densities at specific sites and overall. Applying the site selection criteria used during 2014–2016 to sites sampled during 2007–2012, would exclude a portion of the sites. For comparisons between 2007–2012 and 2014–2016, we investigated using only those 2007–2012 monitoring sites that would meet the revised site selection criteria used for 2014–2016. However, only 3 of the 10 sites would meet the initial (pre-field reconnaissance) criteria, and the resulting small sample size appeared to lead to substantially increased variability. Therefore, comparisons are made using all 10 sites that were sampled during 2007–2012. Snorkeling surveys were not completed in 2013 due to the Rim Fire. The Poopenaut Valley Reach was not included in the current monitoring approach, therefore results from previous surveys of this sub-reach are not reported. Results are expressed as linear densities to account for differences in the number and location of sites sampled.

Trout >125 mm

Comparisons of 2007–2012 and 2014–2016 monitoring data for trout >125 mm are presented below by sub-reach (Figures 20–22). For the Early Intake sub-reach, Rainbow Trout density during previous surveys (2007–2012) were generally within the range of densities observed during 2014–2016, with the exception of 2007, which had substantially lower density compared with other years (Figure 20). Brown Trout densities in the Early Intake sub-reach during 2014–2016 surveys were within the range of densities observed during 2007–2012 surveys. Brown trout density in 2007 was substantially lower compared with other years. The ratio of Rainbow Trout to Brown Trout during 2014–2016 was greater than observed during 2007–2012.

For the Preston Falls sub-reach, Rainbow Trout densities were substantially higher during 2014–2016 compared with 2007–2012 (Figure 21). Brown Trout densities during 2014 and 2016 were within the range of densities observed during 2007–2012, with densities in 2015 being notably higher. The ratio of Rainbow Trout to Brown Trout during 2014–2016 was substantially greater than observed during 2007–2012.

For the O’Shaughnessy sub-reach, Rainbow Trout densities during 2014–2016 were generally higher than observed in 2007–2012 (Figure 22). As observed in the other sub-reaches, Brown Trout densities during 2014–2016 were generally within the range of densities observed during 2007–2012. The ratio of Rainbow Trout to Brown Trout in the O’Shaughnessy sub-reach was relatively high during 2014–2016 monitoring compared with 2007–2012, except for 2010, when no Brown Trout were observed in the sub-reach.

Notable differences between the 2014–2016 and 2007–2012 sampling periods such as those observed in the Preston Falls sub-reach for Rainbow Trout >125 mm are likely the result of differences in the habitat characteristics of the sites sampled. However, similarities in Brown Trout densities between the 2014–2016 and 2007–2012 sampling periods may indicate that the two species utilize available habitats differently.

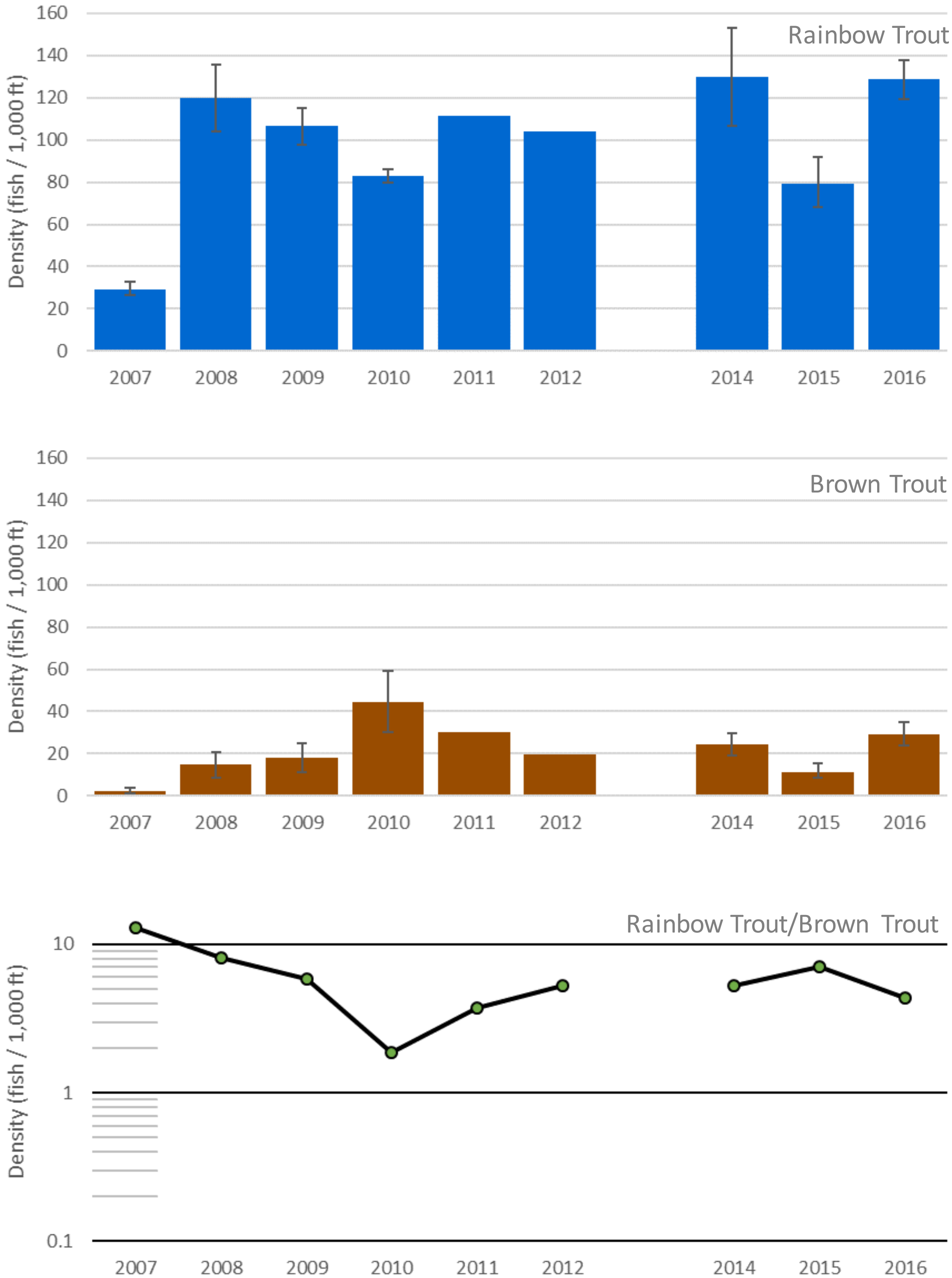

Figure 20. Estimated linear density and relative species composition of Rainbow and Brown Trout >125 mm in Early Intake sub-reach. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

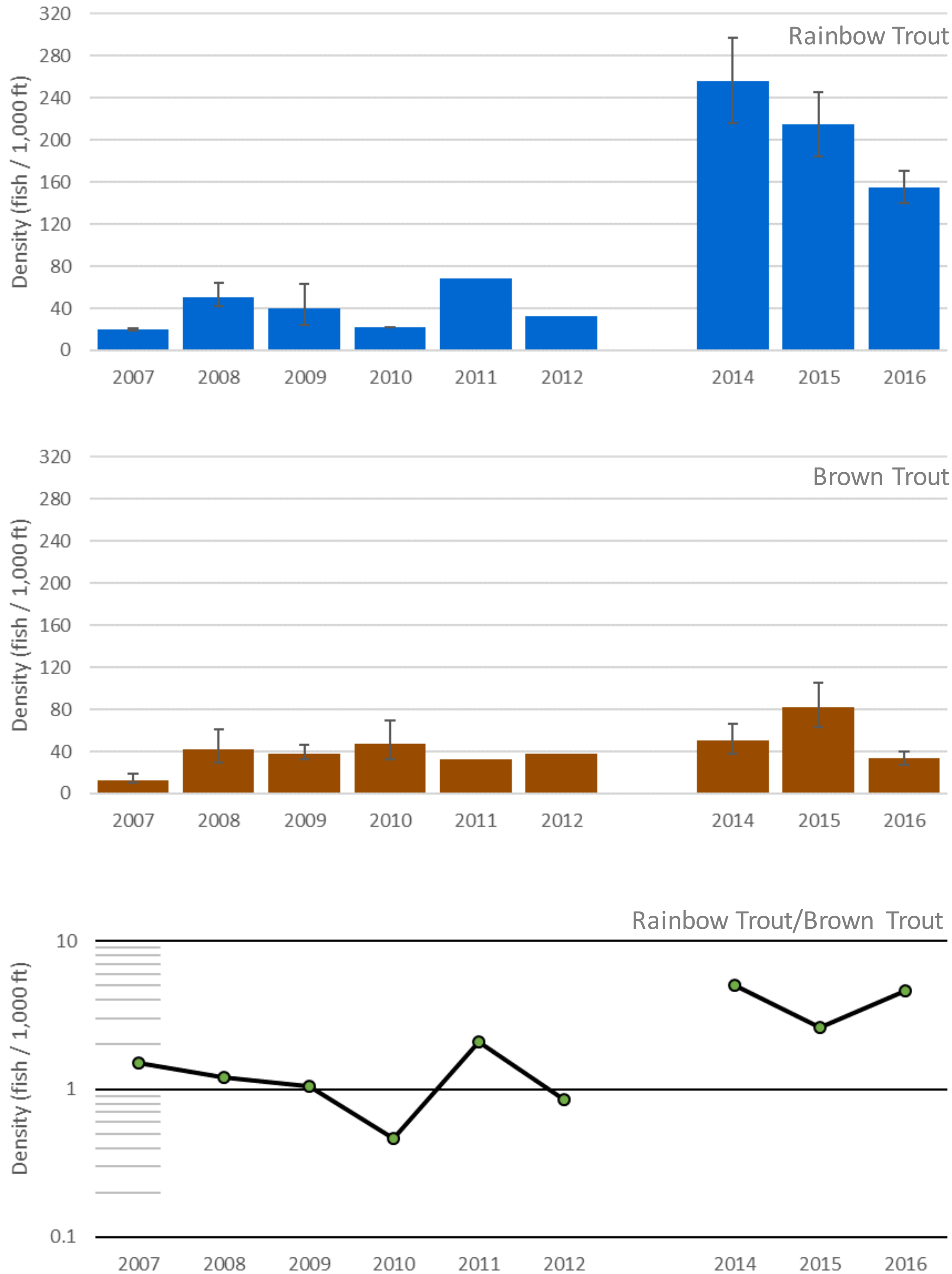

Figure 21. Estimated linear density and relative species composition of Rainbow and Brown Trout >125 mm in Preston Falls sub-reach. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

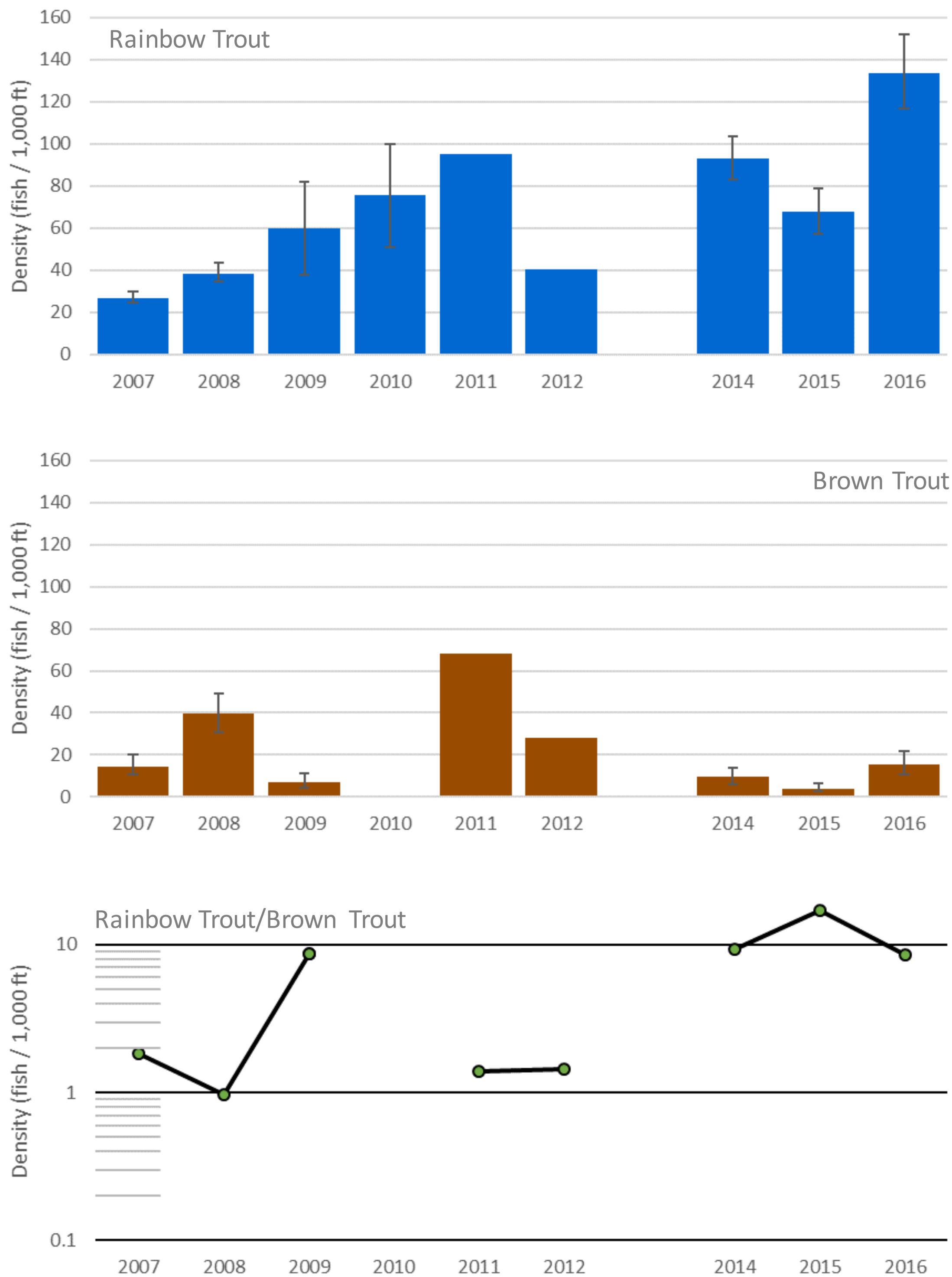

Figure 22. Estimated linear density and relative species composition of Rainbow and Brown Trout >125 mm in O'Shaughnessy sub-reach. Note that no Brown Trout were observed in 2010, and therefore a ratio cannot be calculated. A value of "50" was used to represent a high proportion of Rainbow Trout. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

Trout ≤125 mm

Comparisons of 2007–2012 and 2014–2016 monitoring data for trout ≤125 mm are presented below by sub-reach (Figures 23–25).

For the Early Intake sub-reach, Rainbow Trout densities during 2014–2016 were generally similar to densities observed during previous surveys (2007–2012) (Figure 23). Brown Trout densities in the Early Intake sub-reach during 2014–2016 surveys were within the range of densities observed during 2007–2012 surveys. No Brown Trout ≤125 mm were observed in the Early Intake sub-reach in 2007. The density of Rainbow Trout ≤125 mm was greater than Brown Trout ≤125 mm in all years. The ratio of Rainbow Trout to Brown Trout ≤125 mm during 2014–2016 was relatively stable compared with 2007–2012.

For the Preston Falls sub-reach, densities of Rainbow Trout ≤125 mm were notably higher during 2014–2016 compared with 2007–2012 (Figure 24). Densities of Brown Trout ≤125 mm were variable annually during 2014–2016 and 2007–2012. The density of Brown Trout ≤125 mm was greater than Rainbow Trout in 2008–2010. The ratio of Rainbow Trout to Brown Trout ≤125 mm during 2014–2016 was relatively stable compared with 2007–2012.

For the O'Shaughnessy sub-reach, densities of Rainbow and Brown Trout ≤125 mm were annually highly variable during 2014–2016 and 2007–2012 (Figure 25). No Brown Trout ≤125 mm were observed in the O'Shaughnessy sub-reach during 2010 and 2015. The density of Brown Trout ≤125 mm was greater than the density of Rainbow Trout ≤125 mm in 2007, 2008, and 2012. The ratio of Rainbow Trout to Brown Trout ≤125 mm in the O'Shaughnessy sub-reach was highly variable annually during 2014–2016 and 2007–2012.

In general and as expected, densities of Rainbow and Brown Trout ≤125 mm are more variable annually compared with Rainbow and Brown Trout >125 mm.

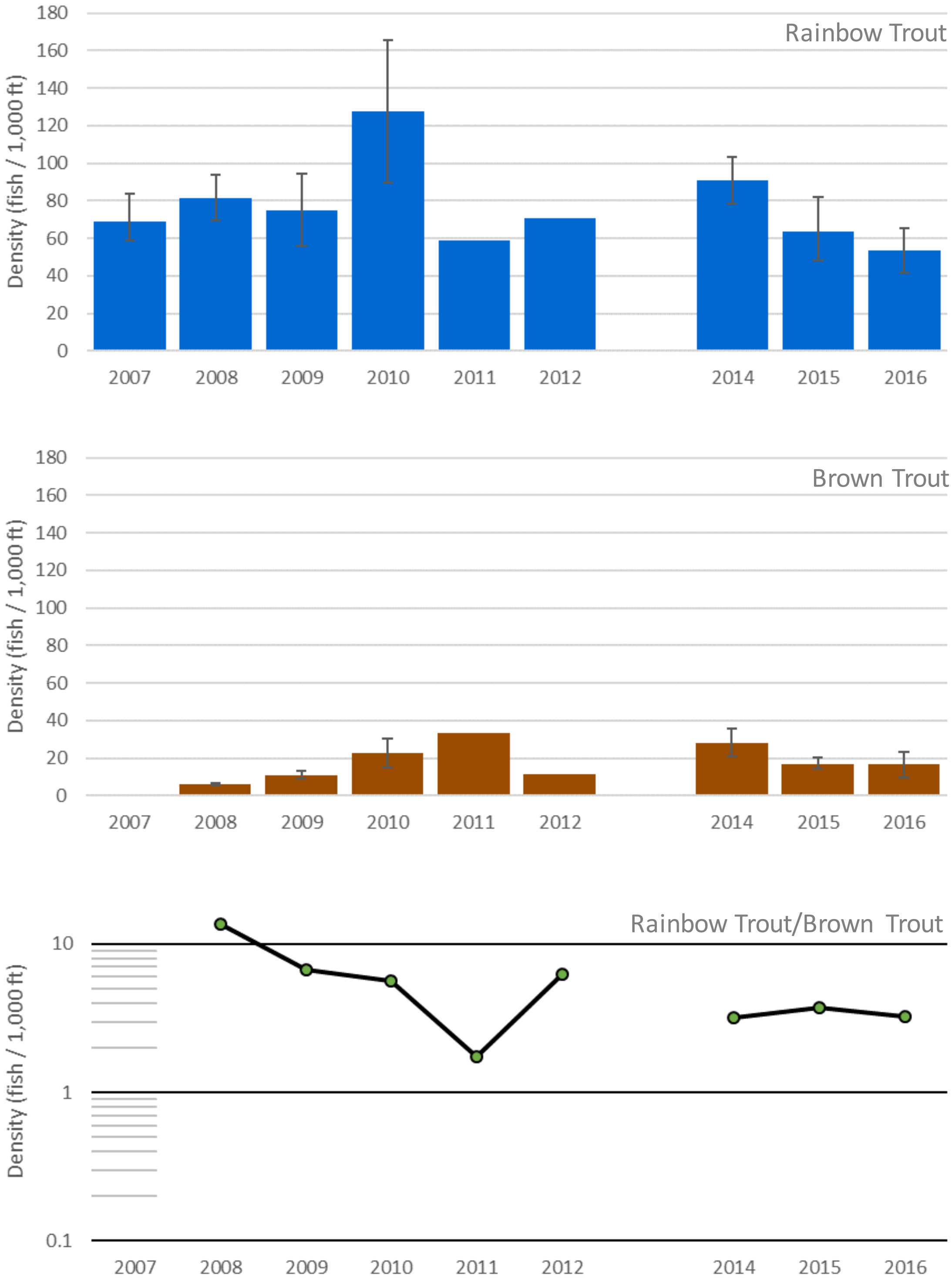

Figure 23. Estimated linear density and relative species composition of Rainbow and Brown Trout ≤125 mm in Early Intake sub-reach. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

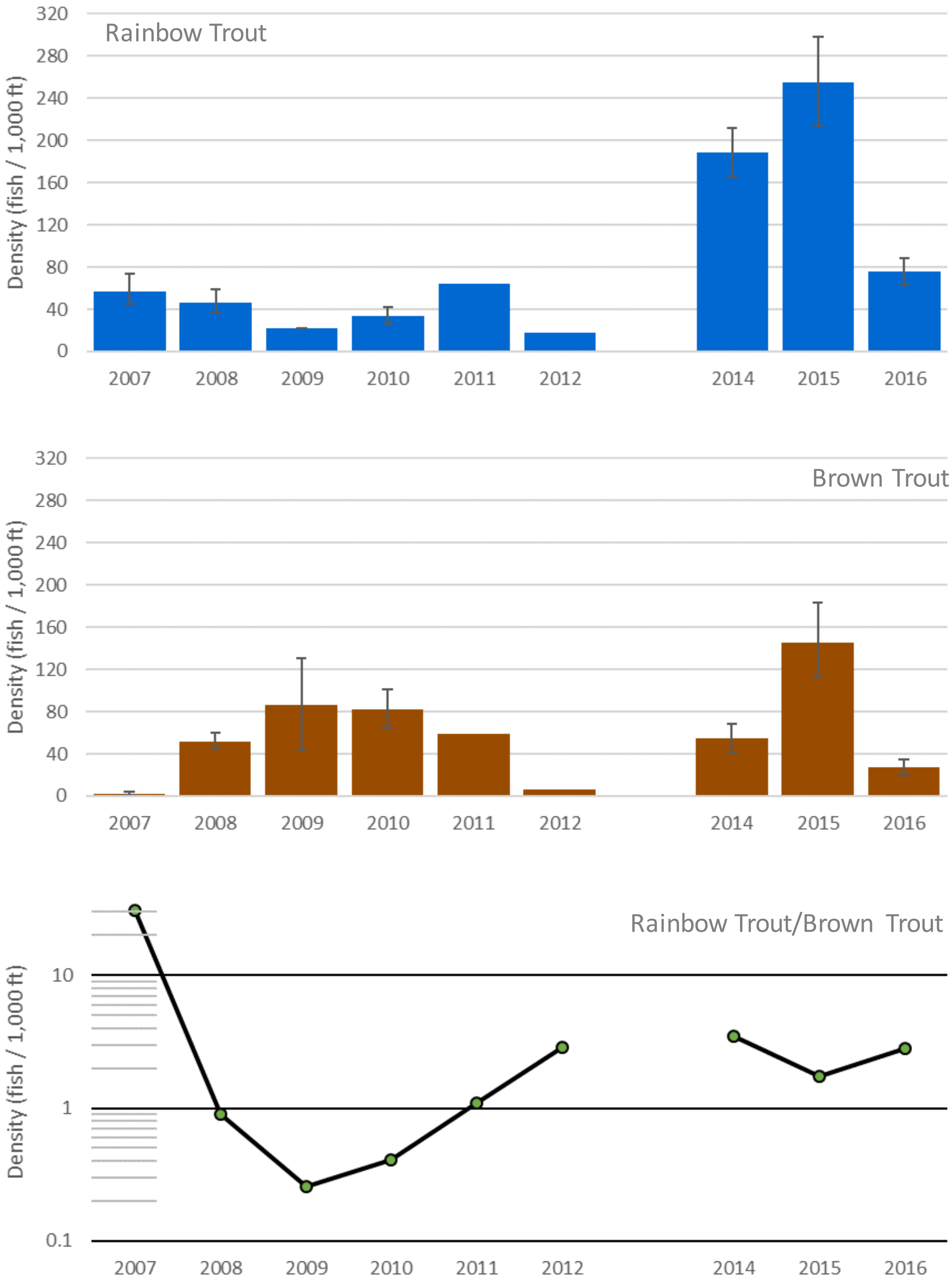

Figure 24. Estimated linear density and relative species composition of Rainbow and Brown Trout ≤125 mm in Preston Falls sub-reach. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

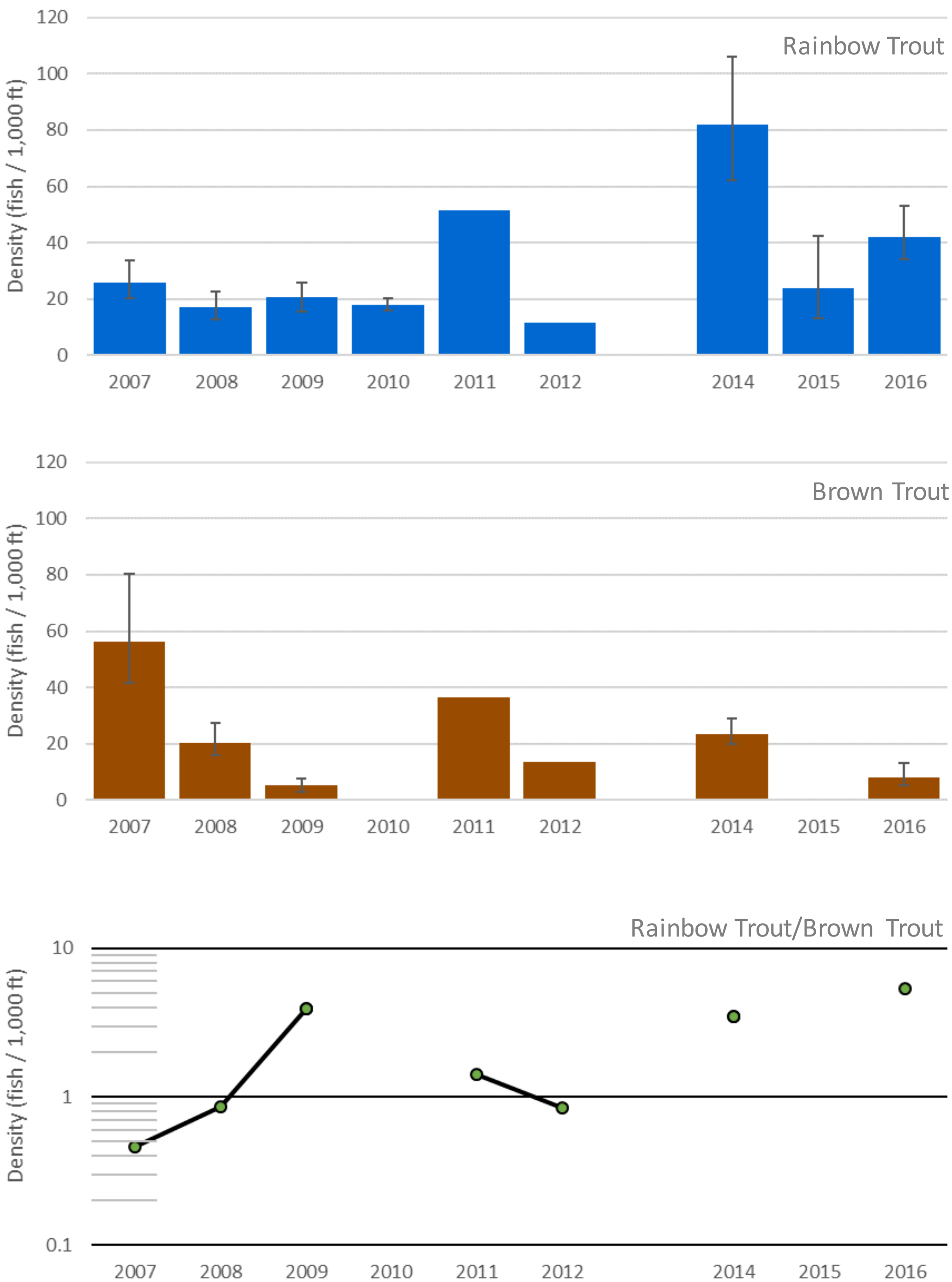

Figure 25. Estimated linear density and relative species composition of Rainbow and Brown Trout ≤125 mm in O'Shaughnessy sub-reach. Note that no Brown Trout were observed in 2010, and therefore a ratio cannot be calculated. A value of "50" was used to represent a high proportion of Rainbow Trout. Monitoring years 2011 and 2012 were single pass dives, therefore no error bars are included.

6.2.2 Above Hetch Hetchy Reservoir Reach

Trout >125 mm

For the Above Hetch Hetchy Reservoir Reach, abundance of Rainbow Trout >125 mm ranged from 1 trout at site 510-PW to 26 trout at site 514-DP (Table 25). Brown Trout >125 mm were observed at one of the four monitoring sites (511-SP) sampled in the Above Hetch Hetchy Reservoir Reach during 2016. The density of Rainbow Trout >125 mm ranged from 10 to 140 fish/1,000 feet and averaged 84 fish/1,000 feet (Table 26). Brown trout density was 14 fish/1,000 feet at site 511-SP (Table 26).

Table 25. Abundance estimates for Rainbow and Brown Trout >125 mm by site in the Above Hetch Hetchy Reach in 2016 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow	Brown	All trout
507-SP[1]	shallow pool	9	0	9
510-PW	pocketwater	1 (±0)	0 (±0)	1 (±0)
511-SP	shallow pool	16 (±6)	2 (±2)	15 (±4)
514-DP	deep pool	26 (±2)	0 (±0)	28 (±4)

[1] Habitats sampled with a single-pass.

Table 26. Linear density (fish/1,000 feet) estimates for Rainbow and Brown Trout >125 mm by site in the Above Hetch Hetchy Reach in 2016.

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow	Brown	All trout
507-SP[1]	shallow pool	68	0	68
510-PW	pocketwater	10	0	10
511-SP	shallow pool	116	14	109
514-DP	deep pool	140	0	151

[1] Habitats sampled with a single-pass.

Trout ≤125 mm

For the Above Hetch Hetchy Reservoir Reach, abundance of Rainbow Trout ≤125 mm ranged from 4 trout at site 510-PW and 514-DP to 7 trout at site 511-SP. Brown Trout ≤125 mm were observed at one of the four monitoring sites (510-PW) sampled in the Above Hetch Hetchy Reservoir Reach during 2016. The density of Rainbow Trout ≤125 mm ranged from 22 to 51 fish/1,000 feet and averaged 37 fish/1,000 feet (Table 27). Age-0 Brown Trout density was 19 fish/1,000 feet at site 510-PW (Table 28).

Table 27. Abundance estimates for Rainbow and Brown Trout ≤125 mm by site in the Above Hetch Hetchy Reach in 2016 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)		
		Rainbow	Brown	All trout
507-SP[1]	shallow pool	5	0	5
510-PW	pocketwater	4 (±2)	2 (±2)	6 (±4)
511-SP	shallow pool	7 (±4)	0 (±0)	9 (±6)
514-DP	deep pool	4 (±2)	0 (±0)	4 (±2)

[1] Habitats sampled with a single-pass.

Table 28. Linear density (fish/1,000 feet) estimates for Rainbow and Brown Trout ≤125 mm by site in the Above Hetch Hetchy Reach in 2016.

Site	Habitat type	Trout ≤125 mm (age-0)		
		Rainbow	Brown	All trout
507-SP[1]	shallow pool	38	0	38
510-PW	pocketwater	38	19	57
511-SP	shallow pool	51	0	65
514-DP	deep pool	22	0	22

[1] Habitats sampled with a single-pass.

6.2.3 Cherry Creek Reach

The 2012 and 2016 fish population monitoring results for trout abundance and linear density in Cherry Creek are presented below for Rainbow Trout >125 mm and ≤125 mm. Rainbow Trout were the only trout species observed in Cherry Creek in 2012 and 2016.

6.2.3.1 2012 monitoring in Cherry Creek Reach

Trout >125 mm

Total trout abundance estimates for all sites combined in 2012 were 192 for Rainbow Trout >125 mm, with the greatest abundance occurring in the Lower Cherry sub-reach (Table 29). There were no Rainbow Trout >125 mm observed in the Upper Cherry sub-reach in 2012 (Table 30). Abundance estimates for Rainbow Trout >125 mm among monitoring sites in the Lower Cherry sub-reach ranged from 18 trout at site 40-SP to 59 trout at site 274-BG (Table 30). Abundance of Rainbow Trout >125 mm was greatest in deep pool habitat (Table 31). Note that confidence intervals are not reported since one-pass sampling methods were used.

In 2012, estimated linear densities of Rainbow Trout >125 mm in the Lower Cherry sub-reach ranged from 99 fish/1,000 feet at site 270-DP to 280 fish/1,000 feet at site 40-SP (Figure 26). Rainbow Trout > 125 mm were not observed at sampling sites in the Upper Cherry sub-reach in 2012. In contrast, the average density of Rainbow Trout at sampling sites in the Lower Cherry sub-reach was 180 fish/1,000 feet during 2012, a substantially higher density compared with 2016.

Table 29. Abundance estimates for Rainbow Trout >125 mm by sub-reach in the Cherry Creek Reach in 2012.

Sub-reach	Trout >125 mm (age-1 and older)
Upper Cherry sub-reach	0
Lower Cherry sub-reach	192
Total	192

Table 30. Abundance estimates for Rainbow Trout >125 mm by site in Cherry Creek Reach in 2012.

Site	Habitat type	Trout >125 mm (age-1 and older)
Upper Cherry sub-reach		
SP 396	shallow pool	0
SP 394	shallow pool	0
SP 278, SP 276	shallow pool	0
Lower Cherry sub-reach		
BG 274	boulder garden	59
DP 270	deep pool	28
DP 135	deep pool	19
DP 131	deep pool	26
SP 45	shallow pool	42
SP 40	shallow pool	18

Table 31. Abundance estimates for Rainbow Trout >125 mm by habitat type in the Cherry Creek Reach in 2012.

Habitat	Trout >125 mm (age-1 and older)
Shallow pool	60
Deep pool	73
Boulder garden	59
Total	192

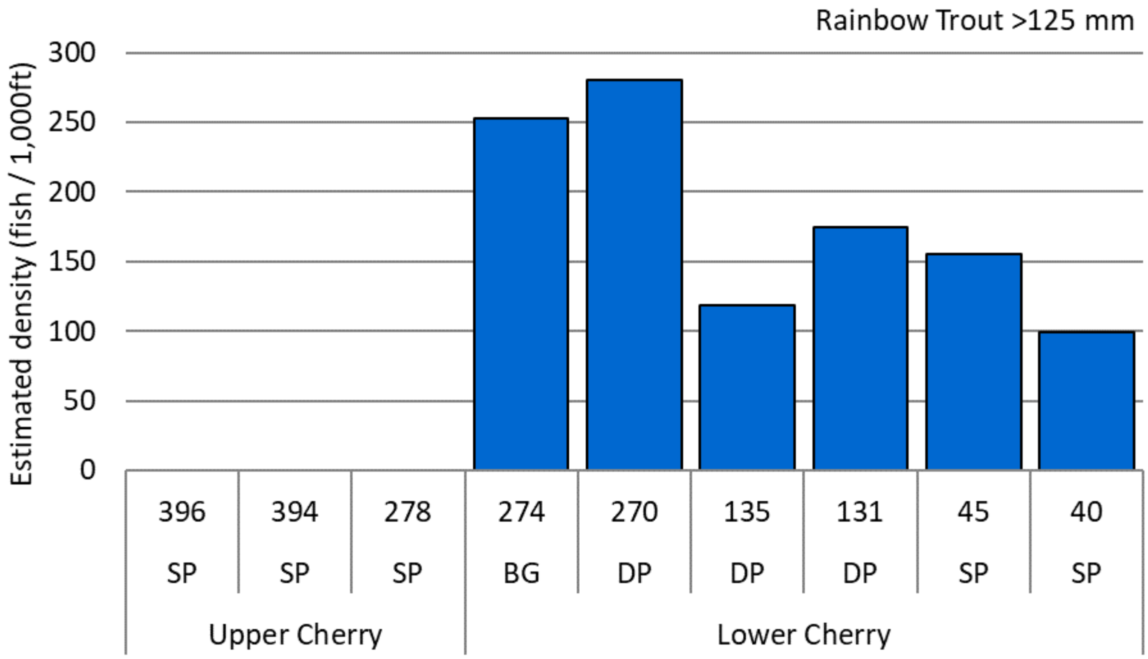

Figure 26. Estimated linear density of Rainbow Trout >125 mm by sub-reach and site in the Cherry Creek Reach in 2012. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden.)

Trout ≤125 mm

Total trout abundance estimates for all sites combined in 2012 were 384 for Rainbow Trout ≤125 mm, with the greatest abundance occurring in the Lower Cherry sub-reach (Table 32). Abundance estimates for Rainbow Trout ≤125 mm among monitoring sites ranged from 0 trout at site 394-SP to 119 trout at site 278-SP (Table 33). Abundance of Rainbow Trout ≤125 mm was greatest in shallow pool habitat (Table 34). Note that confidence intervals are not reported since one-pass sampling methods were used.

Estimated linear density of Rainbow Trout ≤125 mm ranged from 0 fish/1,000 feet at site 394-SP to 613 fish/1,000 feet at site 278-SP (Figure 27). Average linear density was slightly greater for the Lower Cherry sub-reach (223 fish/1,000 feet) compared with the Upper Cherry sub-reach (211 fish/1,000 feet). The greatest density of Rainbow Trout observed in 2012 was at sites near the confluence with Eleanor Creek, which was similar to where the greatest density of Rainbow Trout were observed in 2016.

Table 32. Abundance estimates for Rainbow Trout ≤125 mm by sub-reach in the Cherry Creek Reach in 2012.

Sub-reach	Trout ≤125 mm (age-0)
Upper Cherry sub-reach	120
Lower Cherry sub-reach	264
Total	384

Table 33. Abundance estimates for Rainbow Trout ≤125 mm by site in the Cherry Creek Reach in 2012.

Site	Habitat type	Trout ≤125 mm (age-0)
Upper Cherry sub-reach		
SP 396	shallow pool	1
SP 394	shallow pool	0
SP 278, SP 276	shallow pool	119
Lower Cherry sub-reach		
BG 274	boulder garden	72
DP 270	deep pool	16
DP 135	deep pool	37
DP 131	deep pool	8
SP 45	shallow pool	77
SP 40	shallow pool	54

Table 34. Abundance estimates for Rainbow Trout ≤125 mm by habitat type in the Cherry Creek Reach in 2012.

Habitat	Trout ≤125 mm (age-0)
Shallow pool	251
Deep pool	61
Boulder garden	72
Total	384

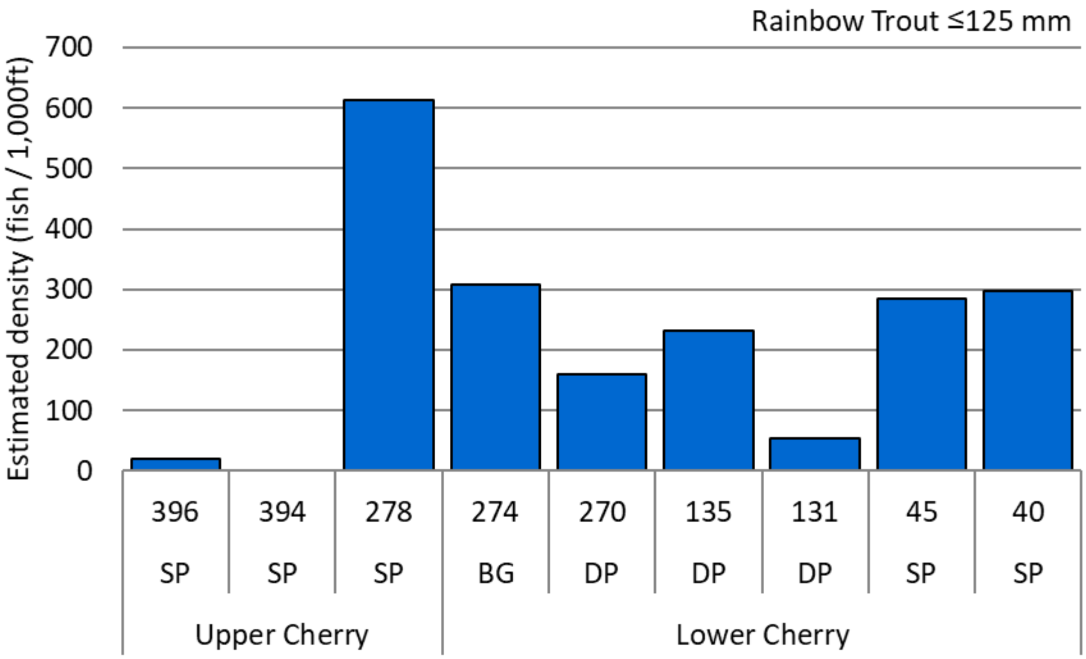

Figure 27. Estimated linear density of Rainbow Trout ≤125 mm by sub-reach and site in the Cherry Creek Reach in 2012. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden.)

6.2.3.2 2016 Monitoring in Cherry Creek Reach

Trout >125 mm

The 2016 fish population monitoring results for trout abundance and density in the Cherry Creek Reach are presented below for trout >125 mm (Tables 35–37, Figures 28). Rainbow Trout were the only trout species observed in Cherry Creek in 2016. Abundance estimates for all sites combined in 2016 were 248 for Rainbow Trout >125 mm (Table 36). In 2016, estimated linear density of Rainbow Trout >125 mm ranged from 33 fish/1,000 feet at site 40-SP to 292 fish/1,000 feet at site 274-BG (Figure 28). The average density of Rainbow Trout >125 mm was slightly higher in the Upper Cherry sub-reach (126 fish/1,000 feet) compared with the Lower Cherry sub-reach (111 fish/1,000 feet). Abundance of Rainbow Trout >125 mm was greatest in deep pool habitat (Table 37).

Abundance estimates for Rainbow Trout >125 mm among monitoring sites were variable, ranging from 5 trout at site 396-SP to 128 trout at site 274-BG (Table 36). Rainbow Trout abundance averaged over all sites in the Lower Cherry sub-reach was higher (48 average fish per site) than the average abundance among sites in the Upper Cherry sub-reach (27 average fish per site).

Table 35. Abundance estimates for Rainbow Trout >125 mm by sub-reach in the Cherry Creek Reach in 2016 (95 percent CI).

Sub-reach	Trout >125 mm (age-1 and older)
Upper Cherry	92 (±19)
Lower Cherry	156 (±30)
Total	248 (±35)

Table 36. Abundance estimates for Rainbow Trout >125 mm by site in the Cherry Creek Reach in 2016 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)
Upper Cherry sub-reach		
396-SP	shallow pool	2 (±2)
394-SP	shallow pool	29 (±12)
392-DP	deep pool	34 (±8)
278-SP	shallow pool	14 (±10)
276-SP	shallow pool	13 (±8)
Lower Cherry sub-reach		
274-BG	boulder garden	68 (±25)
270-DP	deep pool	18 (±2)
135-DP	deep pool	16 (±6)
131-DP	deep pool	13 (±0)
127-DP	deep pool	5 (±4)
40-SP	shallow pool	6 (±0)
34-RN	run	10 (±2)
32-DP	deep pool	20 (±14)

Table 37. Abundance estimates for Rainbow Trout >125 mm by habitat type in the Cherry Creek Reach in 2016 (95 percent CI).

Habitat	Trout >125 mm (age-1 and older)
Shallow pool	64 (±17)
Deep pool	106 (±17)
Boulder garden	68 (±25)
Run	10 (±2)
Total	248 (±35)

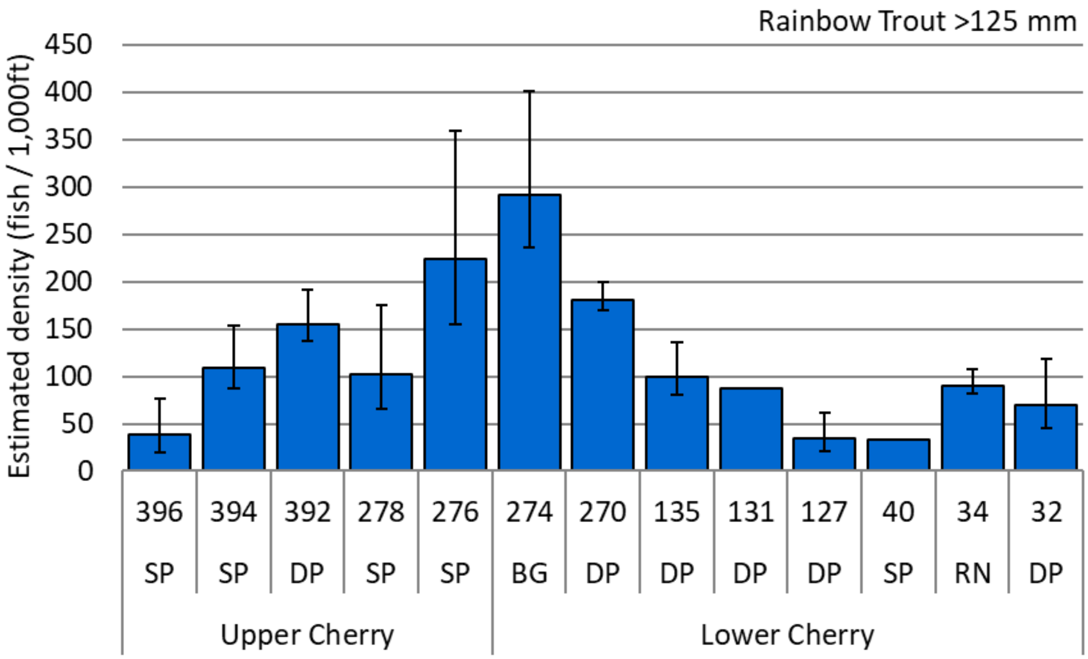

Figure 28. Estimated linear density of Rainbow Trout >125 mm by sub-reach and site in the Cherry Creek Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden, RN = run.)

Trout ≤125 mm

Abundance estimates for all sites combined in 2016 were 271 for Rainbow Trout ≤125 mm (Table 38). Estimated abundance varied substantially by site (Table 39). Abundance of Rainbow Trout ≤125 mm was greatest in deep pool habitat (Table 40). Estimated linear density for Rainbow Trout ≤125 mm ranged from 11 fish/1,000 feet at site 394-SP to 396 fish/1,000 feet at site 276-SP (Figure 29). The Lower Cherry sub-reach had higher estimated average linear density of Rainbow Trout ≤125 mm (161 fish/1,000 feet) compared with the Upper Cherry sub-reach (108 fish/1,000 feet). Interestingly, sites 274-BG and 276-SP had the highest densities of Rainbow Trout ≤125 mm (Figure 29), and were located near the confluence with Eleanor Creek and separated by only one habitat unit (Figure 3).

Table 38. Abundance estimates for Rainbow Trout ≤125 mm by sub-reach in the Cherry Creek Reach in 2016 (95 percent CI).

Sub-reach	Trout ≤125 mm (age-0)
Upper Cherry	42 (±22)
Lower Cherry	229 (±36)
Total	271 (±42)

Table 39. Abundance estimates for Rainbow Trout≤125 mm in the Cherry Creek Reach in 2016 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)
Upper Cherry sub-reach		
396-SP	shallow pool	3 (±2)
394-SP	shallow pool	3 (±2)
392-DP	deep pool	8 (±8)
278-SP	shallow pool	5 (±4)
276-SP	shallow pool	23 (±20)
Lower Cherry sub-reach		
274-BG	boulder garden	60 (±18)
270-DP	deep pool	6 (±2)
135-DP	deep pool	34 (±20)
131-DP	deep pool	27 (±8)
127-DP	deep pool	7 (±4)
40-SP	shallow pool	22 (±6)
34-RN	run	28 (±16)
32-DP	deep pool	45 (±16)

Table 40. Abundance estimates for Rainbow Trout ≤125 mm by habitat type in the Cherry Creek Reach in 2016 (95 percent CI).

Habitat	Trout ≤125 mm (age-0)
Shallow pool	56 (±21)
Deep pool	127 (±28)
Boulder garden	60 (±18)
Run	28 (±16)
Total	271 (±42)

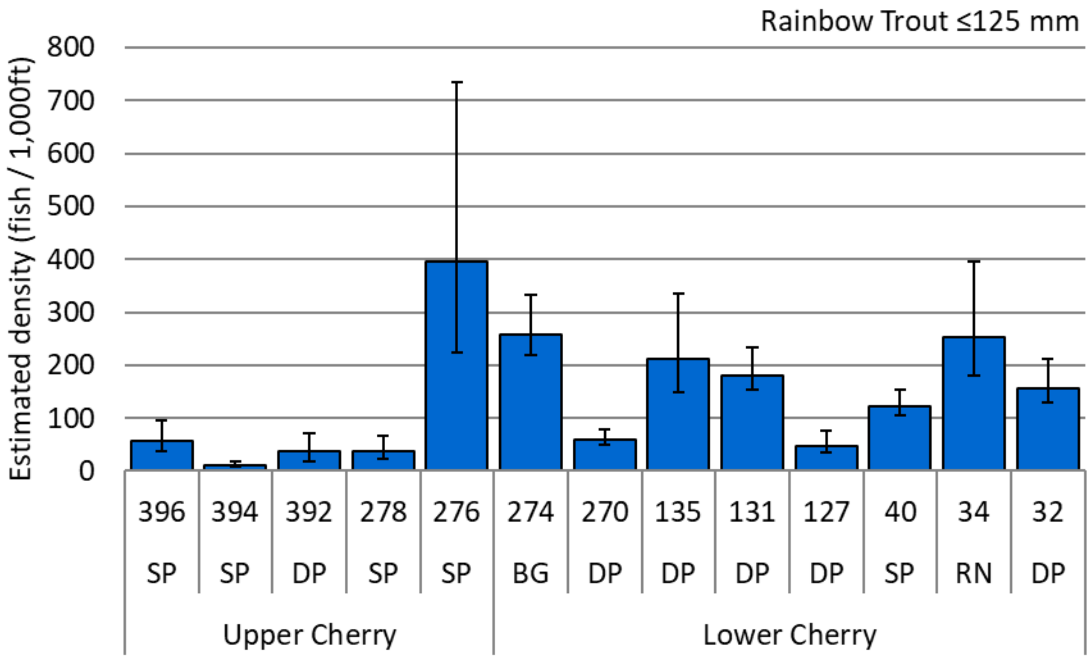

Figure 29. Estimated linear density of Rainbow Trout ≤125 mm by sub-reach and site in the Cherry Creek Reach in 2016. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden, RN = run.)

6.2.3.3 Comparisons between 2012 and 2016 results

For the Upper Cherry sub-reach, linear density of Rainbow Trout >125 mm was significantly higher in 2016 compared with 2012, mainly because no Rainbow Trout >125 mm were observed in the Upper Cherry sub-reach in 2012 (Figure 30). For the Lower Cherry sub-reach, linear density of Rainbow Trout >125 mm was significantly lower in 2016 compared with 2012 (Figure 30). Linear density of Rainbow Trout ≤125 mm was significantly lower in 2016 compared with 2012 for both the Upper Cherry and Lower Cherry sub-reaches (Figure 31).

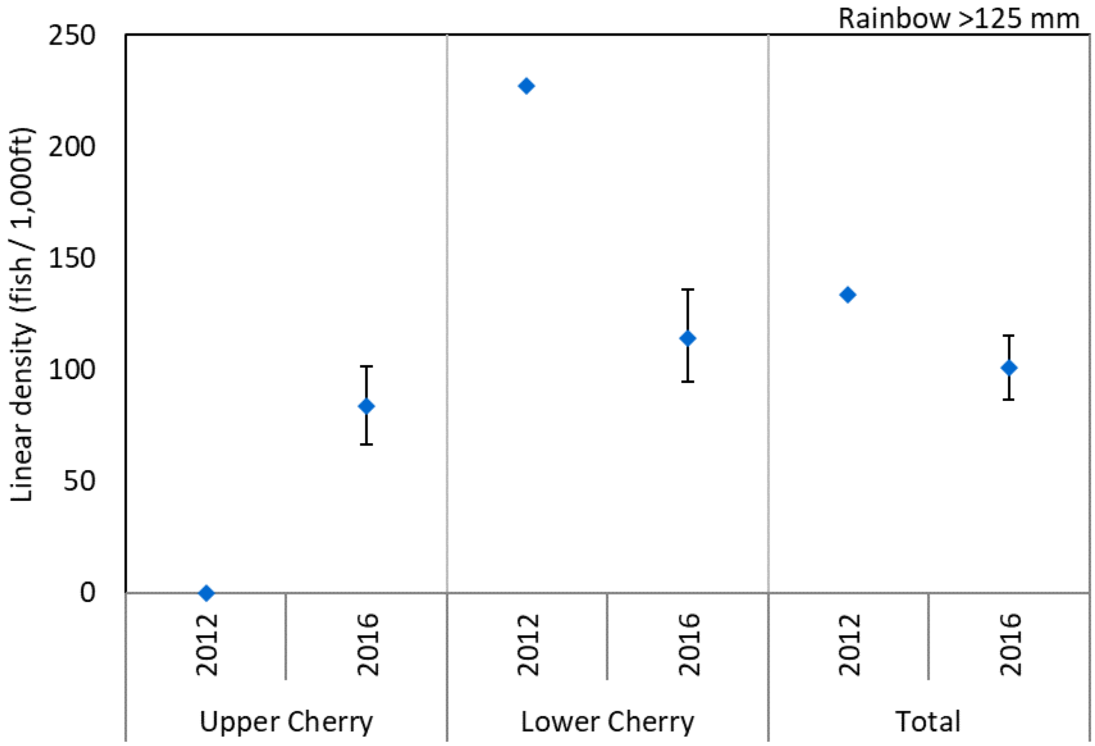

Figure 30. Linear density estimates for Rainbow Trout >125 mm by sub-reach in the Cherry Creek Reach for monitoring years 2012 and 2016. (Error bars indicate 95 percent CI.)

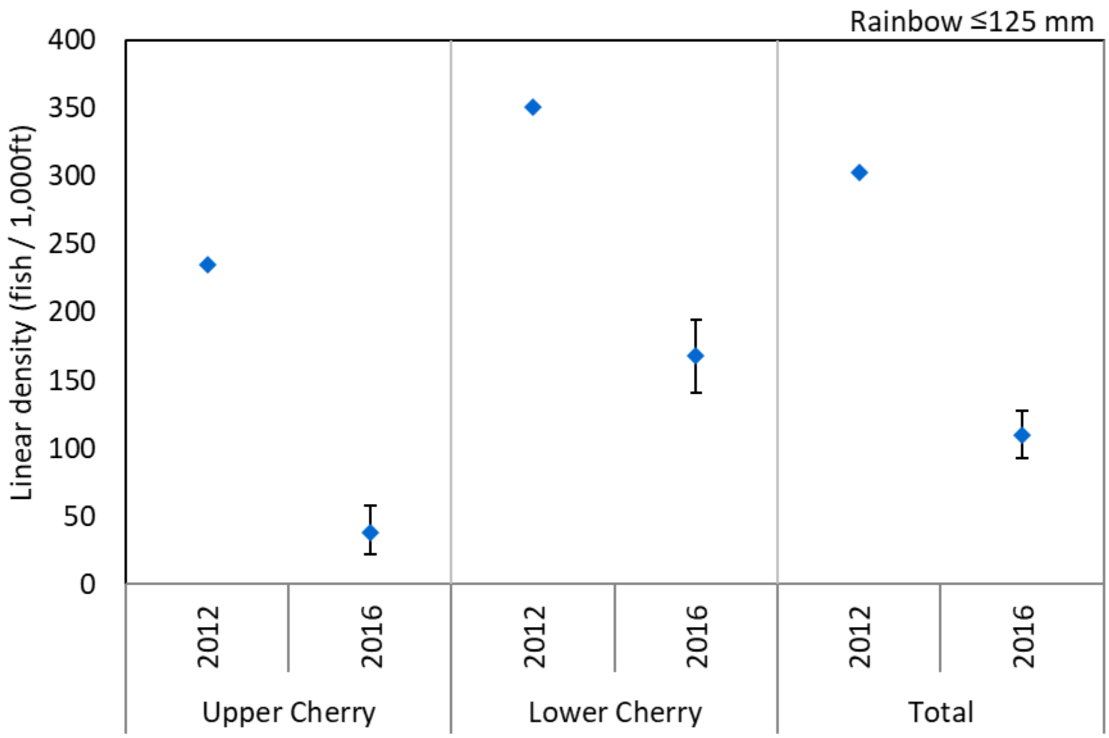

Figure 31. Linear density estimates for Rainbow Trout ≤125 mm by sub-reach in the Cherry Creek Reach for monitoring years 2012 and 2016. (Error bars indicate 95 percent CI.)

6.3 Streamflow

6.3.1 Hetch Hetchy Reach

Streamflow in the Hetch Hetchy Reach is derived from (1) required minimum instream baseflow releases from O'Shaughnessy Dam, (2) local accretion from minor tributaries, and (3) snowmelt spill releases from the dam. Two flow monitoring stations in the Hetch Hetchy Reach effectively bracket the survey area: the USGS gage 11276500 near Hetch Hetchy at the upstream end of the reach ("Hetch Hetchy gage"), and the USGS gage 11276600 above Early Intake at the downstream end of the reach ("Above Early Intake gage") (Figure 32). Hydrographs are presented to illustrate conditions in the reach during Water Years (WY) 2015 and 2016 relative to conditions in previous years (2005–2014) (Figures 33–36). During a typical water year (e.g., WY 2009), flows in the Hetch Hetchy Reach are generally high during the spring and early summer snowmelt runoff period (May–July), and low during the fall and winter (September–February). Short-duration, high-flow events occasionally occur during winter. Minimum baseflow releases are designed to provide optimal temperatures for trout during summer, and are higher than typical unimpaired summer inflows in most years. See RMC Water and Environment and McBain & Trush, Inc. (2007) for a detailed summary of existing instream flow requirements and hydrology.

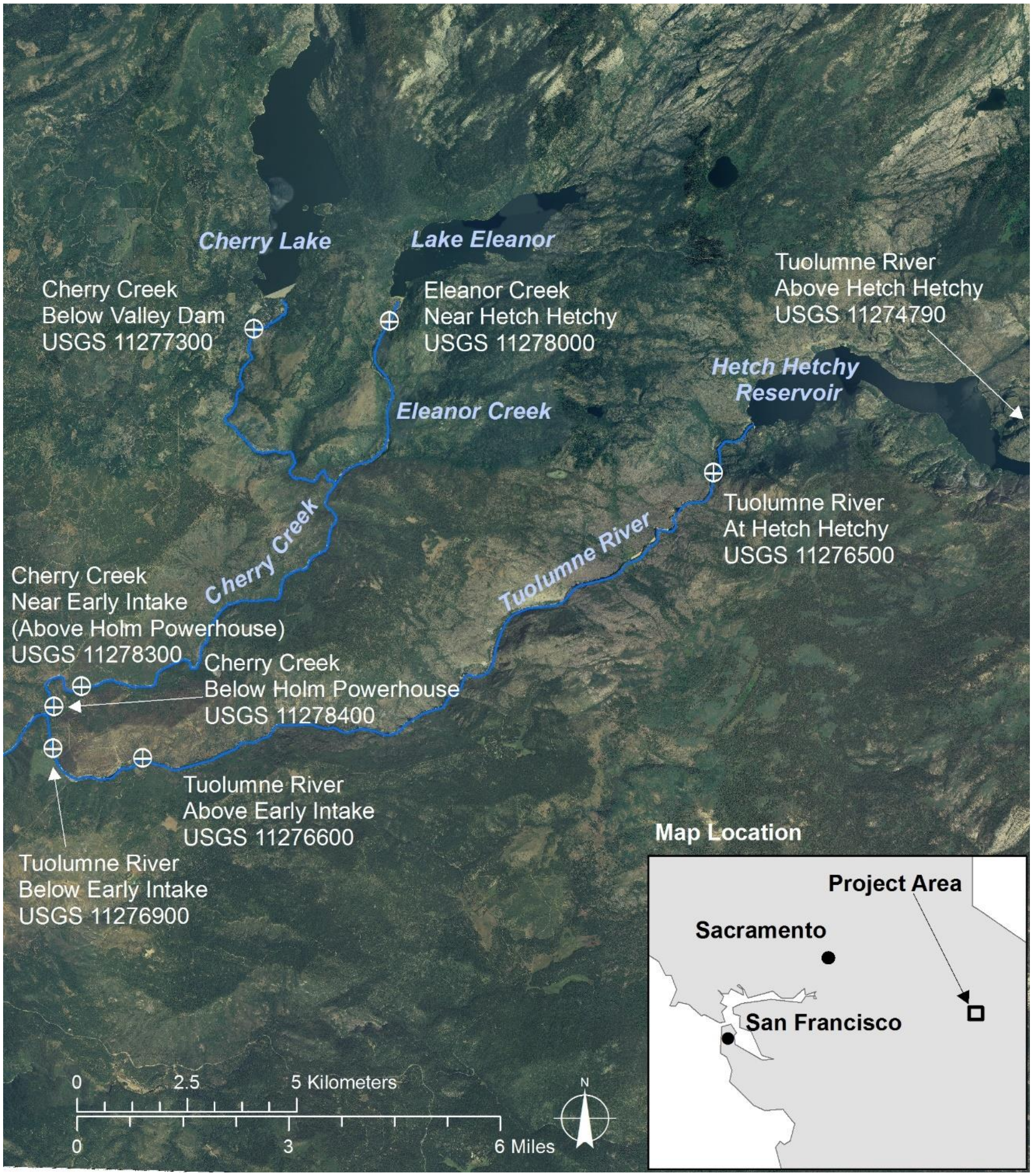

Figure 32. Stream gages in the vicinity of fish monitoring sites the upper Tuolumne River, Cherry Creek, and Eleanor Creek. Stream gages near fish monitoring.

Throughout much of California, WY 2015 was the fourth consecutive year of drought conditions and one of the lowest water years on record. Mean annual flow and average summer flow (May through mid-September) in WY 2015 were the lowest recorded in recent years at both gages, following WY 2014, which had been the lowest at the time. Streamflow was generally similar between WY 2014 and WY 2015 and noticeably lower than in previous years, particularly during February through September. There were no large-magnitude high-flow events during WY 2013 through WY 2015. A few low-magnitude high-flow events were evident at the Above Early

Intake gage in WY 2015 during December and February (Figures 35 and 36). These low-magnitude high-flow events were generated by winter storms and contributed by small local tributaries that enter the Tuolumne River within the reach (below the Hetch Hetchy gage).

Average daily flow in WY 2015 recorded at the Hetch Hetchy gage ranged from about 34 cfs in February to 82 cfs in July. Average daily flow at the Hetch Hetchy gage from October through April remained relatively stable at about 35 to 40 cfs (Figure 33). At the Above Early Intake gage, average daily flow ranged from about 40 cfs in October to 195 cfs in February. Average daily flow at the Above Early Intake gage from June through mid-September remained relatively stable at about 95 to 100 cfs, indicating that about 20 cfs of accretion occurred in the reach during this period in WY 2015 (Figure 35).

Drought conditions in the upper Tuolumne River diminished in WY 2016 with flows more typical of an average water year at both the Hetch Hetchy gage (Figures 33 and 34) and the Above Early Intake gage (Figures 35 and 36). Peak flows exceeded 6,000 cfs at both gages, a magnitude sufficient to scour stored sediments for the first time since the Rim Fire. October baseflows during 2016 were similar to 2015, and relatively low compared with previous years (Figure 36).

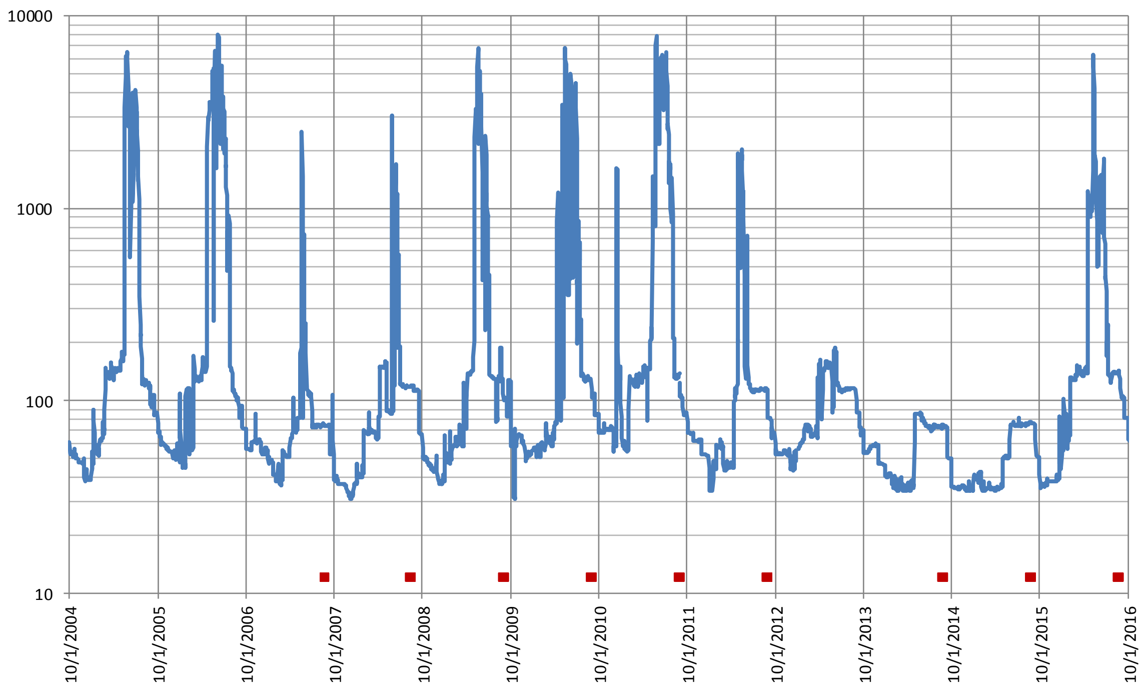

Figure 33. Mean daily streamflow in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2005–2016. Snorkel surveys performed by the SFPUC in mid-August through early September 2007–2011 and 2014–2016 are identified by red markers.

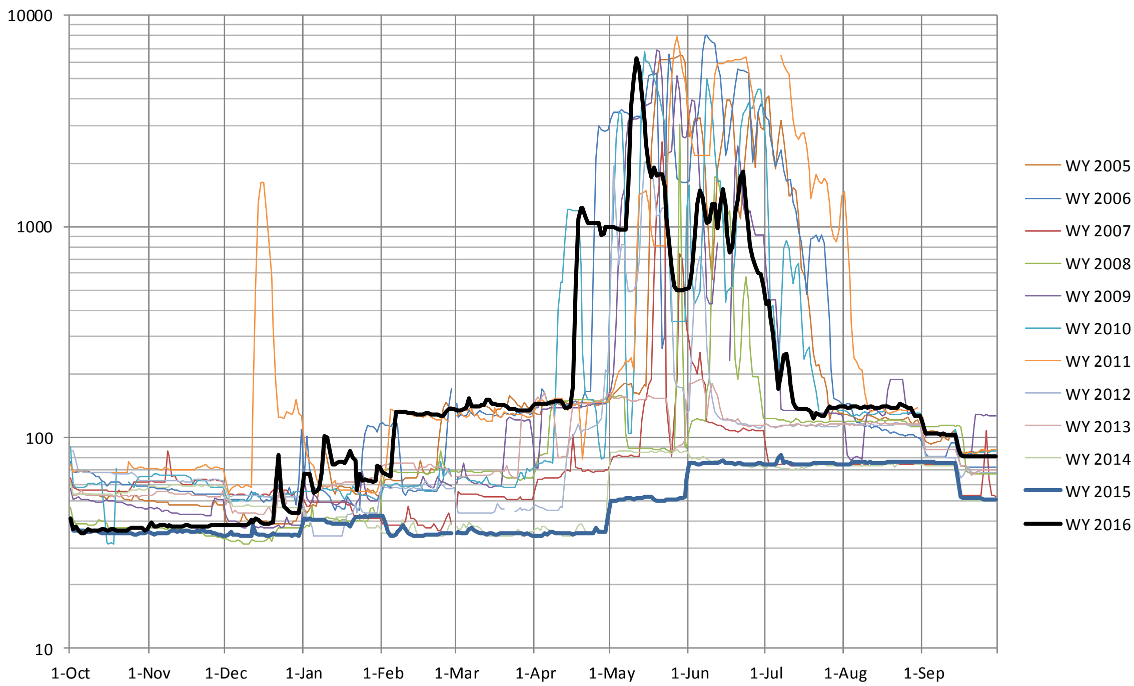

Figure 34. Mean daily streamflow in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2005–2016, presented individually.

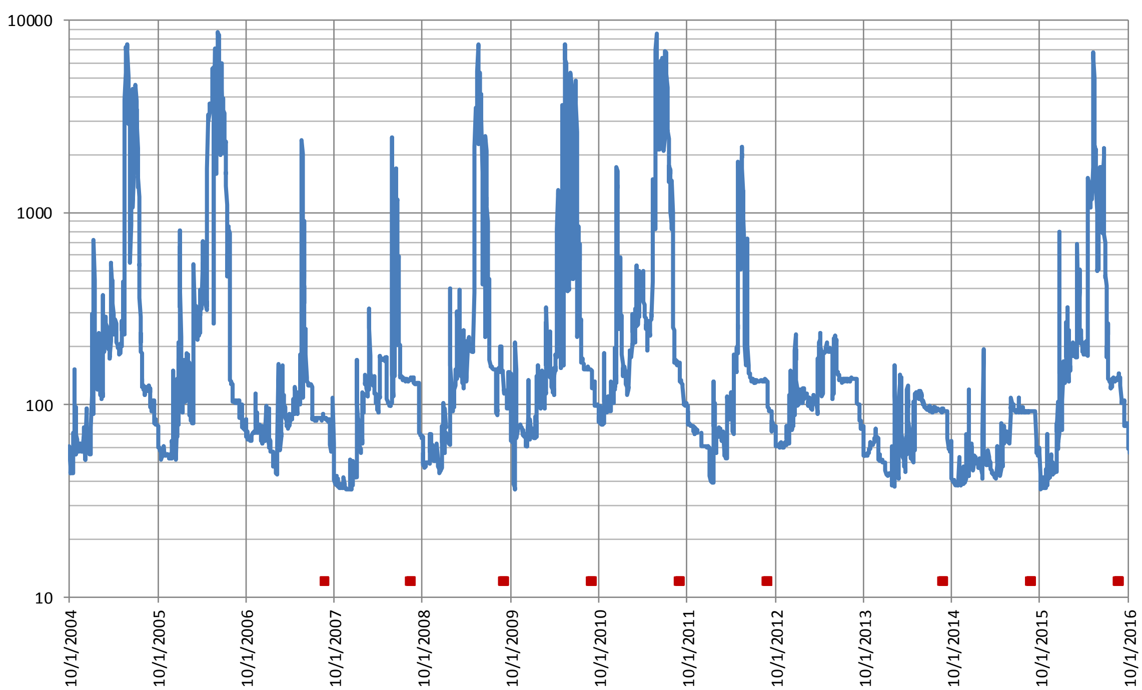

Figure 35. Mean daily streamflow in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2005–2016. Snorkel surveys performed by the SFPUC in mid-August through early September 2007–2011 and 2014–2016 are identified by red markers.

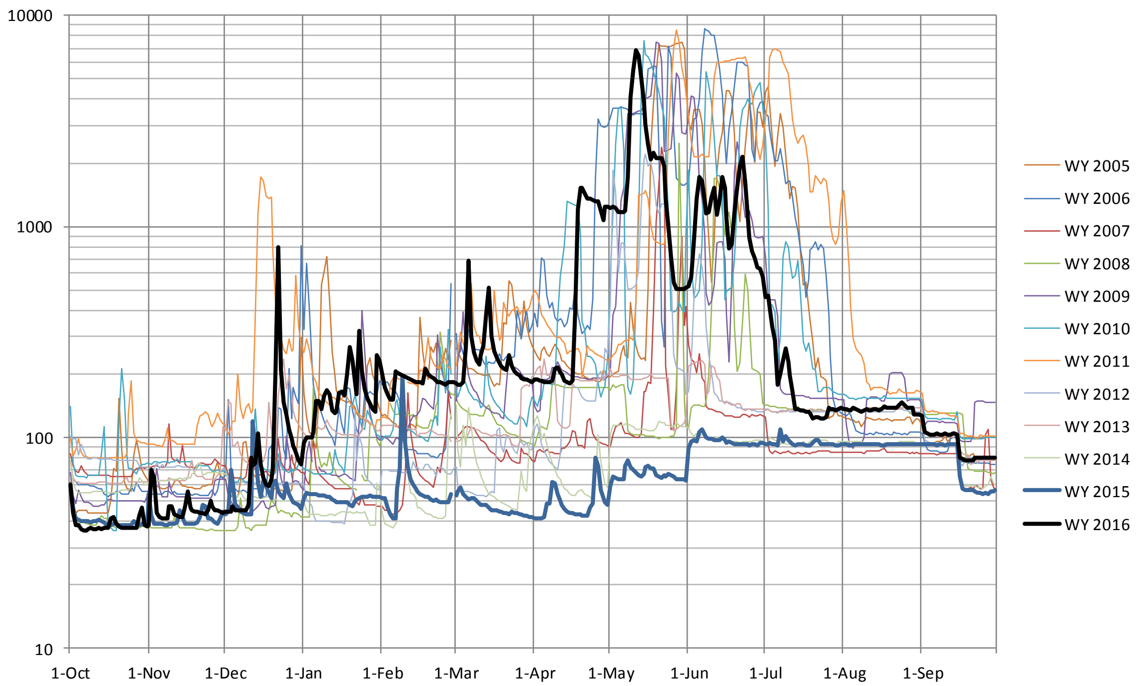

Figure 36. Mean daily streamflow in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2005-2016, presented individually.

6.3.2 Above Hetch Hetchy Reservoir Reach

Streamflow in the Above Hetch Hetchy Reservoir Reach is unregulated. Flow is monitored at USGS gage 11274790 located near the downstream end of the reach ("Above Hetch Hetchy gage"), immediately upstream of Hetch Hetchy Reservoir. Streamflow in the reach is generally lowest in late September and early October. Flows increase from October through May or June, and then decrease from June through October (Figures 35 and 36). Average daily flow in WY 2016 recorded at the Above Hetch Hetchy gage ranged from about 6 cfs in October to 2,210 cfs in June (Figure 36). Interestingly, recent drought conditions (WY 2013–2015) do not stand out as dramatically in the Above Hetch Hetchy Reservoir Reach compared with the other monitoring reaches.

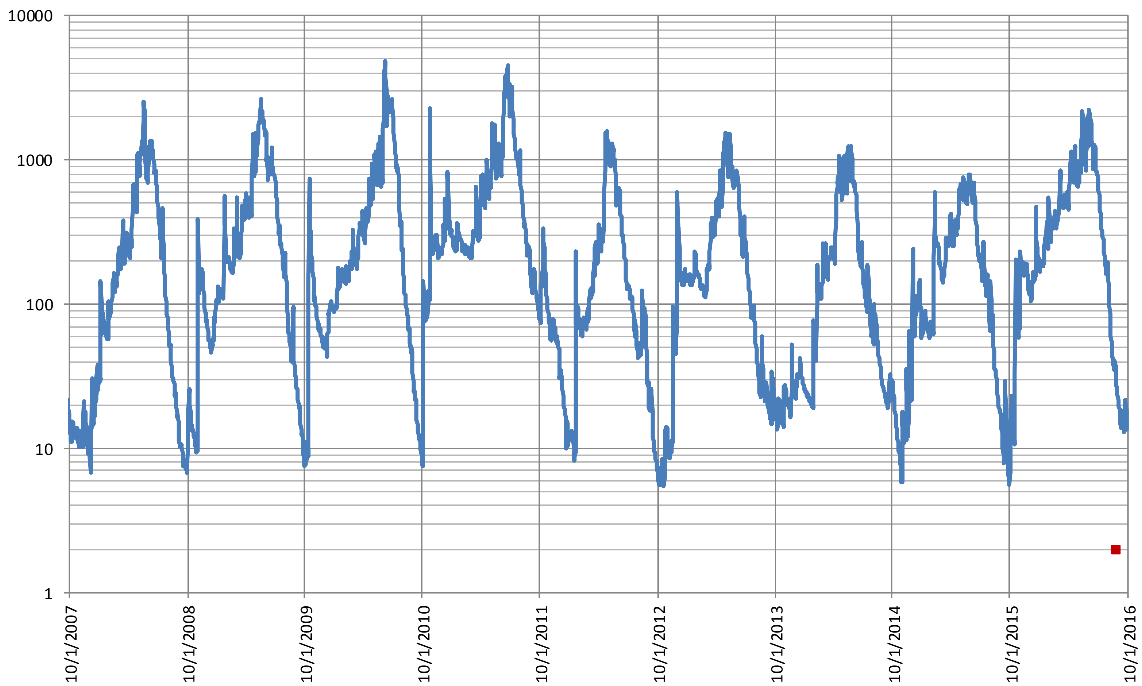

Figure 37. Mean daily streamflow in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2007–2016. Snorkel surveys by the SFPUC in late August 2016 are identified by a red marker.

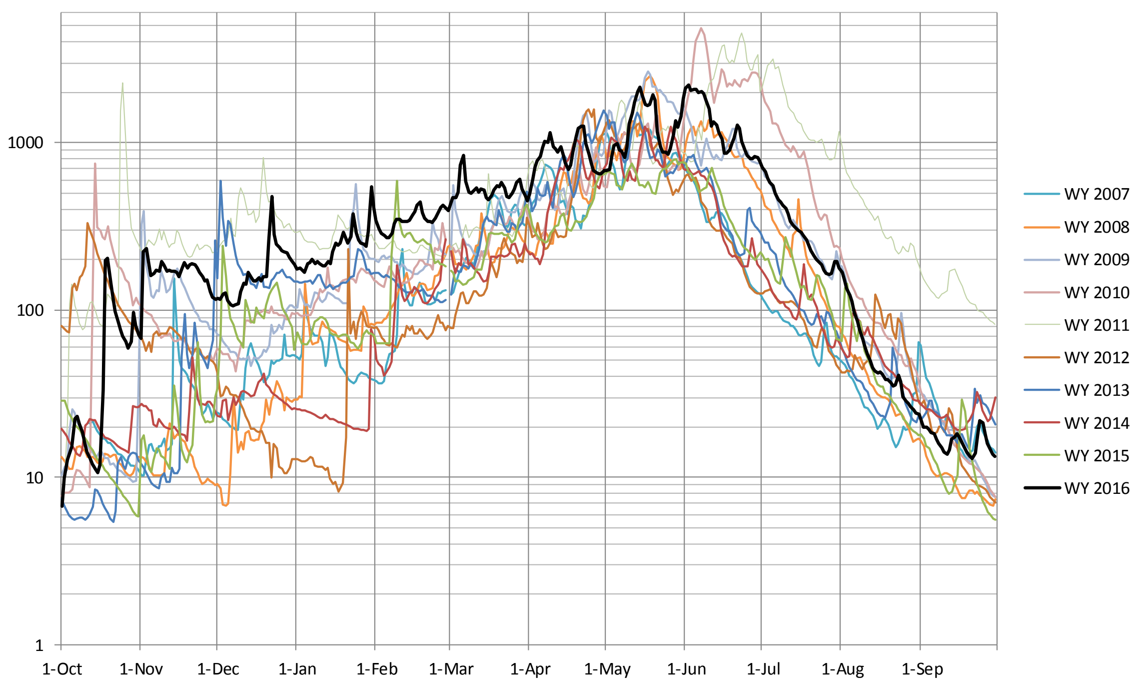

Figure 38. Mean daily streamflow in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2007–2016, presented individually.

6.3.3 Cherry Creek Reach

Streamflow in the Cherry Creek Reach is derived from (1) flow releases from Cherry Valley Dam (downstream of Cherry Lake), (2) flow contributed from Eleanor Creek (downstream of Lake Eleanor), (3) flow from Holm Powerhouse, and (4) local accretion from minor tributaries. Two streamflow monitoring stations in the Cherry Creek Reach bracket the majority of the reach: the USGS gage 11277300 near Cherry Valley Dam at the upstream end of the reach ("Below Cherry Valley Dam gage") and the USGS gage 11278300 above Holm Powerhouse at the downstream end of the reach ("Above Holm Powerhouse gage") (Figure 39). Flows measured at the Above Holm Powerhouse gage include flow contribution from Eleanor Creek in addition to supplemental accretion from small tributaries or other sources. Flow hydrographs are presented to illustrate conditions in the reach during WY 2016 relative to conditions in previous years (the eight years preceding) (Figures 39–42). Flow conditions in the Cherry Creek Reach downstream of Holm Powerhouse are monitored at USGS gage 11278400 ("Cherry Creek Below Holm Powerhouse"). Flow hydrographs are not presented for this reach.

During WY 2007 through WY 2015, flows at the Below Cherry Valley Dam gage generally peak during the spring and early summer snowmelt runoff period (May–July) and are low during the fall and winter (September–February) (Figure 40). Short-duration, high-flow events occasionally occurred during winter in WY 2013 and WY 2011 (Figure 40). During WY 2016, drought conditions in California diminished, although relatively low flow conditions persisted in Cherry Creek to some degree. Flows at the Below Cherry Valley Dam gage ranged from a minimum of 10.5 cfs to a maximum of 202 cfs with no significant peak flow releases after November 1, 2016. Flow releases from Cherry Valley Dam were limited to minimum baseflow releases, except for the October 1–17, 2015 period when operational flow releases were increased up to 200 cfs.

Streamflow was generally similar between WY 2012 and WY 2016 below Cherry Valley Dam, and these two water years were lower compared to most other water years evaluated. Average daily flow in WY 2012 recorded at the Below Cherry Valley Dam gage ranged from about 6 cfs in October to 23 cfs in May. In WY 2016, average daily flows ranged from about 5 cfs in April to 202 cfs in October. There were no large-magnitude high-flow events during WY 2012, but elevated flows up to 200 cfs occurred for the first half of October in WY 2016 (October 2015); these elevated flows were not seen in any of the other water years evaluated (WY 2007 through 2015) (Figure 40). Average daily streamflow were similar during 2012 and 2016 snorkel survey efforts (19 cfs and 17 cfs respectively) (Figure 39).

During WY 2007 through WY 2015, peak flows at the Above Holm Powerhouse gage generally occurred during the spring and early summer snowmelt runoff period (May–July), with fewer, high-flow events occurring during fall and winter (September–February) (Figure 42). During October through June, additional peaking events were interspersed among these high-flow events with steady baseflows occurring from July through September. The numerous high-flow events are a result of natural winter storm events and spring snowmelt runoff. After July 1, 2016, flows were dominated by baseflow releases from Cherry Lake and Eleanor Lake.

During WY 2016, flows ranged from a minimum of 13 cfs in October to a maximum of 609 cfs in May with numerous peaking events from October through June. No high-flow events occurred during the spring and early summer snowmelt runoff period or during fall and winter, which was similar to all other years evaluated. Peak flow events were on average lower in magnitude than other years compared between WY 2007 and WY 2015 (Figure 42) due to drought conditions. Late summer baseflows averaged approximately 49 cfs from early July through mid-September.

Streamflow patterns for WY 2012 at the Above Holm Powerhouse gage were similar to WY 2007 through WY 2015, with peak flows occurring during spring and late fall; however, additional peaking events were noticeably absent compared to all other water years evaluated. Average daily flow in WY 2012 recorded at the Above Holm Powerhouse gage ranged from about 18 cfs from late December to mid-January, to 2,200 cfs in April. Average daily streamflow during snorkel survey efforts for both 2012 and 2016 were similar (42 cfs and 43 cfs respectively) (Figure 42).

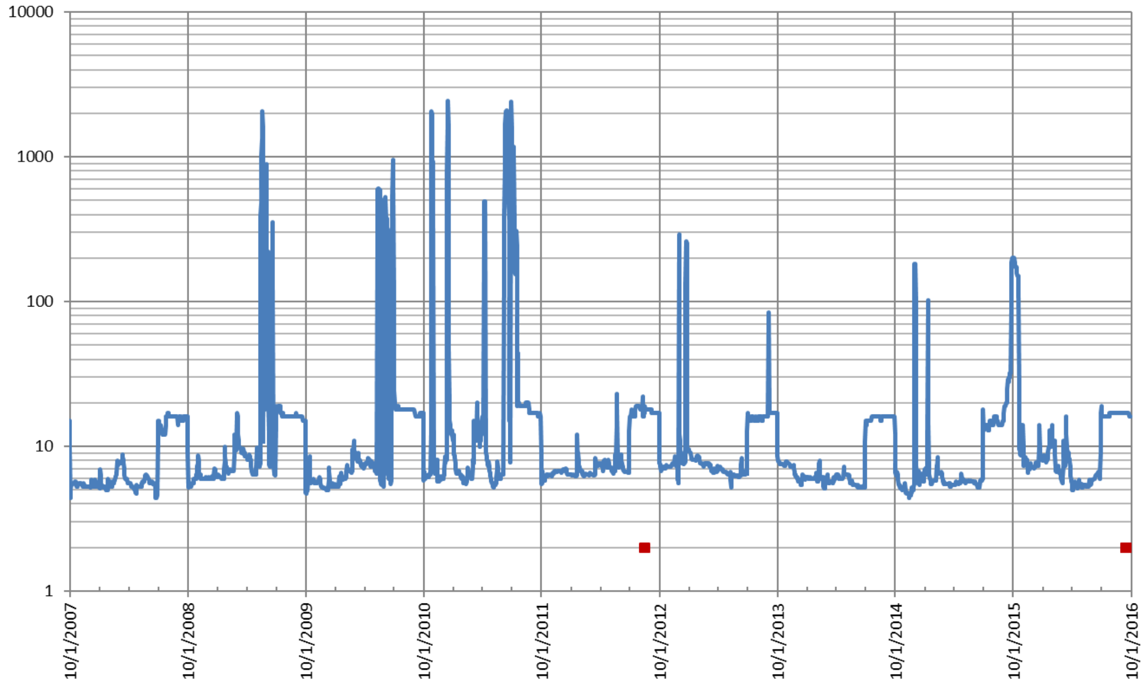

Figure 39. Mean daily streamflow in Cherry Creek at Below Cherry Valley Dam gage (USGS 11277300) for WY 2007–2016. Snorkel surveys performed in August 2012 and September 2016 are identified by red markers.

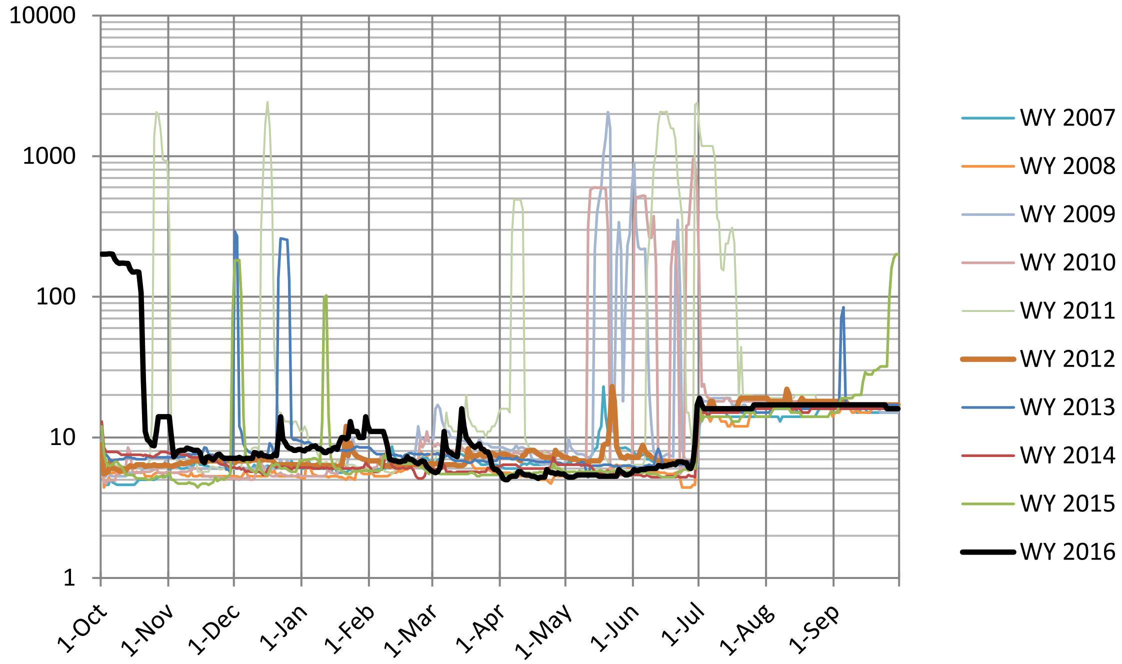

Figure 40. Mean daily streamflow in Cherry Creek at Below Cherry Valley Dam gage (USGS 11277300) for WY 2007–2016, presented individually.

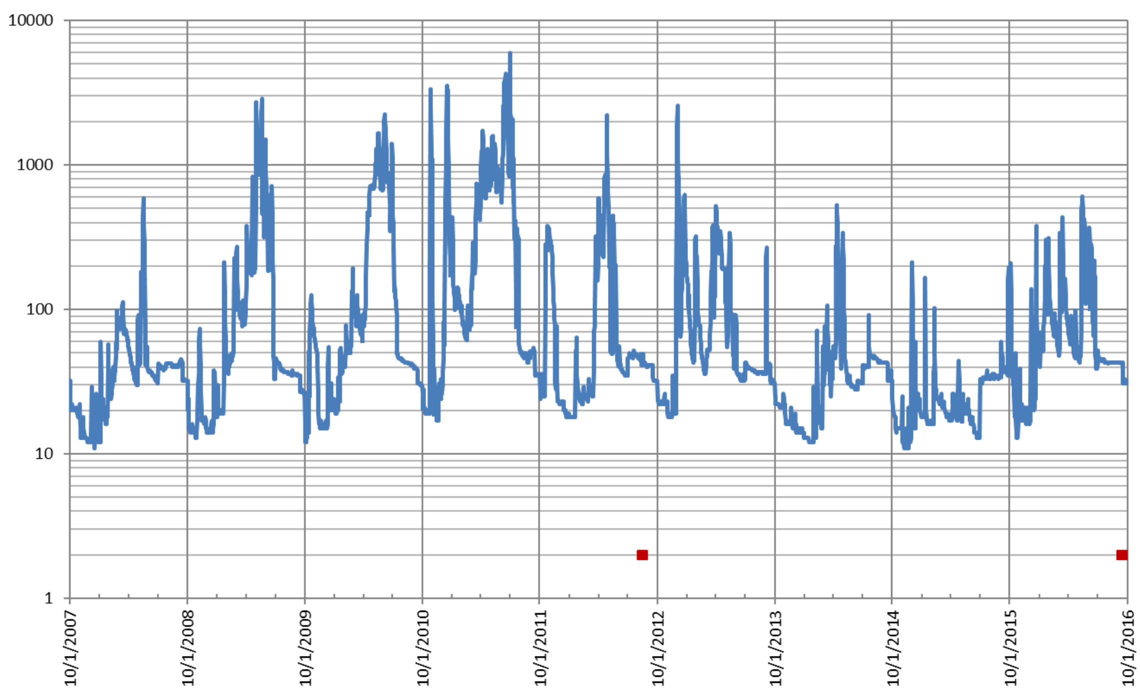

Figure 41. Mean daily streamflow in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2007–2016. Snorkel surveys performed in August 2012 and September 2016 are identified by red markers.

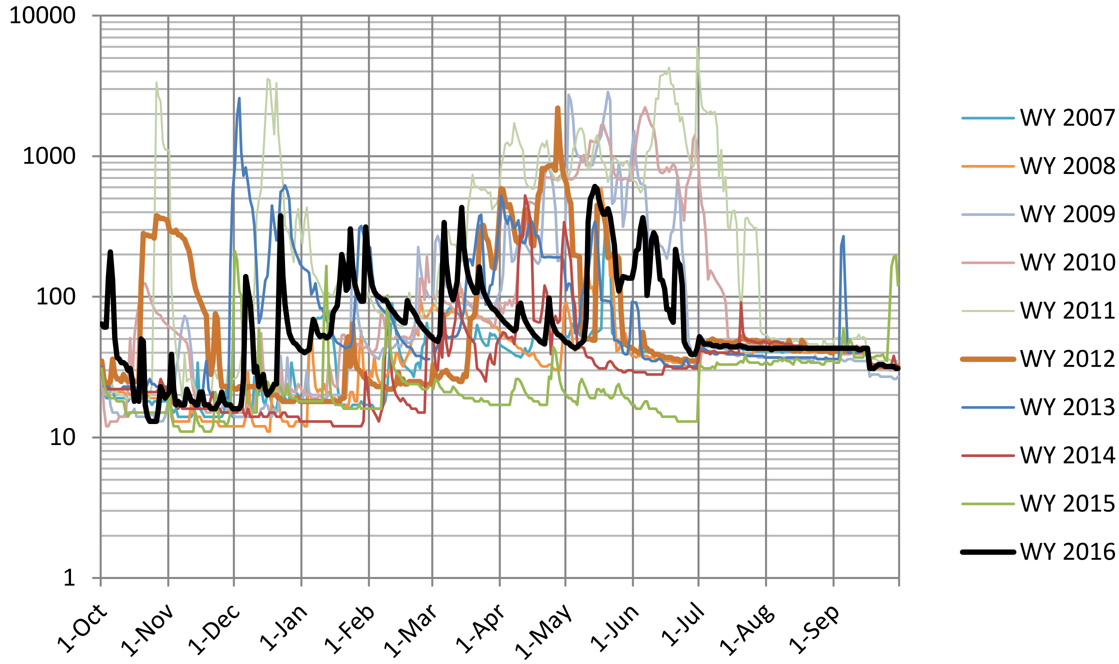

Figure 42. Mean daily streamflow in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2007-2016, presented individually.

6.4 Water Temperature

6.4.1 Hetch Hetchy Reach

Daily water temperature data for the Hetch Hetchy and the Above Early Intake gages (Figure 43) were plotted for WY 2005 through WY 2016, both consecutively (Figures 43 and 44) and individually (Figures 41 and 43) to illustrate annual patterns and compare WY 2015 and WY 2016 to conditions in previous years. Water temperature metrics based on daily data for the WY 2005 through WY 2016 period are presented in Table 38.

Water temperatures at the Hetch Hetchy gage are generally lowest from January through April and highest from June through early August, and then decrease through August as fall approaches. Water temperatures are relatively stable from September through October and decrease slightly in November before decreasing more dramatically in December at the onset of winter (Figure 44). The Above Early Intake gage follows a slightly different annual pattern, with lowest temperatures during December through January, increasing steadily to the highest temperatures in late June to early August, and then steadily decreasing again through fall into winter (Figure 46).

The seasonal range of water temperatures at the Hetch Hetchy gage is relatively narrow compared with the Above Early Intake gage due to the proximity of the Hetch Hetchy gage to O'Shaughnessy Dam and because the hypolimnetic release point from Hetch Hetchy moderates water temperature. During WY 2005–2016, daily average water temperatures at the Hetch Hetchy gage ranged from 42.5 degrees Fahrenheit (°F) to 65.7°F, compared with 34.4°F to 73.9°F at the Above Early Intake gage. Instantaneous water temperatures at the Hetch Hetchy and Above Early Intake gages ranged from 39.6°F to 66.9°F and 33.4°F to 79.3°F, respectively (Table 38).

Despite prolonged drought conditions in WY 2015, maximum daily average water temperature at the Hetch Hetchy gage was relatively low compared with other years during WY 2005–2016 (Table 38). In contrast, both mean and maximum daily average water temperatures at the Above Early Intake gage during WY 2015 were relatively high compared with other years during WY 2005–2016 (Table 38).

In WY 2016, daily average water temperatures at the Hetch Hetchy gage were relatively low in December, and relatively high in late June and early July (Figure 44).

At the Above Early Intake gage, water temperatures were less extreme in WY 2016 compared with WY 2015. Maximum daily average and the maximum daily maximum water temperatures at the Above Early Intake gage were substantially lower in WY 2016 compared with the drought years from WY 2012 through WY 2015. Daily average water temperatures at the Above Early Intake gage in WY 2016 were relatively high in October, and otherwise generally within the range observed during recent years (Figure 46).

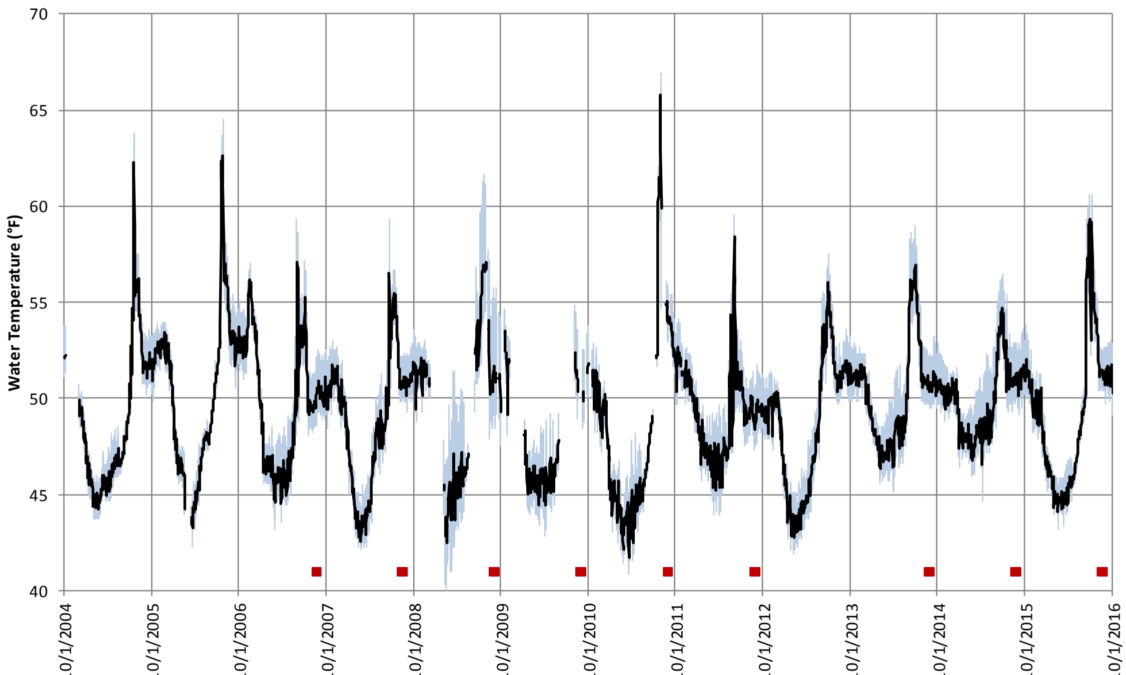

Figure 43. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2005–2016. Snorkel surveys performed by the SFPUC in mid-August through early September 2007–2011 and 2014–2016 are identified by red markers.

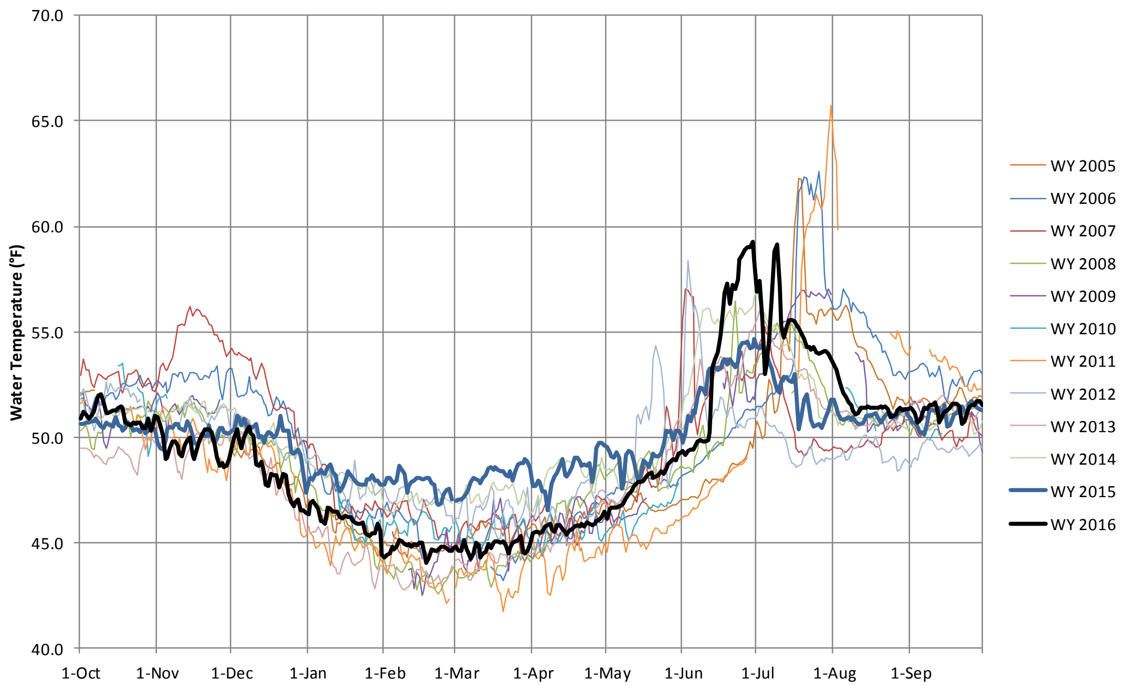

Figure 44. Daily average water temperature in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2005-2016, presented individually.

Table 41. Water temperatures for WY 2005-2016 at USGS gages in Hetch Hetchy and Above Hetch Hetchy Reservoir reaches.

Temperature metric	**Water year**											
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
USGS gage Tuolumne River near Hetch Hetchy (No. 11276500)												
Mean daily average	48.7	50.5	49.9	48.8	49.6	47.1	47.9	49.2	48.5	50.2	50.0	49.2
Minimum daily average	44.2	43.2	44.5	42.6	42.5	48.2	50.5	45.2	42.8	46.3	46.6	44.1
Maximum daily average	62.2	62.6	57.0	56.5	57.0	53.5	65.7	58.4	56.0	56.9	54.7	59.3
Minimum daily minimum	43.7	42.3	43.2	42.1	39.6	42.8	40.8	43.9	41.9	45.1	44.6	43.2
Maximum daily maximum	63.9	64.6	59.4	59.4	61.7	64.2	66.9	59.5	57.6	59.0	56.5	60.6
USGS gage Tuolumne River Above Early Intake (No. 11276600)												
Mean daily average	50.2	52.0	55.3	53.5	52.3	51.9	51.3	53.7	54.6	56.7	58.0	53.3
Minimum daily average	37.3	40.8	34.4	38.2	37.7	38.2	40.7	37.3	37.6	36.1	37.1	39.1
Maximum daily average	68.8	70.3	73.0	69.7	69.4	68.2	67.7	67.1	71.8	73.9	73.1	67.7
Minimum daily minimum	36.5	39.0	33.4	36.9	37.0	37.4	39.4	36.1	36.7	35.1	36.3	38.5
Maximum daily maximum	72.0	73.8	77.5	73.2	73.8	71.4	69.4	71.1	75.6	79.3	78.1	71.4

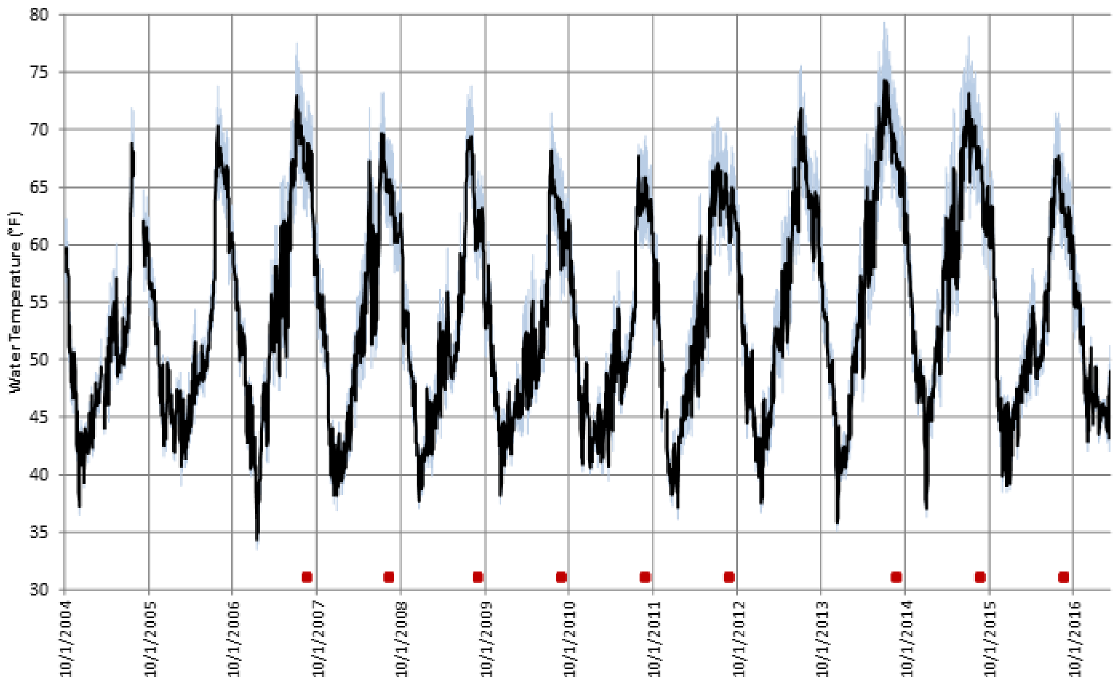

Figure 45. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2005–2016. Snorkel surveys performed by the SFPUC in mid-August through early September 2007–2011 and 2014–2016 are identified by red markers.

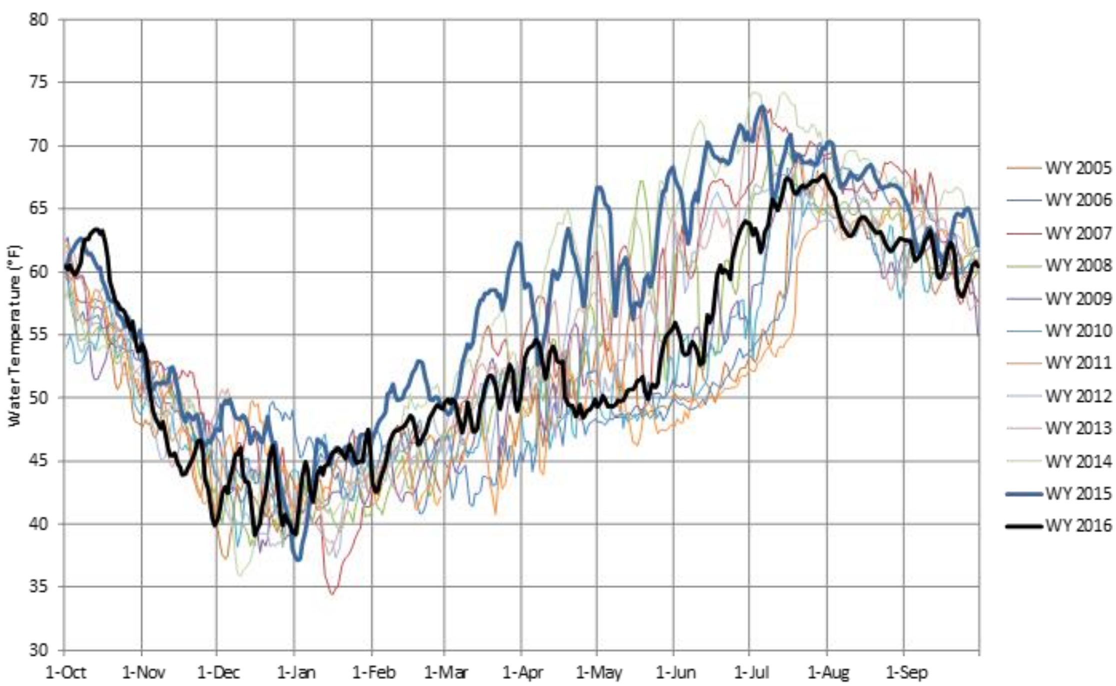

Figure 46. Daily average water temperature in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2005–2016, presented individually.

6.4.2 Above Hetch Hetchy Reservoir Reach

Water temperatures at the Above Hetch Hetchy gage (Figure 47) are generally lowest in December and January and highest in July and August (Figure 48). During WY 2007–2016, mean daily average water temperatures at the Above Hetch Hetchy gage ranged from 45.2°F to 51.0°F, and instantaneous water temperatures ranged from 32.0°F to 70.9°F (Table 39). For WY 2015 and WY 2016, maximum daily average water temperatures were 68.6°F and 70.1°F, respectively.

Table 42. Water temperatures for WY 2005-2016 at USGS gages in Hetch Hetchy and Above Hetch Hetchy Reservoir reaches.

Temperature metric	Water year											
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
USGS gage Tuolumne River Above Hetch Hetchy (No. 11274790)												
Mean daily average	--	--	48.6	48.3	48.1	46.6	45.2	48.7	49.8	49.5	51.0	46.3
Minimum daily average	--	--	32.0	32.5	32.1	32.1	32.7	32.2	32.6	32.2	32.1	32.2
Maximum daily average	--	--	70.1	70.0	68.1	66.9	63.8	70.9	70.5	69.4	69.9	68.6
Minimum daily minimum	--	--	32.0	32.0	32.0	32.0	32.2	32.0	32.0	32.0	32.0	32.0
Maximum daily maximum	--	--	73.0	73.2	71.1	70.2	66.9	74.1	73.8	72.7	73.0	72.3

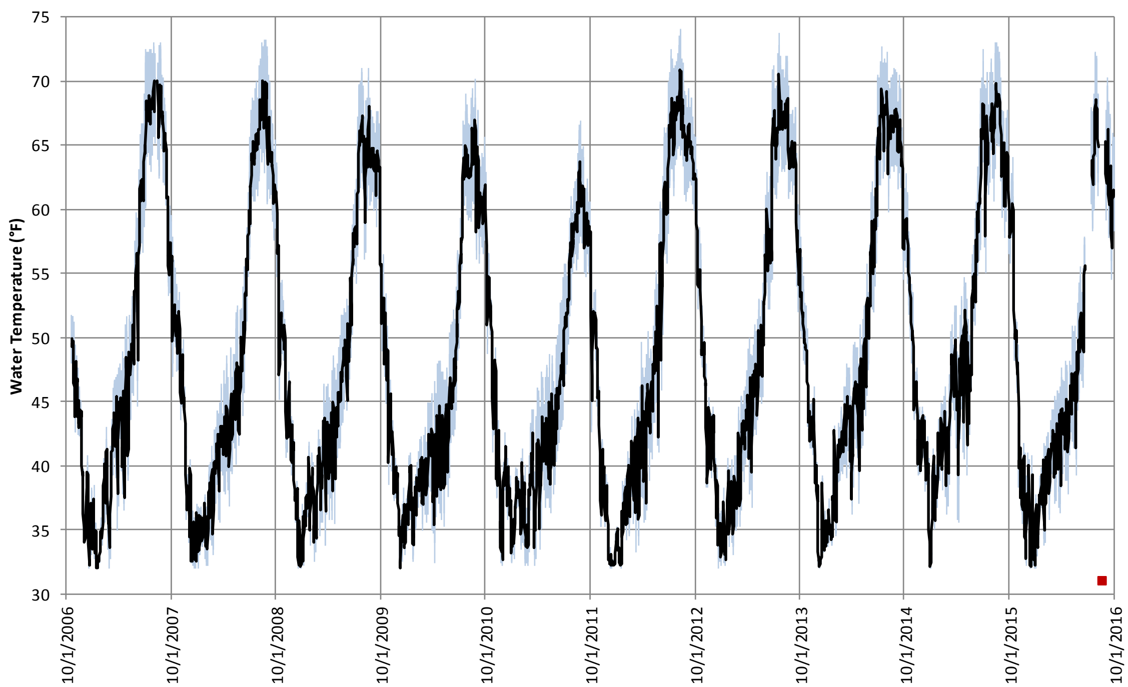

Figure 47. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2007-2016. Snorkel surveys performed by the SFPUC in late August 2016 are identified by a red marker.

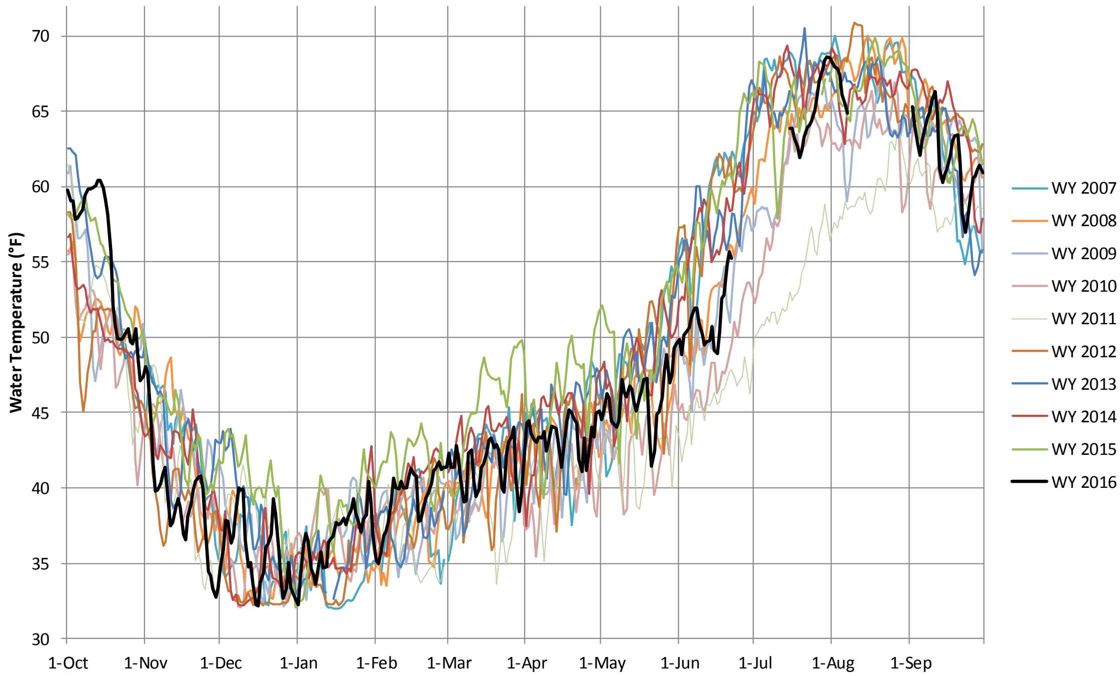

Figure 48. Daily average water temperature in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2007–2016, presented individually.

6.4.3 Cherry Creek Reach

Daily water temperature data for the Below Cherry Valley Dam and the Above Holm Powerhouse gages (Figure 49) were plotted for WY 2007 through WY 2016, both consecutively (Figure 49 and Figure 51) and individually (Figure 50 and Figure 52) to illustrate annual patterns and compare WY 2016 to conditions in previous years. Water temperature metrics based on daily data for the WY 2007 through WY 2016 period are presented in Table 40.

At the Below Cherry Valley Dam gage during WY 2007 through WY 2016, average daily water temperatures ranged from 36.4°F to 63.1°F, and daily minimum and maximum temperatures ranged from 33.4°F to 64.4°F (Table 40). Water temperatures for WY 2007 through WY 2015 at the Below Cherry Valley Dam gage were generally lowest from late December through February and highest in June. Water temperatures remained stable from July through August before decreasing at the onset of fall in September (Figure 50). The annual pattern of daily average water temperatures for WY 2016 generally followed the same pattern as all other water years evaluated, except in October when water temperatures were well above water temperatures observed during other water years evaluated, and higher than the maximum daily maximum water temperature measured during most years (Figure 50, Table 40). This spike in water temperature corresponded with an approximately 200-cfs release in late September through mid-October (Figure 50), and the higher temperature was likely due to loss of the cold-water pool in Cherry Lake due to the drought and low reservoir storage. Overall, low flows did not have a substantial effect on the water temperature in Cherry Creek immediately below Cherry Valley Dam.

At the Above Holm Powerhouse gage during WY 2007 through WY 2016, average daily water temperatures ranged from 31.7 °F to 74.9°F, and daily minimum and maximum temperatures ranged from 31.5°F to 79.3°F (Table 40). The annual pattern of daily average water temperatures at the Above Holm Powerhouse gage follows a slightly different pattern than the Below Cherry Valley Dam gage, with lowest temperatures occurring during late December and increasing steadily to the highest temperatures in late June and July, and then steadily decreasing again through fall into winter with no time periods where water temperatures remain stable (Figure 52). Water temperature pattern for WY 2016 followed the same pattern for all other water years evaluated, except in October where water temperatures spiked abnormally compared with the other water years evaluated (Figure 52). This spike in water temperature corresponded with the early October water temperature spike seen at the Below Cherry Valley Dam gage, but the magnitude of the spike was greatly muted compared with the Below Cherry Valley Dam gage due to natural warming and flow accretion between the gages. However, low flows appear to result in associated increases in water temperatures in Cherry Creek upstream of Holm Powerhouse.

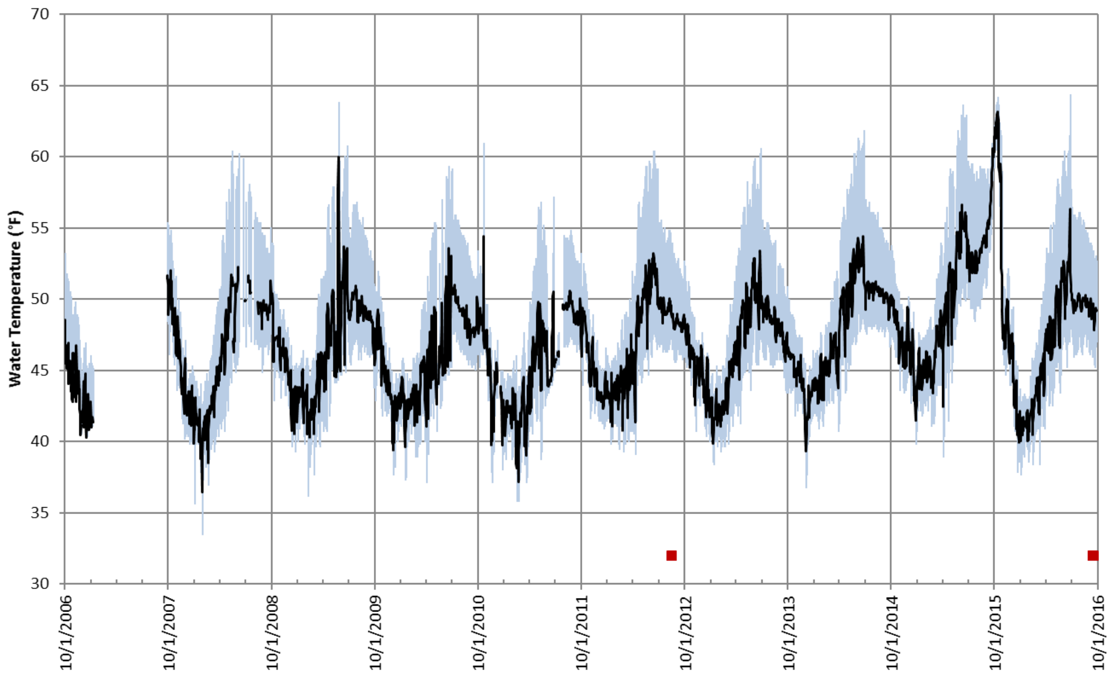

Figure 49. Daily average water temperature (black line) and daily water temperature range (blue lines) in Cherry Creek at Below Cherry Valley Dam gage (USGS 11277300) for WY 2007–2016. Snorkel surveys performed in August 2012 and September 2016 are identified by red markers.

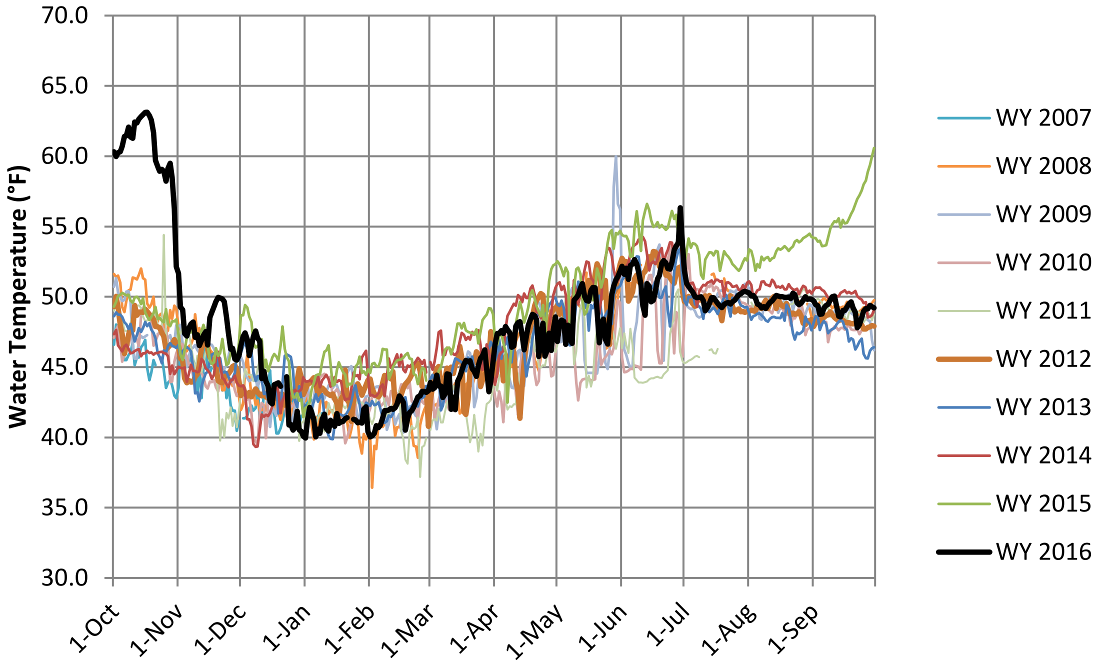

Figure 50. Daily average water temperature in Cherry Creek at Below Cherry Valley Dam gage (USGS 11277300) for WY 2007–2016, presented individually.

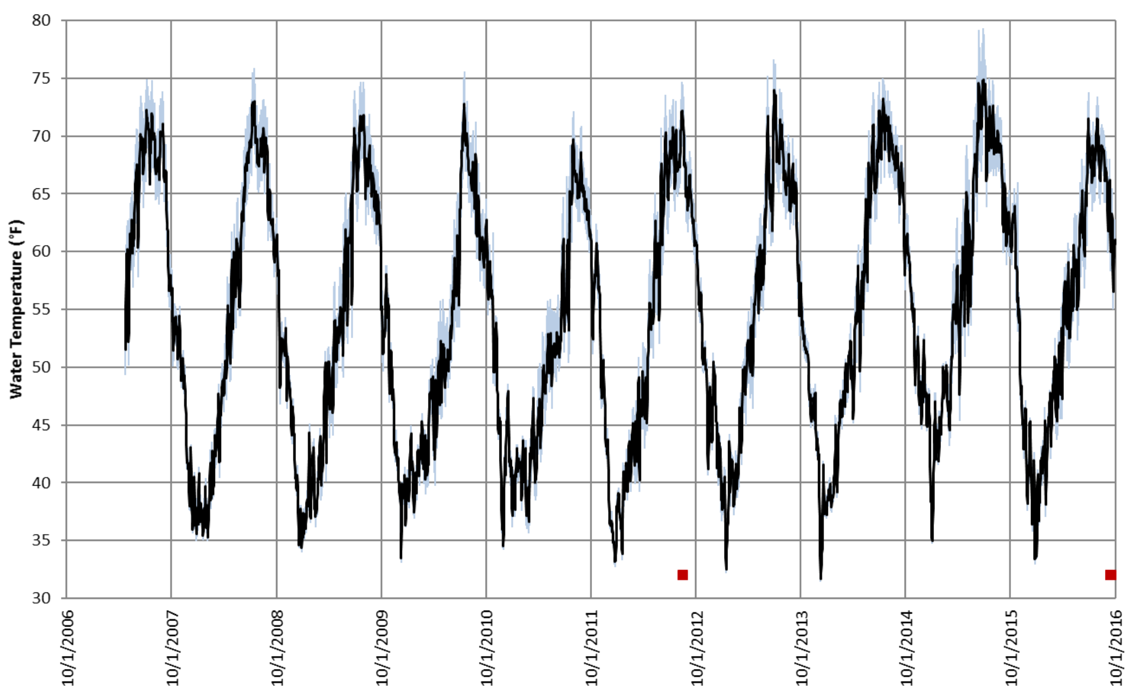

Figure 51. Daily average water temperature (black line) and daily water temperature range (blue lines) in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2007–2016. Snorkel surveys performed in August 2012 and September 2016 are identified by red markers.

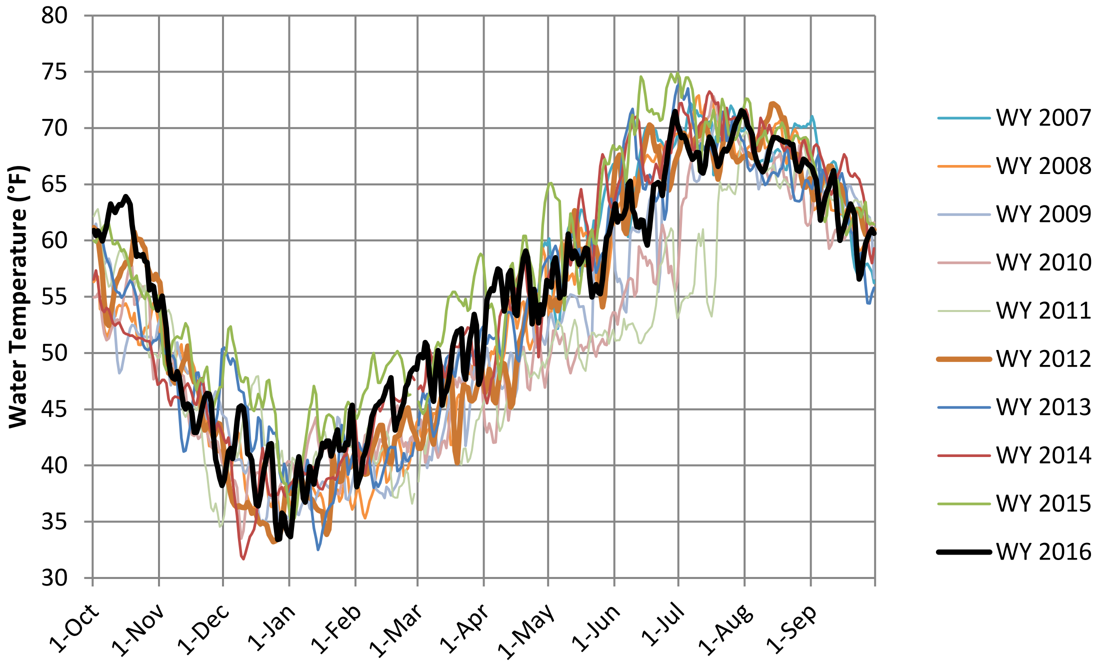

Figure 52. Daily average water temperature in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2007-2016, presented individually.

Table 43. Water temperatures for WY 2007-2016 at USGS gages at upstream and downstream end of Cherry Creek Reach.

Temperature metric	**Water year**									
	2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Below Cherry Valley Dam (USGS 11277300)										
Mean daily average	43.6	46.0	46.7	45.8	45.3	46.9	46.6	47.7	49.6	48.2
Minimum daily average	40.3	36.4	40.3	39.4	37.2	40.8	39.9	39.3	41.4	40.0
Maximum daily average	48.6	52.7	60.0	53.6	54.4	53.2	53.4	54.4	60.6	63.1
Minimum daily minimum	40.3	33.4	36.1	37.0	35.8	39.0	38.3	36.7	38.8	37.6
Maximum daily maximum	53.2	60.4	63.9	59.4	61.0	60.4	60.6	61.9	63.7	64.4
Above Holm Powerhouse (USGS 11278300)										
Mean daily average	65.5	53.1	52.6	51.3	50.9	53.5	54.1	54.7	57.4	54.7
Minimum daily average	51.6	35.3	34.4	33.5	34.5	33.2	32.5	31.7	35.0	33.4
Maximum daily average	72.2	73.0	71.8	72.8	69.7	72.2	74.0	73.3	74.9	71.5
Minimum daily minimum	49.3	34.9	34.0	33.1	34.2	32.7	32.2	31.5	34.7	32.9
Maximum daily maximum	74.9	75.9	74.7	75.6	72.1	74.7	76.6	75.0	79.3	73.8

7 CONCLUSIONS

7.1 Hetch Hetchy Reach

WY 2015 was one of the driest on record, following two other extremely dry water years and extending drought conditions in the region. Effects from the Rim Fire also remained evident with substantial amounts of sediment remaining stored in the channel in the absence of scouring flows that could mobilize these sediment deposits. These types of drought events can have a strong influence on habitat conditions and fish populations over varying time scales. WY 2016 reflected a more typical flow regime, including flows capable of scouring sediments stored in the channel that resulted from the Rim Fire and drought conditions.

Results from the 2015 monitoring indicated that Rainbow Trout density decreased in 2015 compared with 2014 in all three sub-reaches, and that Brown Trout density decreased in the Early Intake and O'Shaughnessy sub-reaches in 2015 compared with 2014. Monitoring results from 2016 indicated that Rainbow Trout density increased in the Early Intake and O'Shaughnessy sub-reaches and decreased in the Preston Falls sub-reach compared with 2015. Brown Trout densities similarly increased in the Early Intake and O'Shaughnessy sub-reaches and also increased for the Preston Falls sub-reach. Rainbow and Brown Trout densities in the Preston Falls sub-reach were frequently substantially higher than densities in the Early Intake and O'Shaughnessy sub-reaches, and strongly influence results that combine all three sub-reaches.

The densities of Rainbow and Brown Trout >125 mm in the Early Intake and O'Shaughnessy sub-reaches show a similar pattern for the 2014–2016 period, suggesting that similar environmental pressures were likely influencing these populations. It is unclear why Rainbow and Brown Trout densities in the Preston Falls sub-reach show different patterns compared with the Early Intake and O'Shaughnessy sub-reaches.

The observed decrease in density from 2014 to 2015 for the Early Intake and O'Shaughnessy sub-reaches could be explained by the extended drought conditions, and then densities rebounded as a result of increased flow conditions in 2016. For the Preston Falls sub-reach, the density of Rainbow Trout >125 mm shows a steady decline from 2014 to 2016, whereas the density of Brown Trout >125 mm was greatest in 2015 and least in 2016. Since water temperature and flow conditions in the Preston Falls sub-reach are expected to be intermediate to those in the Early Intake and O'Shaughnessy sub-reaches, these factors are not likely influencing trout populations differently in the Preston Falls sub-reach. Therefore, differences in density patterns in the Preston Falls sub-reach are more likely influenced by habitat conditions specific to the sub-reach. One potential contributing factor is the influence of the Rim Fire on habitat conditions in the Preston Falls sub-reach, including elevated fine sediments that could decrease invertebrate/food production and availability of overwinter refuge habitat for juvenile and adult trout. In addition, elevated nutrient levels resulting from the Rim Fire could affect productivity and water quality (e.g., levels of dissolved oxygen concentration).

Although density patterns for Rainbow and Brown Trout ≤125 mm were similar at the sub-reach level for the 2014–2016 period, these patterns did not translate directly to the patterns observed for trout >125 mm. For example, relatively high recruitment of Rainbow and Brown Trout ≤125 mm observed in the Preston Falls sub-reach in 2015 did not translate to an increase in the density of trout >125 mm in 2016.

The fish population monitoring approach and sampling framework developed in 2014 and implemented in 2014–2016 appear to be effective for efficiently sampling fish populations in key sub-reaches of the Hetch Hetchy Reach of the Tuolumne River, and for detecting changes in abundance from one year to the next and population trends over longer periods of time.

7.2 Above Hetch Hetchy Reservoir Reach

Monitoring of the Above Hetch Hetchy Reservoir Reach was initiated in 2016. Rainbow Trout densities in the Above Hetch Hetchy Reservoir Reach were within the range of densities observed in the Hetch Hetchy Reach for trout >125 mm and ≤125 mm. Brown Trout were observed at two of the four monitoring sites surveyed in 2016, but all Brown Trout >125 mm were observed at site 511-SP and all Brown Trout ≤125 mm were observed at site 510-PW. The density of Rainbow Trout >125 mm was relatively low at site 510-PW, compared with pocketwater habitat surveyed in the Hetch Hetchy Reach.

Streamflow and water temperature at the Above Hetch Hetchy gage are not affected by management and represent natural flow and water temperature regimes. The WY 2016 annual hydrograph showed a typical pattern compared with other water years during 2007–2015, although without an early-season high magnitude peak flow event as seen in some years. In WY 2016, mean daily streamflow was relatively high compared with other years during WY 2007–2015, particularly during October through May. Water temperature during WY 2016 appears typical compared with recent years, except for a short spike in water temperature during October that was associated with a corresponding spike in streamflow, resulting in relatively high water temperature for a short time.

7.3 Cherry Creek Reach

During WY 2016, drought conditions persisted in much of California and affected flows in Cherry Creek by eliminating the pattern of peak flows during the spring and early summer snowmelt runoff period (May–July) and in the fall and winter (September–February). Appreciable changes in the hydrograph seen in 2016 can have a strong influence on habitat conditions and fish populations over varying time scales.

Results from the 2016 monitoring effort in Cherry Creek indicated that Rainbow Trout densities were higher in 2016 compared with 2012 in the Upper Cherry sub-reach and lower in 2016 compared with 2012 in the Lower Cherry sub-reach. Although the exact causes are uncertain, the differences likely resulted from a combination of factors related to drought conditions in 2012–2015 (e.g., high water temperatures and low flows) and effects of the Rim Fire (e.g., increased sediment and nutrient loading).

Water temperature also appears to have a strong influence on trout density, with relatively low trout density at sites located near Cherry Valley Dam where water temperatures typically remain below 55°F throughout the year.

The fish population monitoring approach and sampling framework for Cherry Creek appear to be effective for efficiently sampling fish populations in key habitat units and for detecting changes in abundance from year to year and population trends over longer periods of time.

8 RECOMMENDATIONS

8.1 Hetch Hetchy Reach

Minor modifications to the suite of monitoring sites sampled in the O’Shaughnessy sub-reach during 2014 were applied in 2015 as they were likely to be beneficial for evaluating long-term trends in trout populations. Decreasing the number of shallow pool sites sampled from two to one and adding a deep pool site more closely represents the existing relative frequency (by length) of habitat types in the sub-reach. This was achieved by adding site 223-DP and removing site 249-SP. Site 223-DP was sampled in 2014 and had high densities of trout relative to other monitoring sites in the O'Shaughnessy sub-reach that year, so continuing to monitor this site made sense, even though it was not sampled in 2015. Sites 249-SP and 267-SP were both sampled during 2014 and 2015. Both Brown and Rainbow Trout were observed in site 267-SP in 2014 and 2015, and monitoring this shallow pool should continue to contribute useful data. No trout were observed at site 249-SP in 2015, and only low densities were found there in 2014; dropping site 249-SP therefore made sense as a way of better representing the proportion of habitats in this reach. In 2016, monitoring sites surveyed in the O'Shaughnessy sub-reach provided the best representation of habitats within the sub-reach to date.

For 2017, sampling should continue in the same monitoring sites in the O'Shaughnessy sub-reach that were sampled in 2016 (Table 41). Similarly, for the Preston Falls sub-reach, monitoring sites should remain the same as sampled in 2016. For the Early Intake sub-reach, sampling at site 38-DP should be discontinued for 2017 and future surveys; otherwise, monitoring sites should remain the same as sampled in 2016. Future fisheries monitoring is scheduled for mid-September to ensure streamflow is within a range of 70–100 cfs.

Table 44. O'Shaughnessy sub-reach monitoring site modifications.

Year	O'Shaughnessy sub-reach monitoring sites				
	Site 223 deep pool	**Site 227 deep pool**	**Site 229 pocketwater**	**Site 249 shallow pool**	**Site 267 shallow pool**
2014	Sampled	Sampled	Not included	Sampled	Sampled
2015	Not included	Sampled	Site added and sampled	Sampled	Sampled
2016	Sampled	Sampled	Only lower half sampled (high water)	Dropped	Sampled
2017 recommendations	Continue monitoring	Continue monitoring	Continue monitoring full site	Discontinue monitoring	Continue monitoring

8.2 Above Hetch Hetchy Reservoir Reach

Monitoring sites in the Above Hetch Hetchy sub-reach were added in 2016, and will continue to be sampled in 2017 to help understand the effects of managed flows on long-term population trends. The number of sites sampled in the Above Hetch Hetchy Reservoir Reach may be adjusted or expanded in 2017. Any adjustments or expansion of sampling sites in 2017 should consider the criteria used to select monitoring sites in the Hetch Hetchy and Cherry Creek reaches.

8.3 Cherry Creek Reach

Minor modifications to the suite of monitoring sites sampled in Cherry Creek would likely be beneficial for evaluating long-term trends in trout populations. Increasing the number of boulder garden habitats surveyed would more closely represent the existing frequency of habitat types by length found in Cherry Creek. In addition, sampling more than one boulder garden habitat would allow assessment of whether Rainbow Trout densities are higher in this habitat type relative to other habitat types surveyed, or if the higher abundance was driven by the survey site's proximity to the confluence with Eleanor Creek and its potential increases in food inputs, or preferential water temperatures. Removing site 32-DP from the survey is also recommended, as this habitat unit was long with sandy substrate and was not representative of other deep pools in Cherry Creek.

9 REFERENCES

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