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Upper Tuolumne River Ecosystem Program Hetch Hetchy Reach Fisheries Monitoring Revised Sampling Approach and 2014 Results

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Cover photo: Aquatic habitat in the Preston Falls subreach during fall 2014.

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1 INTRODUCTION AND PURPOSE

Since 2007, the San Francisco Public Utilities Commission (SFPUC) has conducted annual monitoring of fish populations in the Upper Tuolumne River between O'Shaughnessy Dam and Early Intake (the Hetch Hetchy Reach). Annual monitoring of fish populations in the Hetch Hetchy Reach serves as a basis for evaluating aquatic habitat conditions, and assists in understanding whether changes in downstream flow release management at O'Shaughnessy Dam as part of the SFPUC's Upper Tuolumne River Ecosystem Program (UTREP) result in measureable and meaningful effects on the fish populations over time. To better focus field surveys on monitoring objectives and develop a more efficient and effective sampling strategy, the existing fish population monitoring approach was re-evaluated, and as a result, monitoring site locations and field methods were modified for 2014 and future years from those used previously (i.e., 2007–2010).

Given the management focus of regulatory agencies to support sport fishing values, fish population monitoring in the Hetch Hetchy Reach has focused, and will continue to focus, on native rainbow trout (*Oncorhnychus mykiss*) and non-native brown trout (*Salmo trutta*). Other native fish species that are observed in the reach include riffle sculpin (*Cottus gulosus*), California roach (*Lavinia symmetricus*), and Sacramento sucker (*Catostomus occidentalis*). These non-salmonid species have, thus far, only been observed downstream of Preston Falls.

The purpose of this technical memorandum is to provide a summary of the sampling approach developed for 2014 and future fish population monitoring surveys, field methods, and monitoring results. Because 2014 was the first year of implementing a newly revised sampling approach, results generally focus on data from this year. Estimates of abundance and linear density of trout are given. In addition, limited comparisons with data collected previously are presented. After multiple years of monitoring data are available using this approach, evaluating trends and potential effects of the UTREP flow management will be possible.

2 SAMPLING APPROACH

The revised sampling approach was designed to evaluate the trout (rainbow and brown) population at a sufficient level of detail to detect meaningful differences over time. The approach focuses sampling on locations that are likely to provide "good" habitat conditions for trout based on the Stillwater Sciences conceptual model of factors affecting habitat use in the Hetch Hetchy Reach. In this context, "good" habitat refers to habitat units 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. This focused sampling approach is appropriate for the objective of evaluating trends in the trout population over time (for the sites sampled), but is not appropriate for developing a population estimate for the entire Hetch Hetchy Reach.

The sampling framework uses U.S. Fish and Wildlife Service (USFWS) habitat typing (1992) to define the distribution and abundance of aquatic habitat in the reach. Monitoring sites were selected from within this framework based on criteria developed to meet sampling objectives and key sampling considerations, including selecting sites that could be effectively sampled using snorkel methods for estimating fish population abundance.

The primary sampling objective was to incorporate methods that control statistical bias and allow sample variance and confidence intervals to be calculated for abundance estimates. These methods improve the ability to detect differences among sites, differences among the sampled subreaches, and changes over time that are statistically significant or not. Reducing sampling variability whenever possible is critical to the sampling approach because a result of reducing effort for efficiency can be an increase in sample variance, which can reduce the ability to detect meaningful differences and changes.

Key sampling considerations included:

- Efficiency. Sampling efficiency is largely driven by site selection. Generally, sampling sites should be representative of the classified habitat type. The travel time to a site and the time required to sample a site are primary considerations for improving efficiency. Other considerations include survey set-up time and travel time between sites.
- Effectiveness. Sampling effectiveness is based on the ability of observers to see and accurately identify and count fish present within a monitoring site. Snorkel methods are most effective in habitats with good water clarity, moderate water depths, and low-to-moderate habitat complexity. Deep pools, shallow riffles, and complex habitat such as boulder garden-pocketwaters can be difficult to sample effectively.
- Repeatability. The repeatability of surveys at a given site is strongly influenced by factors affecting the ability to effectively sample the site. Additional factors that can improve repeatability include sampling at the same time of year and using the same field crew as much as possible each year to ensure year-to-year consistency in sampling.

3 MONITORING SITES

3.1 Site Selection

Monitoring sites were selected based on criteria developed to meet the sampling objectives. These selection criteria were intended to focus effort on sites that can be efficiently and effectively sampled, with high repeatability, and that likely support a range of trout age- and size-classes.

The following criteria were used to guide site selection:

- The site is representative of a given subreach;
- The site has reasonably safe and efficient access;
- Sample length is limited to approximately 100 to 300 feet (ft), and sample width is such that five snorkelers maximum would be needed;
- The site can be effectively sampled using snorkel methods (e.g., pool, run, and pocketwater), and is not too deep or complex;
- The site a has riffle, pocketwater, or cascade of at least moderate length upstream to control for food supply;
- The site has clear upstream and downstream boundaries; and
- The site avoids large deep pools with little cover or complexity where suitable habitat is almost exclusively at the extreme upstream end.

An initial pool of potential monitoring sites (habitat units) were identified for the Early Intake, Preston Falls, and O'Shaughnessy subreaches based on the site selection criteria described above. Habitat unit lengths were based on the USFWS geographic information system habitat unit polygon coverage and associated attributes. Other site selection criteria, such as width, depth, and complexity, were initially evaluated using orthophotography of the Hetch Hetchy Reach with a GIS overlay of the USFWS habitat unit boundaries.

The initial pool of potential monitoring sites was refined based on site reconnaissance conducted on July 14–16, 2014. During this effort, potential monitoring sites were visited and evaluated for their suitability. In some cases, only a portion of a habitat unit was considered feasible to sample, and the proposed site boundaries were adjusted accordingly. The final pool of potential monitoring sites, including alternate sites in case adjustments were needed in the field, were prioritized based on site reconnaissance considering the selection criteria above, and used as a guide during the 2014 fish population monitoring surveys.

3.2 Surveyed Sites

A total of 16 monitoring sites were sampled during 2014 fish population monitoring surveys: six in the Early Intake subreach, six in the Preston Falls subreach, and four in the O'Shaughnessy subreach (Table 1, Figure 1). Monitoring sites included deep pool, shallow pool, and pocketwater habitat types. These three habitat types comprise about 75 to 90 percent of the subreaches sampled (Table 2). Run, riffle, cascade, and chute habitat types were not represented because they did not meet the site selection criteria, there was very little representation within the subreaches sampled, or both.

The length of each monitoring site sampled was estimated with GIS using the polygon coverage (.kmz) defining upstream and downstream boundaries (provided by the SFPUC), orthorectified aerial photography, and Tuolumne River "center line" stationing (both provided by McBain Associates). Length estimates were used to calculate fish density (fish/1,000 ft) at each site to adjust for variable site lengths and facilitate making relative comparisons between sites, reaches, and years.

Sampling coverage by length was 10 percent, 11 percent, and 8 percent for the Early Intake, Preston Falls, and O'Shaughnessy subreaches, respectively (Table 3). Within the subreaches, sampling coverage by length for deep pool, shallow pool, and pocketwater habitat types was 7–14 percent, 24–38 percent, and 0–14 percent, respectively (Table 3).

Table 1. 2014 fish population monitoring sites and estimated surveyed lengths.

Site #[1]	Habitat type[1]	Stationing[2]		Surveyed length (ft)
		Downstream	Upstream	
Early Intake				
11	Shallow Pool	150,869	151,022	153
13	Deep Pool	151,119	151,313	194
18	Pocketwater	153,819	153,966	147
27	Shallow Pool	155,909	156,182	273
34	Deep Pool	158,217	158,389	172
37	Pocketwater	159,119	159,237	118
Preston Falls				
44	Pocketwater	160,389	160,556	167
46	Deep Pool	160,588	160,766	179
49	Shallow Pool	160,954	161,107	153
56	Deep Pool	161,897	162,141	244
74	Deep Pool	167,742	167,992	250
76	Shallow Pool	168,153	168,299	146
O'Shaughnessy				
223	Deep Pool	202,988	203,219	231
227	Deep Pool	203,478	203,623	146
249	Shallow Pool	207,276	207,451	175
267	Shallow Pool	210,226	210,481	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] Based on the GIS center line for the Tuolumne River (data provided to Stillwater Sciences by McBain Associates).

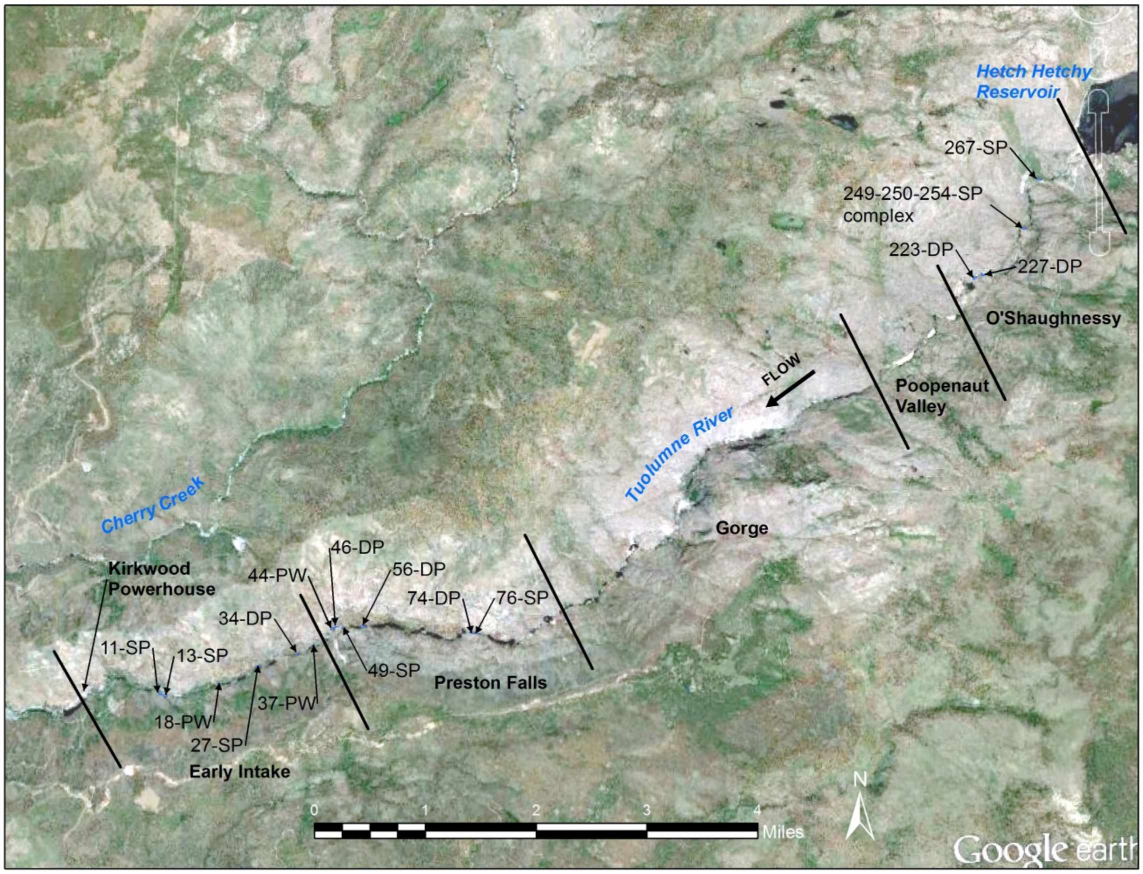


Figure 1. 2014 fish population monitoring site locations.

Table 2. Habitat type composition (percent) by length in study subreaches.

Study reach	Habitat type*							
	DP	SP	Run	Rif	CA	PW/CA	PW	CH
Early Intake	23	12	5	0	0	7	53	0
Preston Falls	66	12	2	1	2	5	11	1
O'Shaughnessy	55	11	<1	7	4	6	10	6

* DP = deep pool, SP = shallow pool, Run = run/glide, Rif = riffle, CA = cascade, PW/CA = pocketwater/cascade, PW = pocketwater, CH = chute

Table 3. Percent sampling coverage of habitat types by length in study subreaches.

Study reach	Habitat type			
	Deep pool	Shallow pool	Pocketwater	All types
Early Intake	14	33	5	10
Preston Falls	10	24	14	11
O'Shaughnessy	7	38	0	8

4 METHODS

Fish population monitoring surveys were performed during August 25–29, 2014. Three-pass bounded-count snorkel surveys were performed at each of the 16 monitoring sites. Field crews generally consisted of five snorkelers and one data recorder. Snorkelers entered the stream downstream from the monitoring site and snorkeled in an upstream direction, each within a designated lane. Snorkelers identified, counted, and visually estimated total length (TL) of the fishes in their own snorkel lane while moving upstream at a slow, even, and uniform pace. Dive slates were used to keep track of fish data during each snorkel pass, 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.

The three-pass method allows a population estimate and confidence intervals to be computed using a bounded counts estimator (Routledge 1982), rather than assuming that observed fish counts represent the total population for each site. The bounded count estimates true fish abundance by taking the difference between the highest count and next highest count from the multiple passes and adding this difference back to the highest count. The bounded counts method also allows an error estimate to be calculated. This method assumes that each pass misses some of the fish and no fish are counted twice during a pass. It also assumes that any set of fish counts is uniformly distributed between zero and the true total so that the difference in counts between any two counts represents the number missed in the highest count.

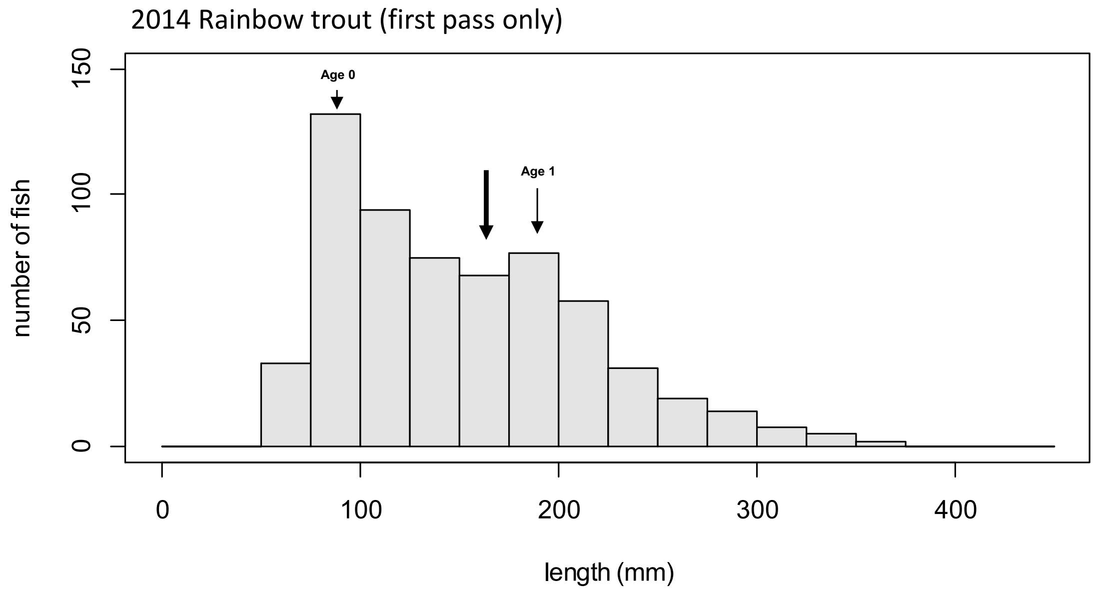
5 RESULTS AND DISCUSSION

5.1 Length and Age

Length data from monitoring surveys were used to identify a length threshold for differentiating age-0 from age-1 and older trout. Length class distributions for rainbow and brown trout based on 2014 data are slightly different from those based on data compiled for 2007–2010 monitoring (Figures 2 and 3). During the 2007–2010 monitoring period, age-0 and age-1 brown trout were slightly larger than rainbow trout of the same age, as was expected based on differences in spawning and emergence timing between the two species. In 2014, however, age-1 rainbow trout were apparently a bit larger than age-1 brown trout, and the threshold between age-0 and age-1 was slightly larger for rainbow trout compared with brown trout. During 2014, age-0 rainbow trout were more abundant than age-1 rainbow trout, as indicated by the relatively greater number of fish having lengths of about 50–160 millimeters (mm) compared with 160–235 mm. The difference in abundance between age classes was not evident based on the 2007–2010 monitoring data. Rainbow and brown trout were slightly larger in 2014 compared with 2007–2010. Potential factors influencing increased growth in 2014 could be associated with the following:

- The Rim Fire. Fire-related mortality factors such as increased fine sediment may have decreased rearing densities and reduced competition. Increased nutrients may have increased some food resources.
- Drought. Mild spring conditions resulted in an earlier and longer growing season.
- Water Temperature. Warmer than normal conditions promoted growth (closely related to drought conditions).
- Monitoring Sites. Sites were preferentially selected for conditions supporting “good” growth and production.

Both the 2014 and 2007–2010 data indicate substantial overlap between age classes, which is common with length-frequency data since fish emerge at different times and grow at different rates based on competition and their environment. The size distribution of rainbow trout observed during the 2007–2010 surveys suggests a length threshold of about 3.5 in (85 mm) between age-0 and age-1 based on mixture modeling (Figure 4). Observed age-0 brown trout were somewhat larger, with a length threshold between age-0 and age-1 of about 4 in (105 mm) based on mixture modeling (Figure 4). The same mixture modeling analysis was not performed for the 2014 data due to relatively small sample size; however, 2014 data indicate that the size threshold between age-0 and age-1 for rainbow and brown trout is closer to 5 in (125 mm).



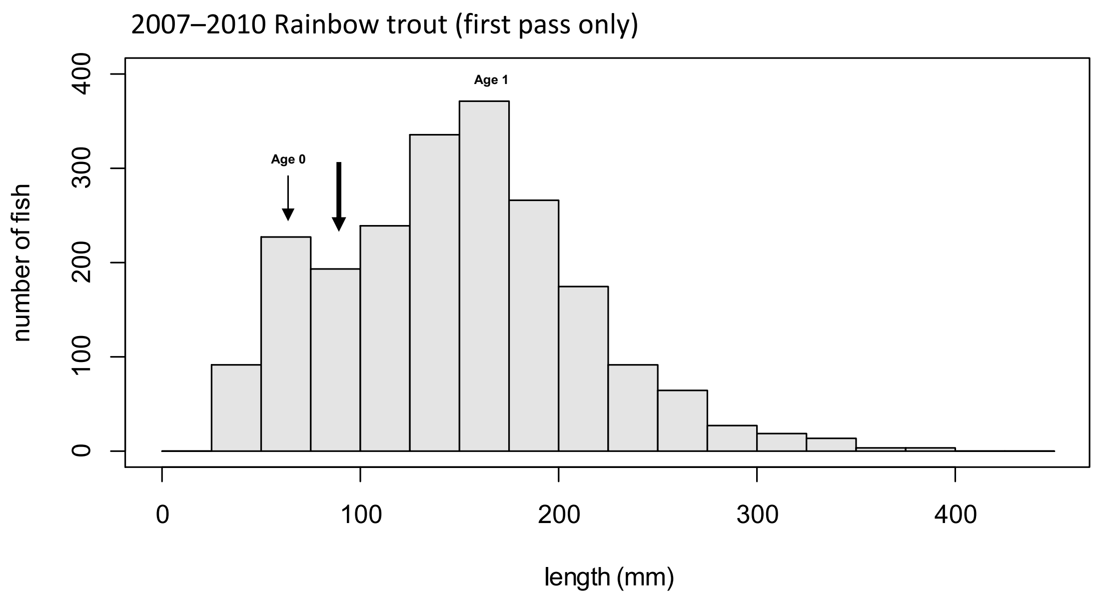
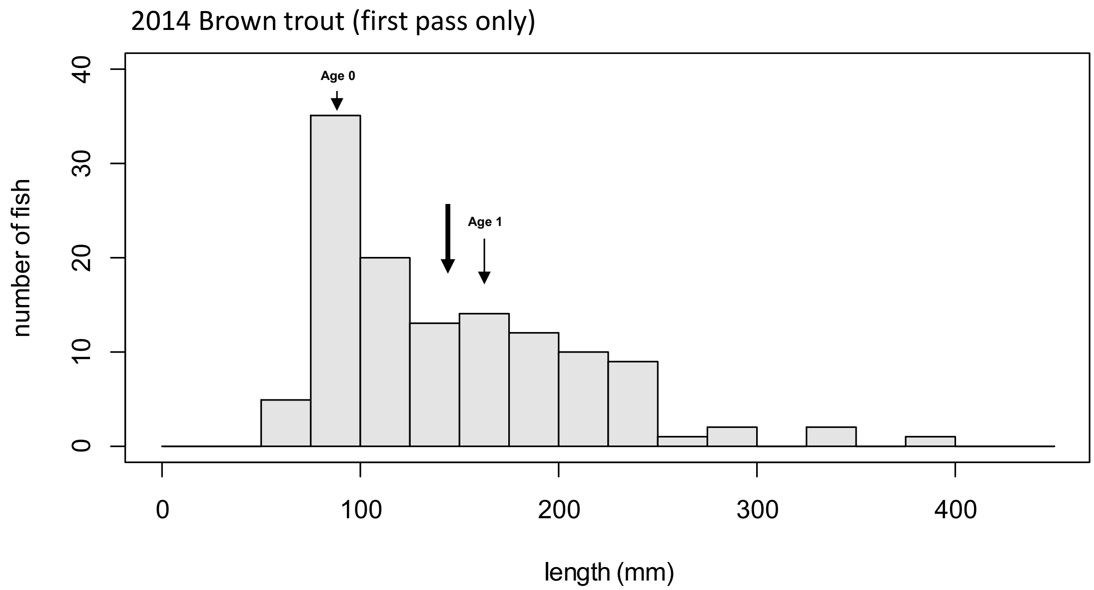


Figure 2. Length class distribution for rainbow trout (*O. mykiss*) for 2014 (upper) and 2007–2010 (lower) sampling periods, based on all monitoring sites surveyed using first pass only. Large arrows indicate the approximate threshold between age-0 and age-1 trout.



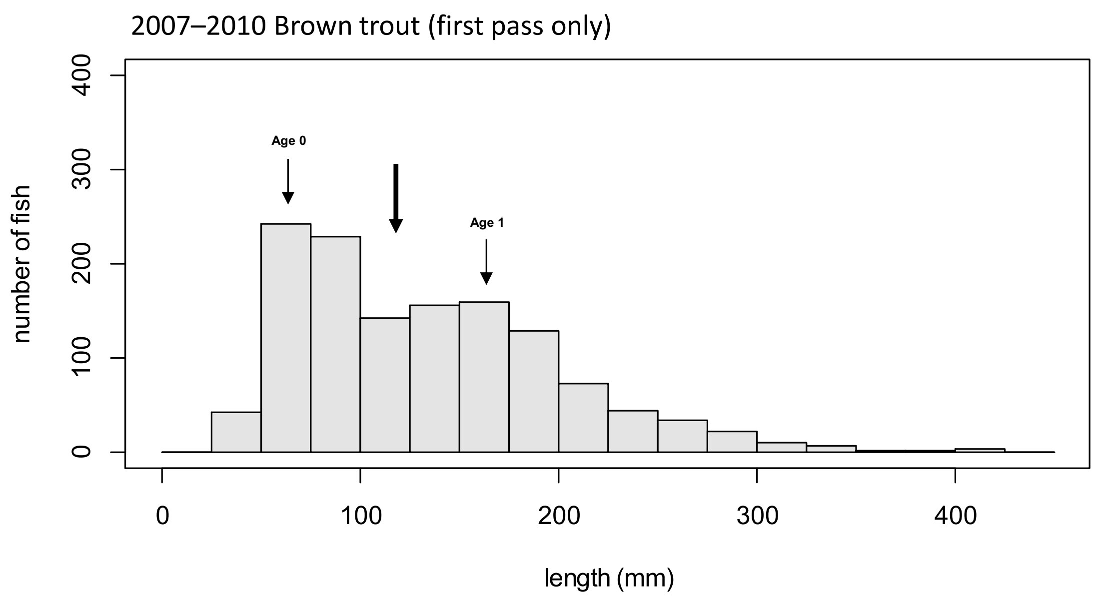


Figure 3. Length class distribution for brown trout (*S. trutta*) for 2014 (upper) and 2007-2010 (lower) sampling periods, based on all monitoring sites surveyed using first pass only. Large arrows indicate the approximate threshold between age-0 and age-1 trout.

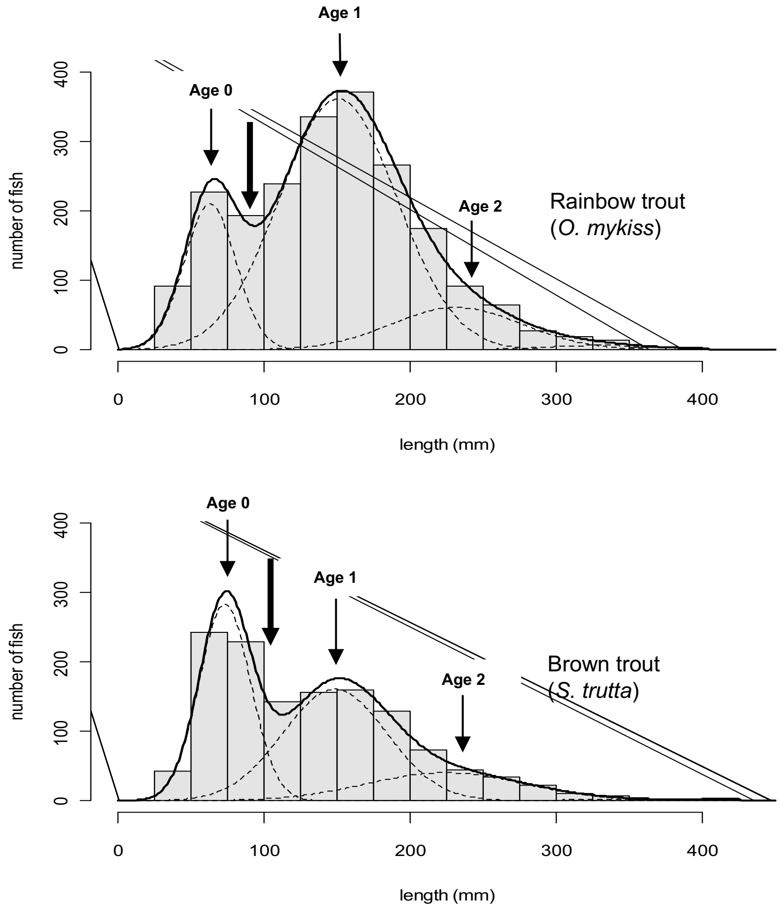


Figure 4. Size distributions of rainbow trout and brown trout observed during snorkel surveys (2007–2010). Histograms show the actual counts seen in all sites in all surveys (using only first-pass data from sites with multiple-passes). The solid lines show normal-mixture models fitted using the mix algorithm with the R program; the individual estimated components are shown as dotted lines and represent estimates of age class distribution (i.e., age-0 corresponds to the furthest left curve, age-1 corresponds to the second from the left). Large arrows indicate the approximate threshold between age-0 and age-1 trout.

5.2 Abundance and Relative Abundance

Annual fish population abundance results presented below focus on age-1 and older trout to reduce the effect of annual variations in the numbers of age-0 fry, which can reduce the ability to detect meaningful trends in the population of older juveniles and adults. Fry abundance commonly fluctuates substantially from year to year based on spawning and incubation success, and generally is not a good indicator of the abundance of older age classes, which are typically more limited by habitat quantity and quality.

The 2014 fish population monitoring results for trout abundance, relative abundance, and density are presented below both for trout ≥125 mm (Tables 4 through 9, Figures 5 through 7) and ≥100 mm (Tables 10 through 15, Figures 8 through 10). Results for both length thresholds were prepared to assess whether substantial differences between these size thresholds were evident, and due to uncertainty in knowing which threshold may be most appropriate in future years.

Observed differences between results for a length threshold of 100 mm vs. 125 mm are generally minor. Results (summary tables and figures) for both thresholds are included here for completeness in Sections 5.2.1 and 5.2.2. The following summary of 2014 monitoring results for abundance, relative abundance, and density focuses on trout ≥125 mm.

Total trout abundance estimates for all sites combined were 504, 92, and 606, for rainbow, brown, and all trout, respectively (Table 5). Note that estimates for all trout include unidentified trout that are not considered in the species-specific estimates. The ratio of rainbow trout to brown trout was 5.5:1 for all sites combined, and ranged from 1.0:1 to 14.3:1 at individual monitoring sites (Tables 4 through 6). Trout abundance and density at monitoring sites were greatest in the Preston Falls subreach and least in the O'Shaughnessy subreach. Density estimates for all trout at monitoring sites generally were within the range of 100 to 300 fish/1,000 ft (Tables 7–9), with only a few sites standing out as having relatively high (i.e., sites 74 and 76) or low (i.e., sites 249 and 267) density.

Confidence intervals (95 percent) for abundance estimates appear relatively narrow, and would presumably show statistically significant differences in densities between sites (although t-tests or other statistical comparisons have not been performed) (Figures 5 through 10). Narrow confidence intervals support the notion that the sampling approach developed and implemented in 2014 will likely be sufficient to identify trends and detect statistically significant differences in trout abundance if substantial and meaningful changes to the trout population occur in the future.

Note that monitoring sites 46 and 49, and to a lesser degree site 44, were particularly affected by coarse sediment (i.e., sand and gravel) supplied to the reach subsequent to the Rim Fire. Sediment from a small tributary entering from the north at the upstream end of site 49 formed a large alluvial delta fan deposit. In the case of site 46, the pool had been filled and would no longer be considered deep. Based on conditions at these monitoring sites in 2014, the sites will be of particular 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 at these sites.

5.2.1 Trout ≥125 mm

Table 4. 2014 abundance estimates for rainbow and brown trout ≥125 mm by monitoring site.

Site #	Habitat type	Rainbow	Brown	All trout	Rainbow/brown
Early Intake					
11	Shallow Pool	12 (±2)	3 (±2)	21 (±10)	4.0
13	Deep Pool	22 (±8)	2 (±2)	27 (±12)	11.0
18	Pocketwater	26 (±6)	3 (±2)	35 (±14)	8.7
27	Shallow Pool	40 (±22)	7 (±2)	47 (±22)	5.7
34	Deep Pool	10 (±4)	7 (±4)	25 (±14)	1.4
37	Pocketwater	27 (±6)	4 (0)	33 (±8)	6.8
Preston Falls					
44	Pocketwater	27 (±4)	0 (0)	27 (±2)	n/a
46	Deep Pool	28 (±12)	3 (±2)	31 (±14)	9.3
49	Shallow Pool	27 (±14)	2 (±2)	31 (±18)	13.5
56	Deep Pool	49 (±8)	11 (±8)	53 (±2)	4.5
74	Deep Pool	94 (±27)	32 (±16)	110 (±12)	2.9
76	Shallow Pool	67 (±31)	10 (±2)	77 (±29)	6.7
O'Shaughnessy					
223	Deep Pool	43 (±4)	3 (±2)	53 (±12)	14.3
227	Deep Pool	17 (±6)	2 (±2)	17 (±6)	8.5
249	Shallow Pool	2 (±2)	2 (±2)	4 (±4)	1.0
267	Shallow Pool	13 (±4)	1 (0)	15 (±6)	13.0

n/a = not applicable

Table 5. 2014 abundance estimates for rainbow and brown trout ≥125 mm by subreach.

Subreach	Rainbow	Brown	All trout	Rainbow/brown
Early Intake	137 (±25)	26 (±6)	188 (±34)	5.3
Preston Falls	292 (±46)	58 (±18)	329 (±39)	5.0
O'Shaughnessy	75 (±8)	8 (±3)	89 (±15)	9.4
All subreaches	504 (±53)	92 (±19)	606 (±54)	5.5

Table 6. 2014 abundance estimates for rainbow and brown trout ≥125 mm by habitat type.

Habitat type	Rainbow	Brown	All trout	Rainbow/brown
Shallow Pool	161 (±41)	25 (±4)	195 (±42)	6.4
Deep Pool	263 (±33)	60 (±18)	316 (±29)	4.4
Pocketwater	80 (±9)	7 (±2)	95 (±16)	11.4
All habitats	504 (±53)	92 (±19)	606 (±54)	5.5

Table 7. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥125 mm by monitoring site.

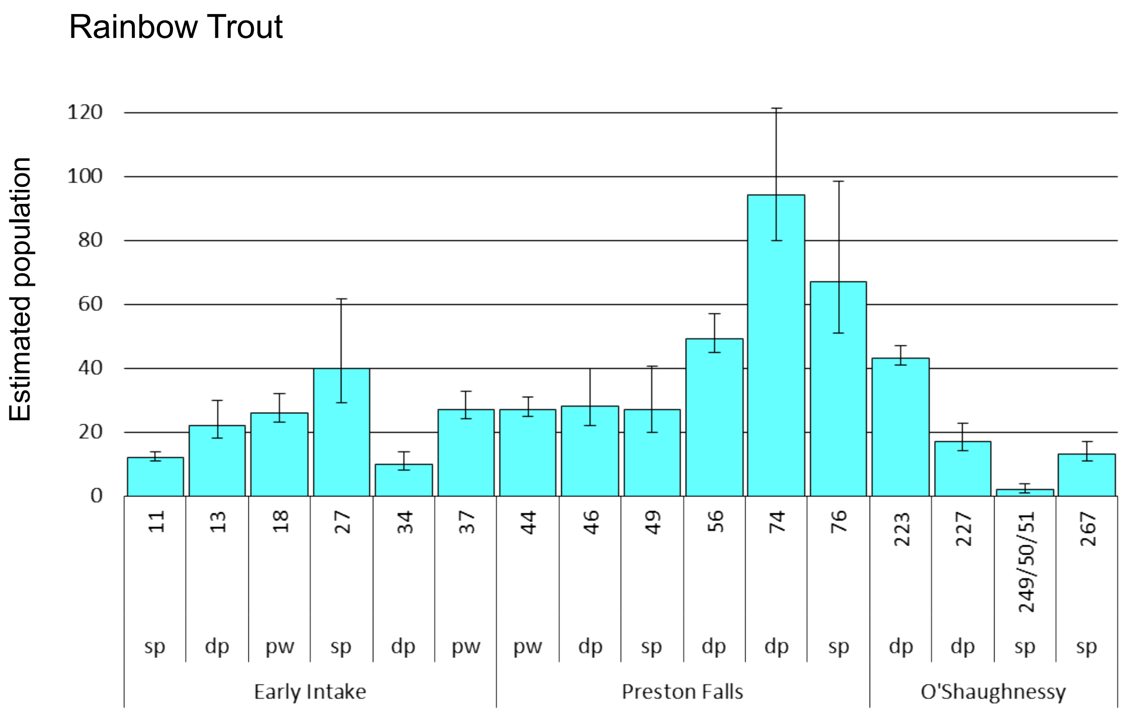
Site #	Habitat type	Rainbow	Brown	All trout
Early Intake				
11	Shallow Pool	78	20	137
13	Deep Pool	114	10	139
18	Pocketwater	177	20	238
27	Shallow Pool	146	26	172
34	Deep Pool	58	41	146
37	Pocketwater	228	34	279
Preston Falls				
44	Pocketwater	161	0	161
46	Deep Pool	157	17	174
49	Shallow Pool	177	13	203
56	Deep Pool	201	45	217
74	Deep Pool	376	128	440
76	Shallow Pool	457	68	526
O'Shaughnessy				
223	Deep Pool	186	13	230
227	Deep Pool	117	14	117
249	Shallow Pool	11	11	23
267	Shallow Pool	51	4	59

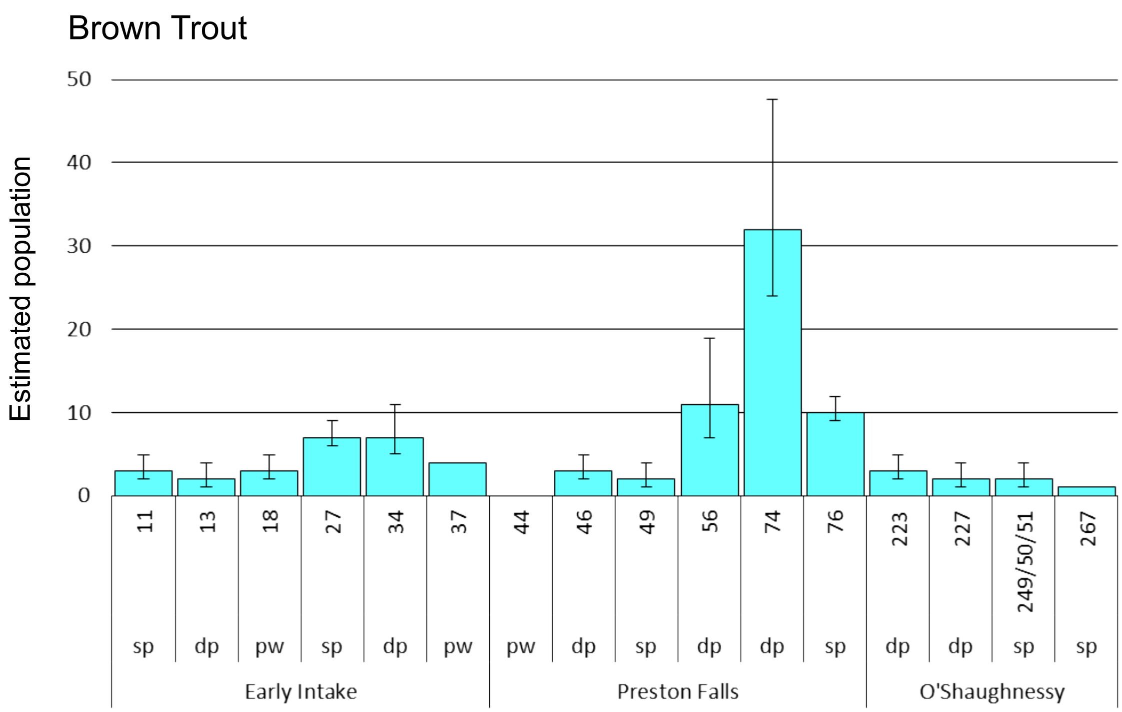
Table 8. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥125 mm by subreach.

Subreach	Rainbow	Brown	All trout
Early Intake	130	25	178
Preston Falls	256	51	289
O'Shaughnessy	93	10	110
All Subreaches	168	31	202

Table 9. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥125 mm by habitat type.

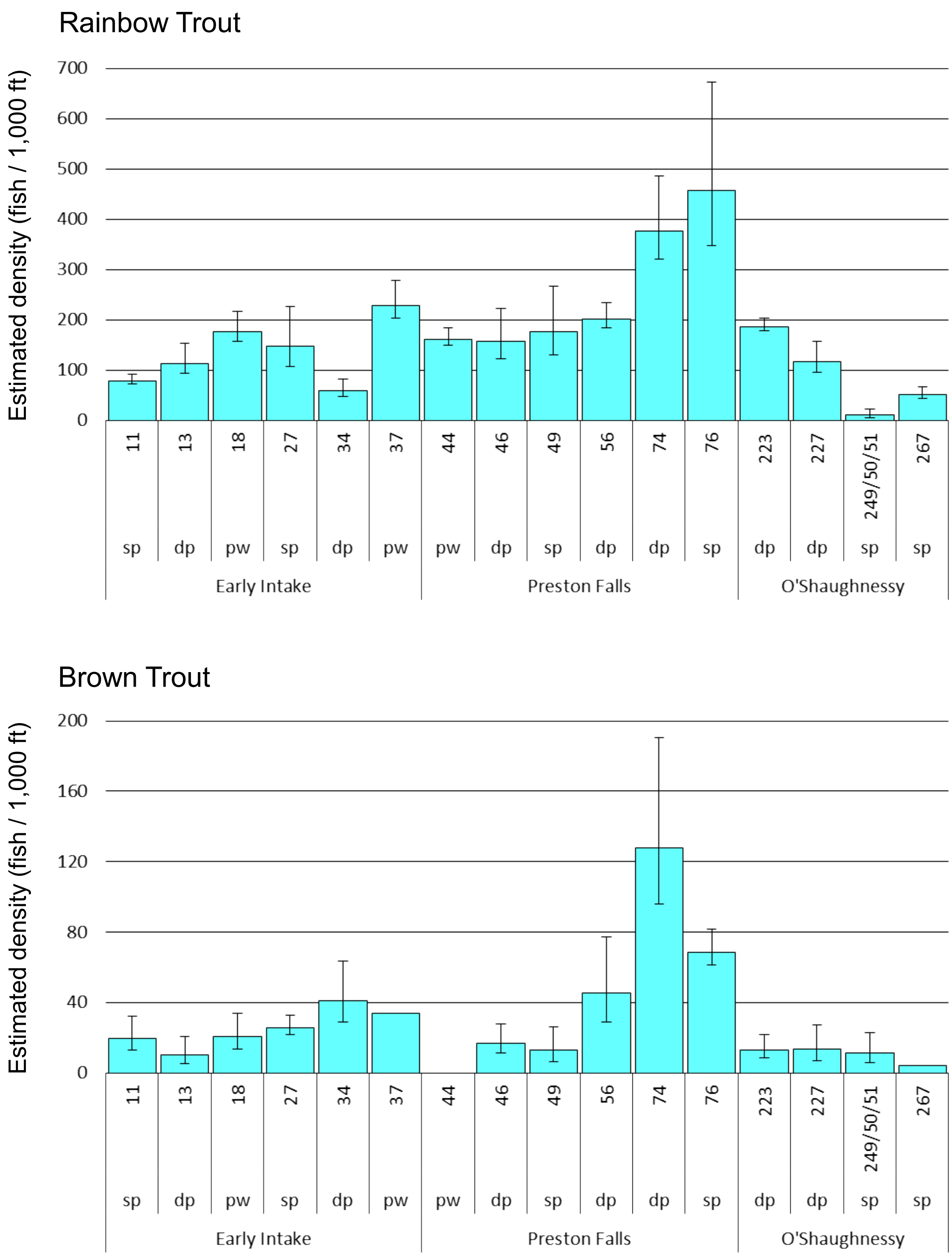
Habitat type	Rainbow	Brown	All trout
Shallow Pool	139	22	169
Deep Pool	186	42	223
Pocketwater	185	16	220
All habitats	168	31	202





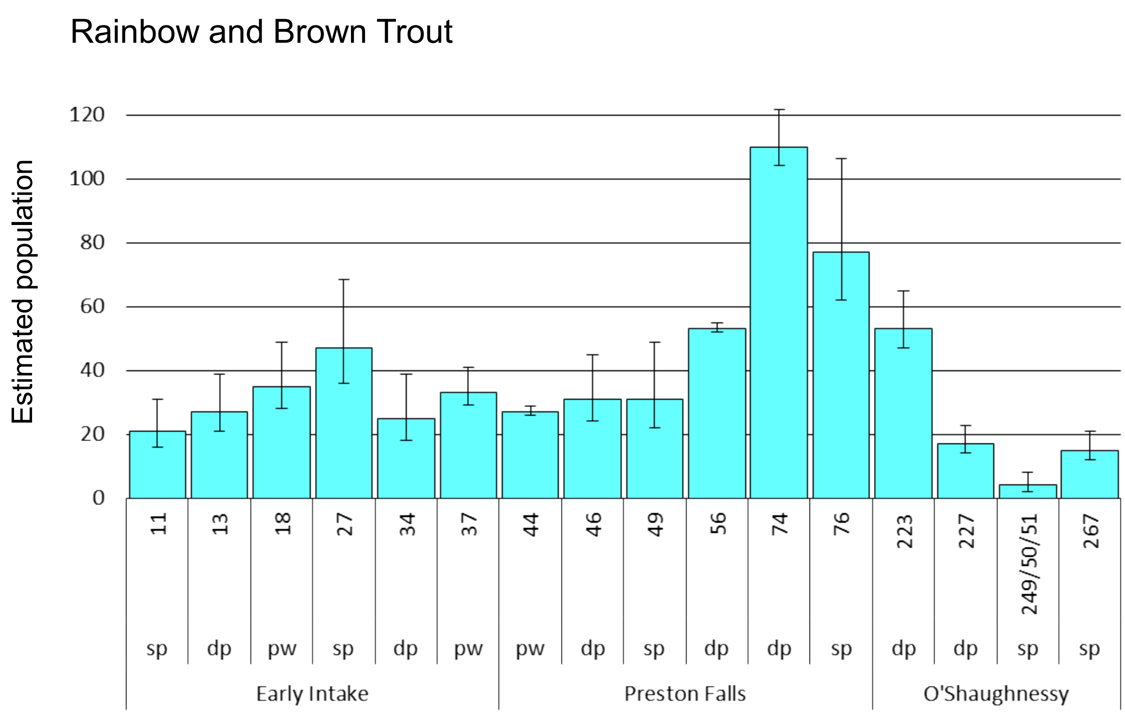
sp = shallow pool, dp = deep pool, pw = pocketwater

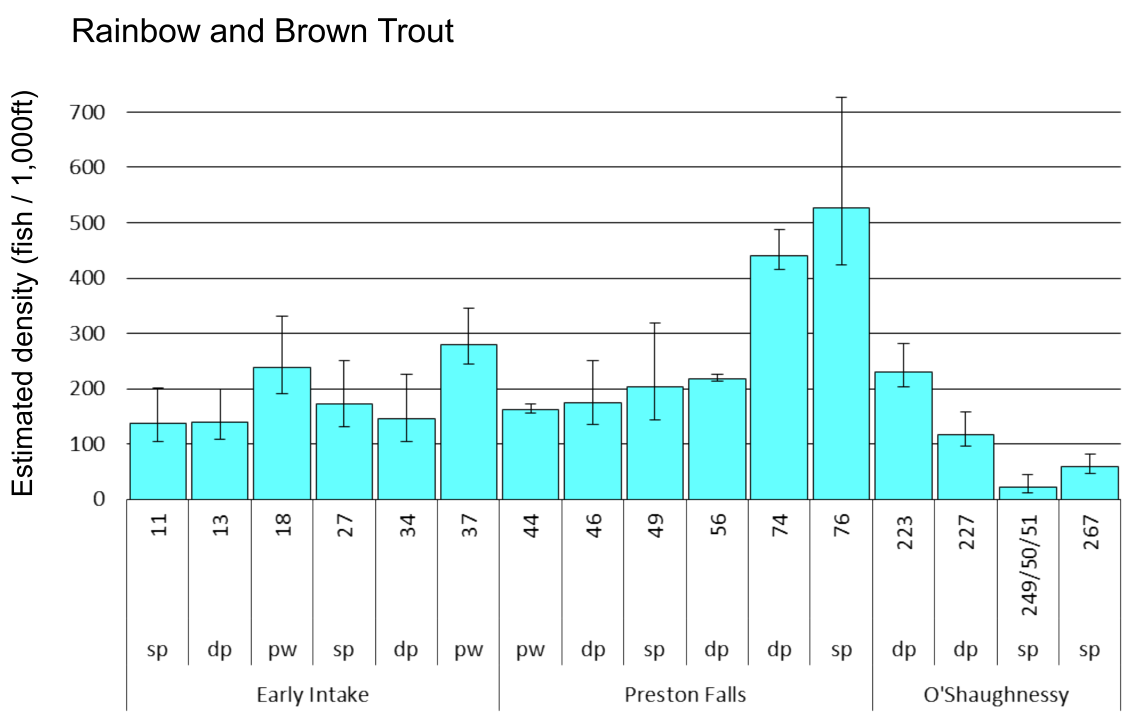
Figure 5. Estimated abundance of rainbow and brown trout with fork-length ≥125 mm by survey site during 2014.



sp = shallow pool, dp = deep pool, pw = pocketwater

Figure 6. Estimated linear density (fish/1,000 ft) of rainbow and brown trout with fork-length ≥125 mm by survey site during 2014.





sp = shallow pool, dp = deep pool, pw = pocketwater

Figure 7. Estimated abundance and linear density (fish/1,000 ft) of rainbow and brown trout (combined) with fork-length ≥125 mm by survey site during 2014.

5.2.2 Trout ≥100 mm

Table 10. 2014 abundance estimates for rainbow and brown trout ≥100 mm by monitoring site.

Site #	Habitat type	Rainbow	Brown	All trout	Rainbow/brown
Early Intake					
11	Shallow Pool	13 (0)	2 (0)	22 (±8)	6.5
13	Deep Pool	22 (±6)	1 (0)	28 (±10)	22.0
18	Pocketwater	44 (±14)	3 (±2)	55 (±24)	14.7
27	Shallow Pool	51 (±29)	10 (±2)	62 (±31)	5.1
34	Deep Pool	10 (±4)	13 (±8)	32 (±20)	0.8
37	Pocketwater	27 (±4)	9 (±4)	37 (±6)	3.0
Preston Falls					
44	Pocketwater	37 (±10)	2 (±2)	36 (±6)	18.5
46	Deep Pool	31 (±4)	3 (±2)	34 (±6)	10.3
49	Shallow Pool	32 (±2)	2 (0)	34 (±2)	16.0
56	Deep Pool	54 (±8)	11 (±6)	61 (±4)	4.9
74	Deep Pool	121 (±37)	36 (±10)	131 (±2)	3.4
76	Shallow Pool	70 (±20)	13 (±2)	81 (±16)	5.4
O'Shaughnessy					
223	Deep Pool	45 (0)	3 (±2)	55 (±8)	15.0
227	Deep Pool	17 (±6)	2 (±2)	16 (±4)	8.5
249	Shallow Pool	6 (±6)	6 (±4)	11 (±8)	1.0
267	Shallow Pool	13 (±2)	1 (0)	15 (±4)	13.0

Table 11. 2014 abundance estimates for rainbow and brown trout ≥100 mm by subreach.

Subreach	Rainbow	Brown	All trout	Rainbow/brown
Early Intake	167 (±33)	38 (±9)	236 (±46)	4.4
Preston Falls	345 (±44)	67 (±12)	377 (±18)	5.1
O'Shaughnessy	81 (±9)	12 (±5)	97 (±12)	6.8
All Subreaches	593 (±56)	117 (±16)	710 (±51)	5.1

Table 12. 2014 abundance estimates for rainbow and brown trout ≥100 mm by habitat type.

Habitat type	Rainbow	Brown	All trout	Rainbow/brown
Shallow Pool	185 (±36)	34 (±5)	225 (±37)	5.4
Deep Pool	300 (±39)	69 (±14)	357 (±25)	4.3
Pocketwater	108 (±17)	14 (±5)	128 (±25)	7.7
All habitats	593 (±56)	117 (±16)	710 (±51)	5.1

Table 13. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥100 mm by monitoring site.

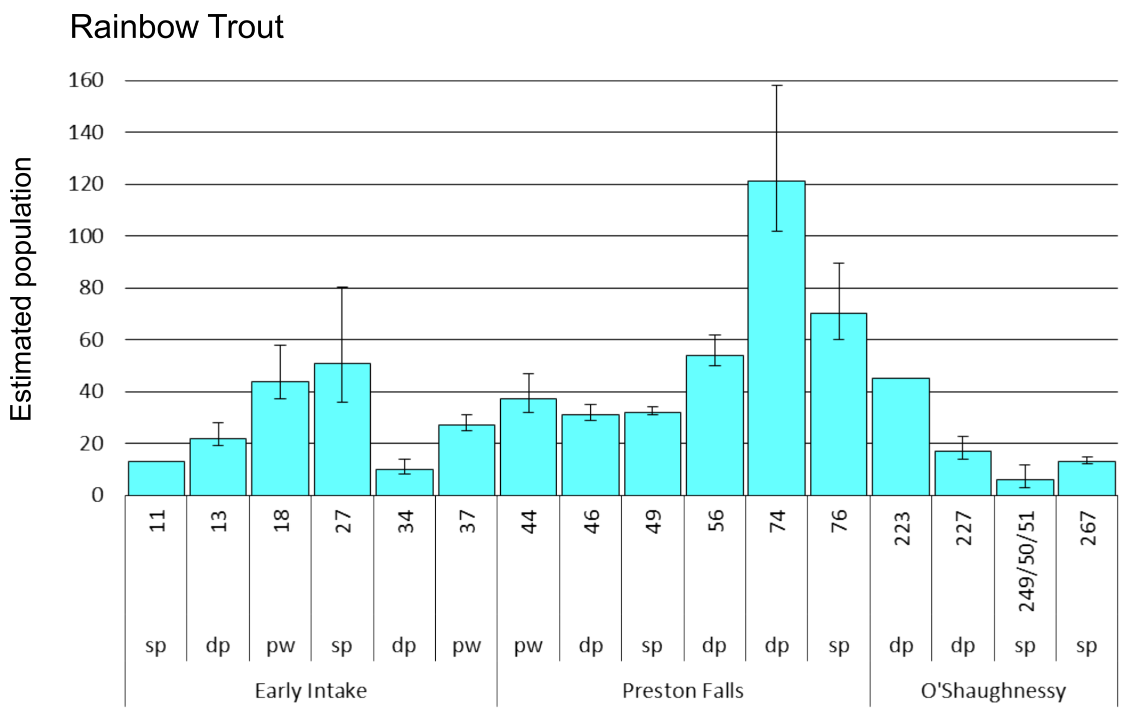
Site #	Habitat type	Rainbow	Brown	All trout
Early Intake				
11	Shallow Pool	85	13	143
13	Deep Pool	114	5	144
18	Pocketwater	299	20	374
27	Shallow Pool	187	37	227
34	Deep Pool	58	76	186
37	Pocketwater	228	76	313
Preston Falls				
44	Pocketwater	221	12	215
46	Deep Pool	174	17	190
49	Shallow Pool	209	13	222
56	Deep Pool	222	45	250
74	Deep Pool	484	144	524
76	Shallow Pool	478	89	553
O'Shaughnessy				
223	Deep Pool	195	13	238
227	Deep Pool	117	14	110
249	Shallow Pool	34	34	63
267	Shallow Pool	51	4	59

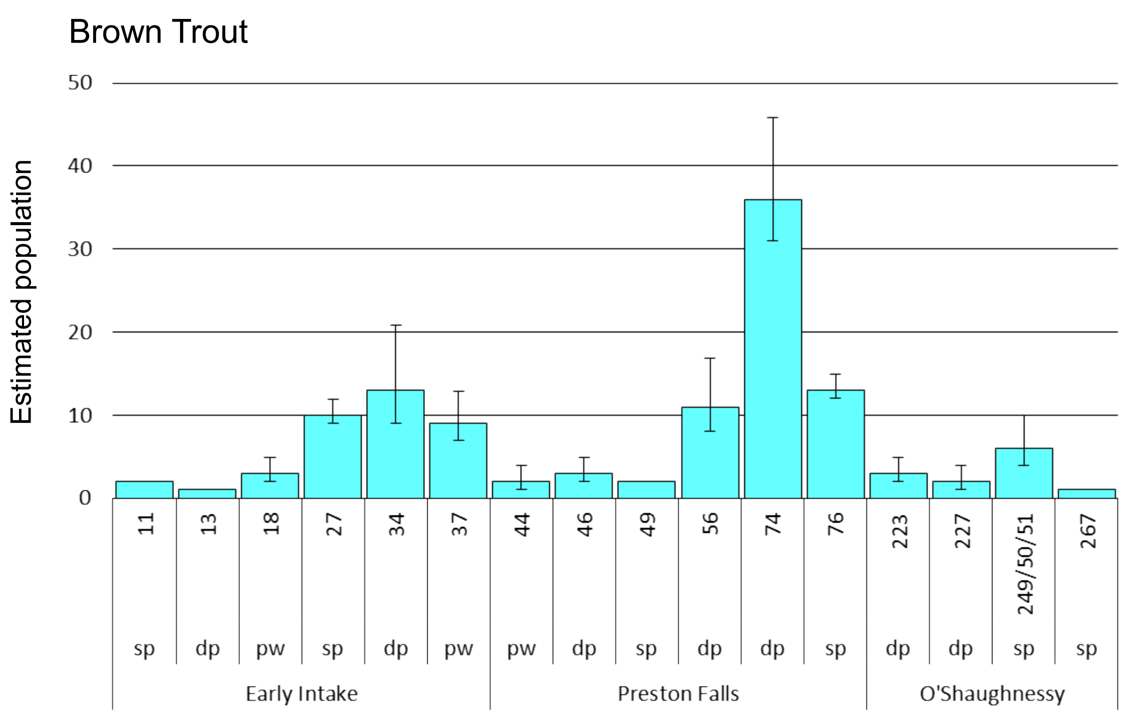
Table 14. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥100 mm by subreach.

Subreach	Rainbow	Brown	All trout
Early Intake	158	36	223
Preston Falls	303	59	331
O'Shaughnessy	101	15	120
All Subreaches	198	39	236

Table 15. 2014 linear density (fish/1,000 ft) estimates for rainbow and brown trout ≥100 mm by habitat type.

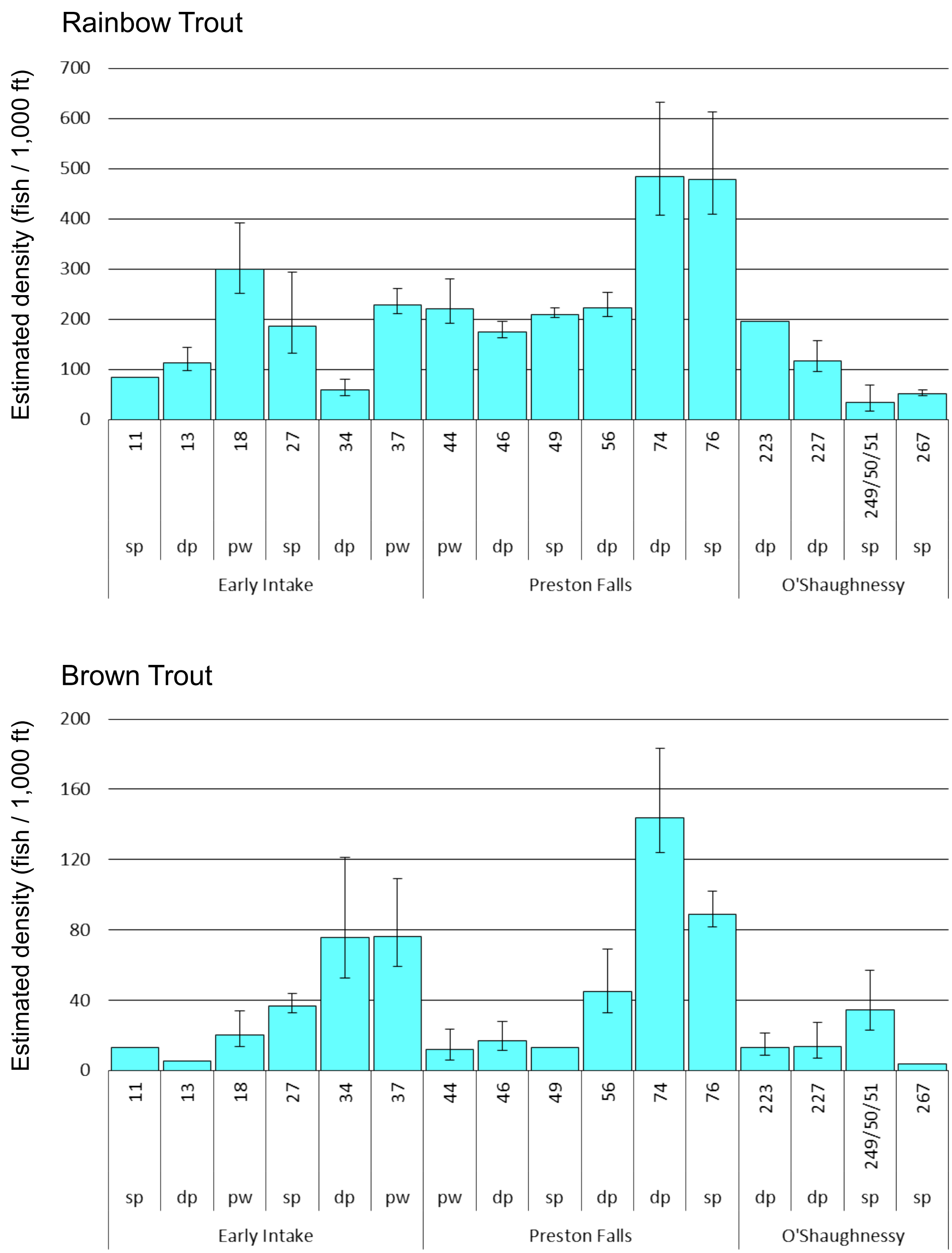
Habitat type	Rainbow	Brown	All trout
Shallow Pool	160	29	195
Deep Pool	212	49	252
Pocketwater	250	32	296
All habitats	198	39	236





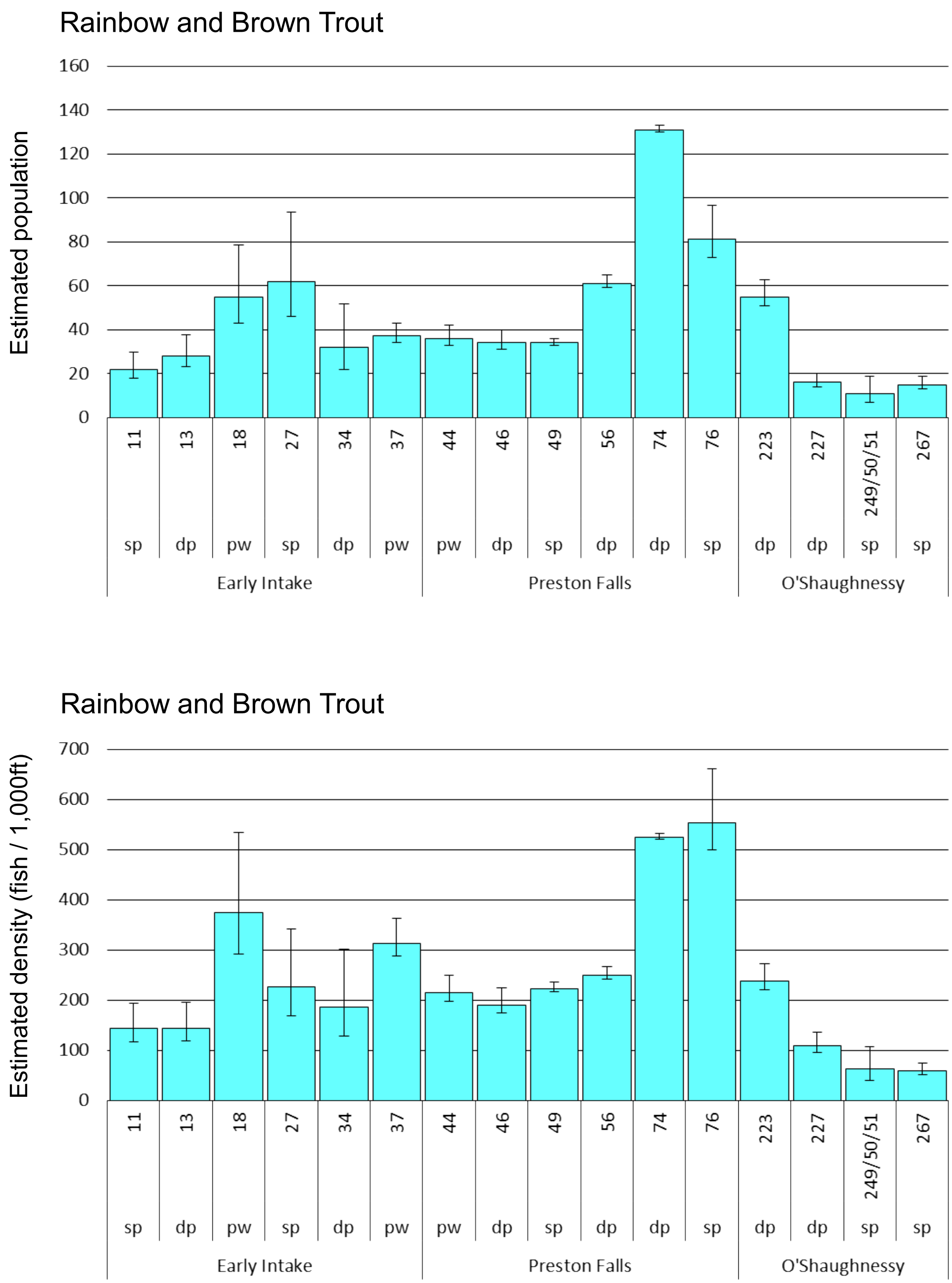
sp = shallow pool, dp = deep pool, pw = pocketwater

Figure 8. Estimated abundance of rainbow and brown trout with fork-length ≥100 mm by survey site during 2014.



sp = shallow pool, dp = deep pool, pw = pocketwater

Figure 9. Estimated linear density (fish/1,000 ft) of rainbow and brown trout with fork-length ≥100 mm by survey site during 2014.



sp = shallow pool, dp = deep pool, pw = pocketwater

Figure 10. Estimated abundance and linear density (fish/1,000 ft) of rainbow and brown trout (combined) with fork-length ≥100 mm by survey site during 2014.

5.3 Comparisons with Previous Survey Data

Reach-level results for 2014 were compared with previously reported Hetch Hetchy Reach data sets to investigate whether large differences were evident. Comparisons were made with (1) rotenone surveys conducted by USFWS in 1970 and 1977 (Ridenhour 1977, 1978), (2) snorkel surveys conducted by Vondracek in 1985 (Vondracek 1985), (3) snorkel surveys conducted by USFWS in 1988–1990 (USFWS 1990, 1991), and (4) snorkel surveys conducted by the SFPUC annually from 2007 to 2010 (SFPUC unpublished data) (Figures 11 through 13). A length threshold of 125 mm, differentiating age-0 from age-1 and older trout, was used for comparisons with historical data sets presented below. Note that methods and sampling locations were inconsistent between the data sets and, therefore, inferences from comparisons between these data sets should be treated with caution.

The 2014 monitoring results for brown trout were generally within but toward the low end of the range reported for previous surveys (Figures 11 through 13). Rainbow trout density in the Preston Falls and O'Shaughnessy subreaches were higher in 2014 than for previous surveys, and the corresponding ratio of rainbow trout to brown trout was also higher for the Preston Falls subreach. On average, rainbow trout abundance in 2014 was higher and brown trout abundance was lower than in the previous data sets. Correspondingly, the ratio of rainbow trout to brown trout was also generally higher in 2014 than in the other data sets.

In the Preston Falls subreach, rainbow trout density was noticeably higher than observed during previous surveys (about 68 percent higher than next-highest estimate) (Figure 12); however, this apparent difference was likely strongly influenced by differences in the habitat characteristics of the sites sampled, and their associated densities. For 2014, monitoring sites were selected to avoid long (>300 ft) habitats with low complexity. Sites 74 and 76 are examples of sites sampled during 2014 in the Preston Falls subreach with high complexity and high density (376 fish/1,000 ft and 457 fish/1,000 ft, respectively). For comparison, sites sampled in 2007–2010 included two long pool habitats (i.e., site PF-2 at 573 ft, and site GRG-1 at 940 ft) with relatively low densities (45 fish/1,000 ft and 48 fish/1,000 ft, respectively). These differences could easily explain the relatively high estimate in 2014 compared with 2007–2010.

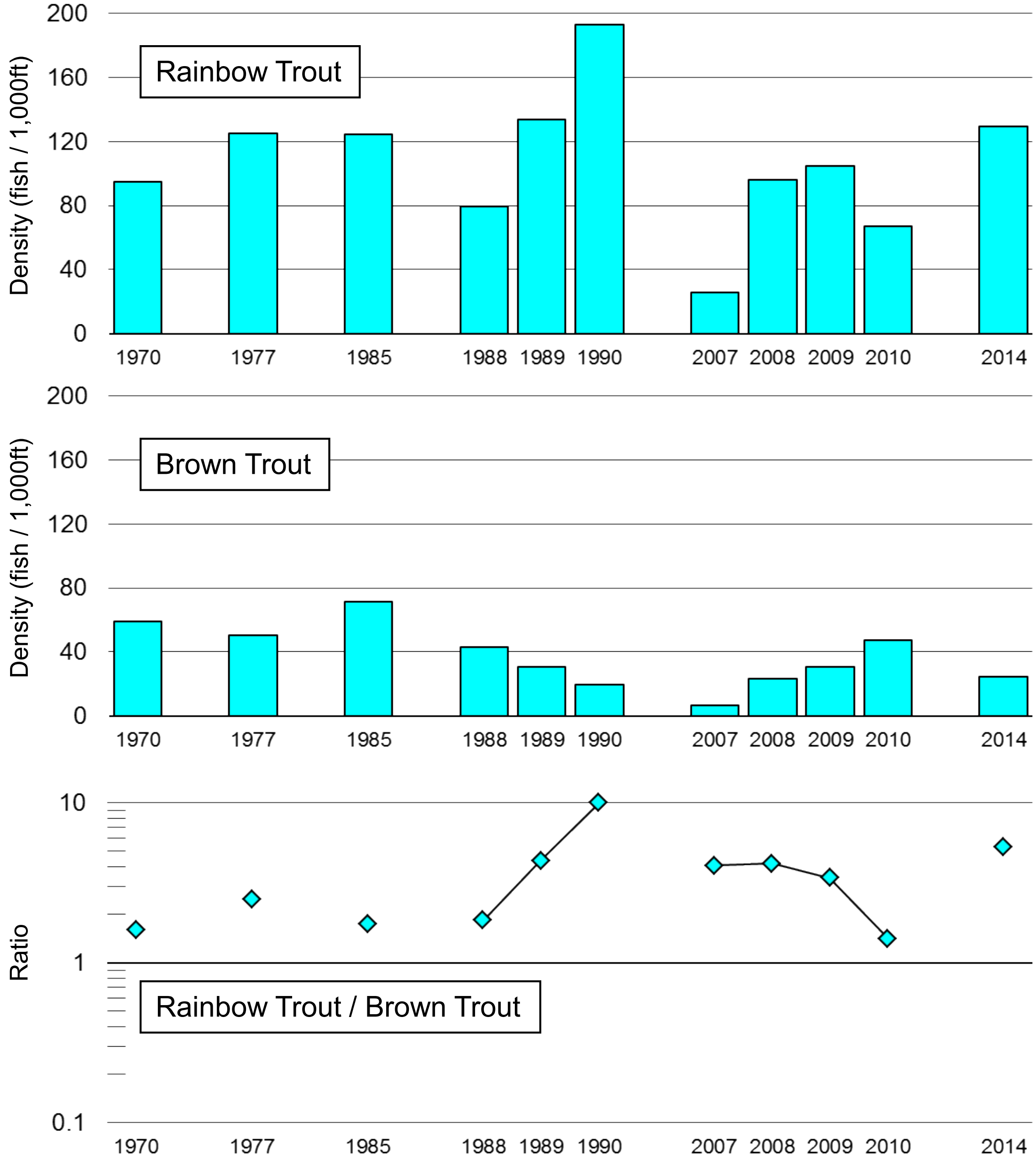


Figure 11. Rainbow and brown trout age 1 and older (length ≥125 mm) estimated density and dominance in the Early Intake subreach.

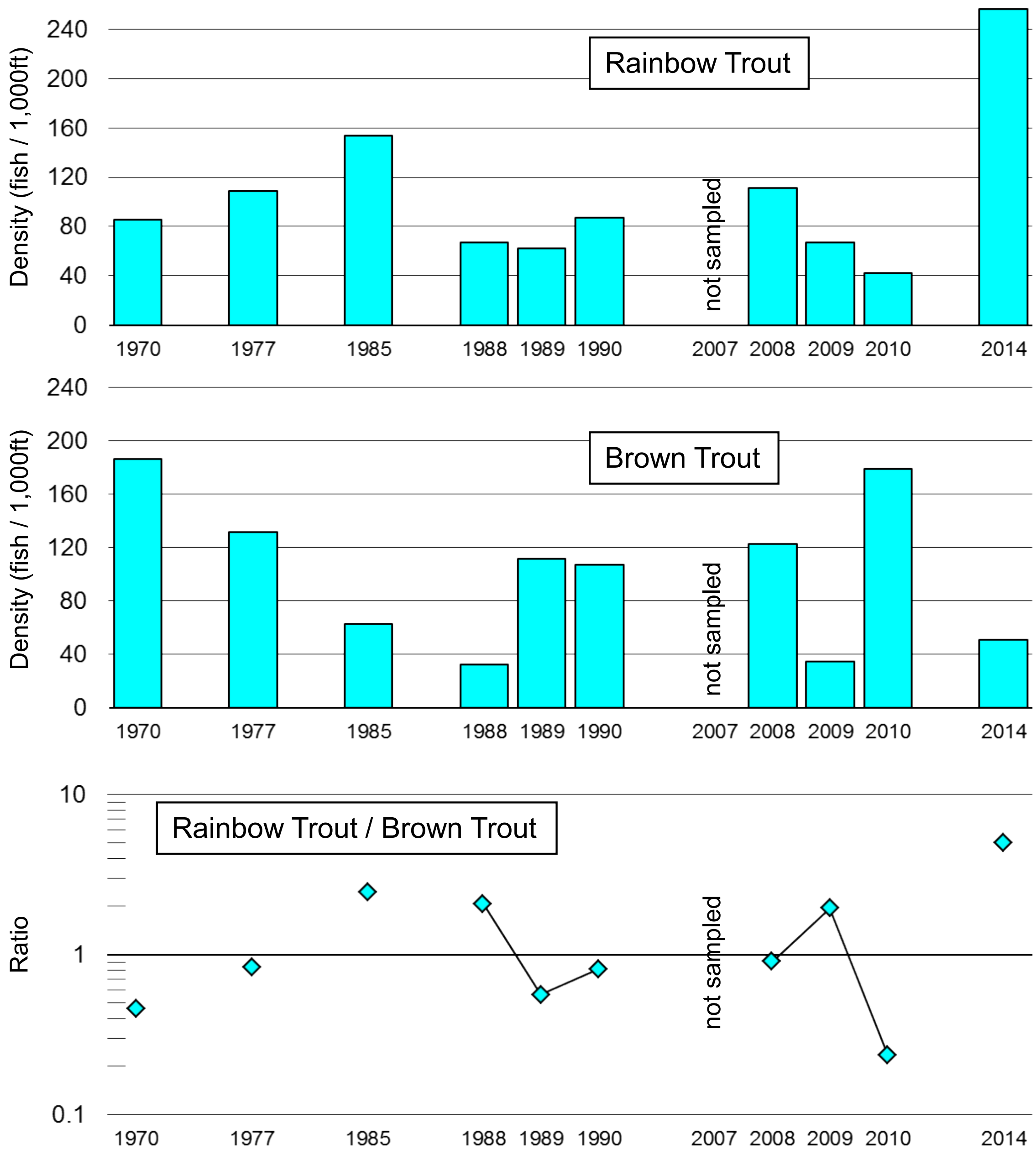


Figure 12. Rainbow trout and brown trout age 1 and older (length ≥125 mm) estimated density and dominance in the Preston Falls subreach.

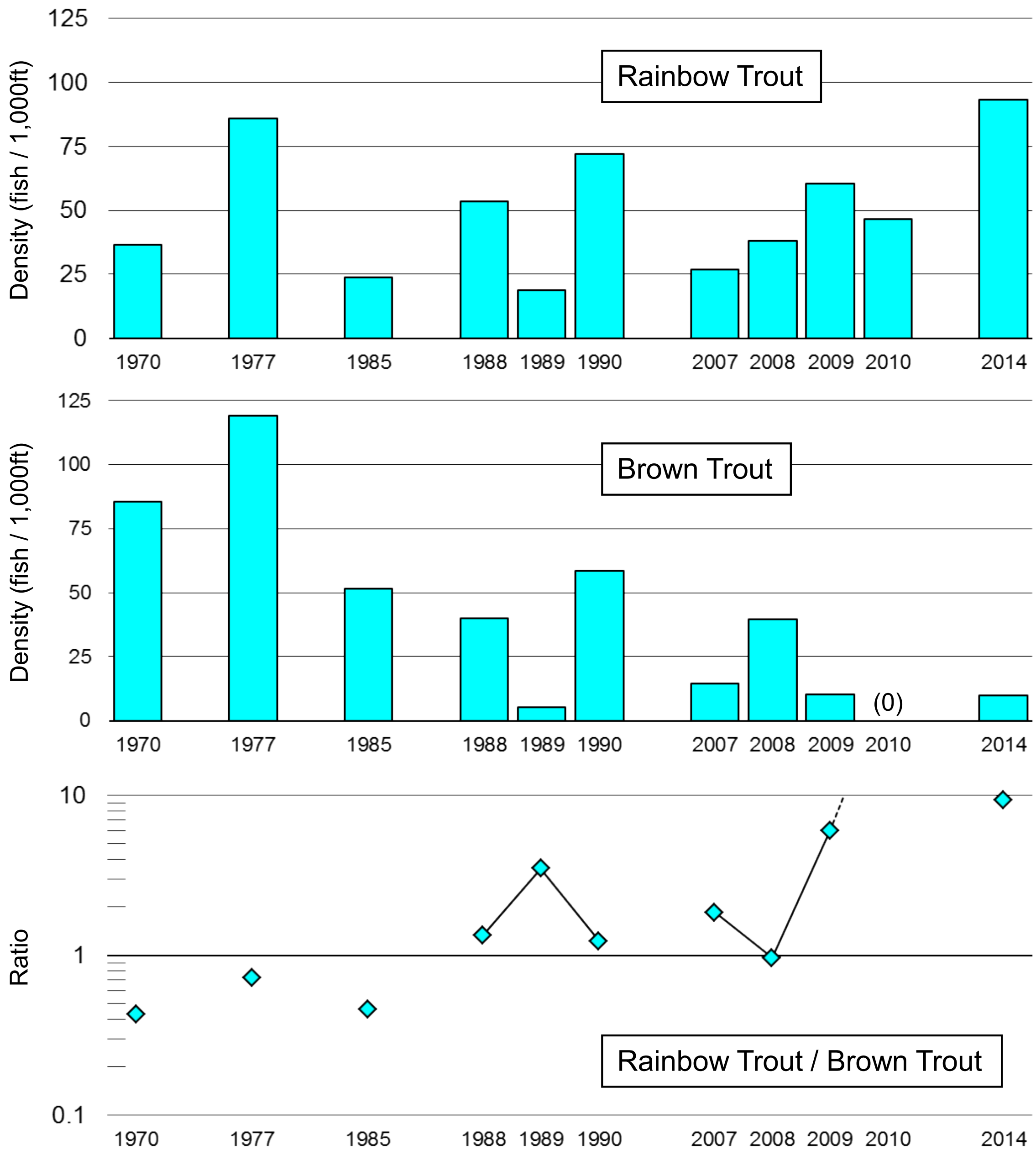


Figure 13. Rainbow trout and brown trout age 1 and older (length ≥125 mm) estimated density and dominance in the O'Shaughnessy subreach.

5.4 Evaluation of One-Pass vs. Three-Pass Dive Surveys

The sampling approach developed and implemented in 2014 uses three-pass snorkel methods at each monitoring site to allow for calculations of sample variance and confidence intervals around abundance estimates. Because conducting three snorkel passes at all sites is labor-intensive, data from the 2014 monitoring effort were used to investigate the consequence of only conducting one snorkel pass at a subset of monitoring sites in terms of added variance.

When some sites receive only one dive pass, the population of that site was estimated by expanding the observed dive count of the site by the factor *f*, where

> *f*= (total estimated population of the three-pass sites)/(total number seen first pass of the three-pass sites)

To evaluate the effect of using single passes in some number *m* of sites, all the possible ways of choosing *m* sites were considered, and for each of these, estimated the population as above by ignoring the data from these sites after the first pass. For example, there are 1,820 ways of choosing 4 sites out of the 16 available. These 1820 alternatives yield 1,820 estimates for the total population. The population estimates ranged from 532 to 636, with a median value of 594; 95 percent of the estimates were between 560 and 621. Figures 14 through 17 illustrate the consequences of conducting only one dive pass for a subset of sites based on this approach. Figure 14 considers the total population estimate for all sites combined (actual estimate is 606±54, Table 5). Figures 15 through 17 consider the total population estimate for deep pool, shallow pool, and pocketwater habitat types, respectively.

Note that this evaluation focuses on total population estimates, which consider all fish and are expected to result in a smaller variance (and smaller effect) than would be expected for estimates for a subset of the population such as rainbow trout within a particular reach. Ultimately, the intent is to evaluate possible effects of management actions at a relatively fine scale where sample sizes may be small, and where the consequence of reducing the number of passes on the uncertainty in an estimate would likely be greater than observed here.

The conclusions from this evaluation are:

- Omitting the second and third passes at a low number of sites introduced relatively little added uncertainty, by comparison with the uncertainty inherent in the bounded-counts method.
- The downside of only conducting one pass at a subset of monitoring sites is that all of the analyses would become substantially more complicated. So far, this assessment only looked at the particular question of what happens to the raw estimate of total population. In practice, the estimated uncertainty in this number is also a concern. The calculation of variance for the two-phase survey is complicated, but the overall confidence interval will increase as the number of three-pass sites decreases.
- The bottom line is that one pass is better than none, and three passes are better than one pass. The recommendation is to implement the three-pass approach at all sites, but to only complete one pass if field logistics and/or time constraints indicate that three passes could not be completed safely or would require adding an extra field day (for example).

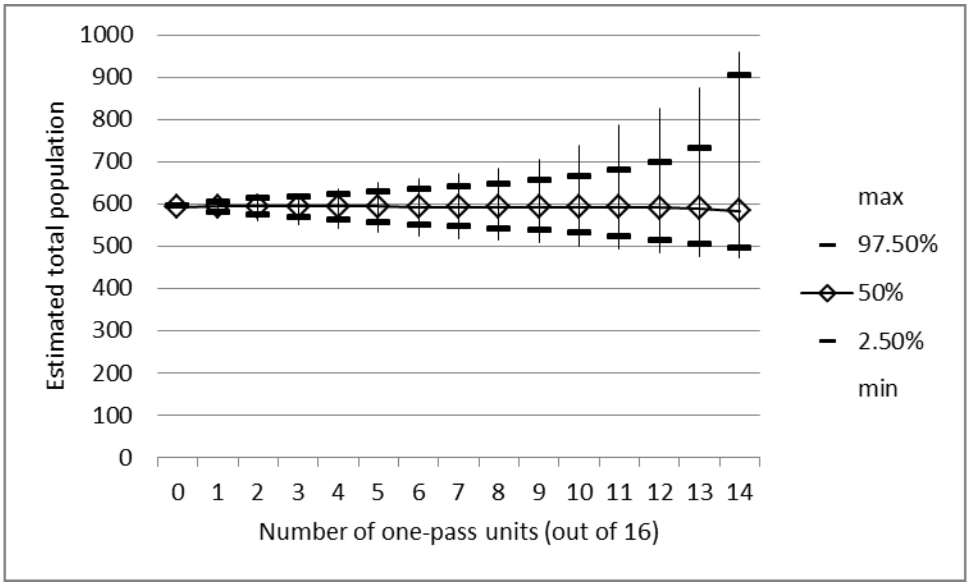


Figure 14. Example of potential consequence of only performing one-pass dives on some fraction of monitoring sites on estimate of total fish abundance, for all sites combined.

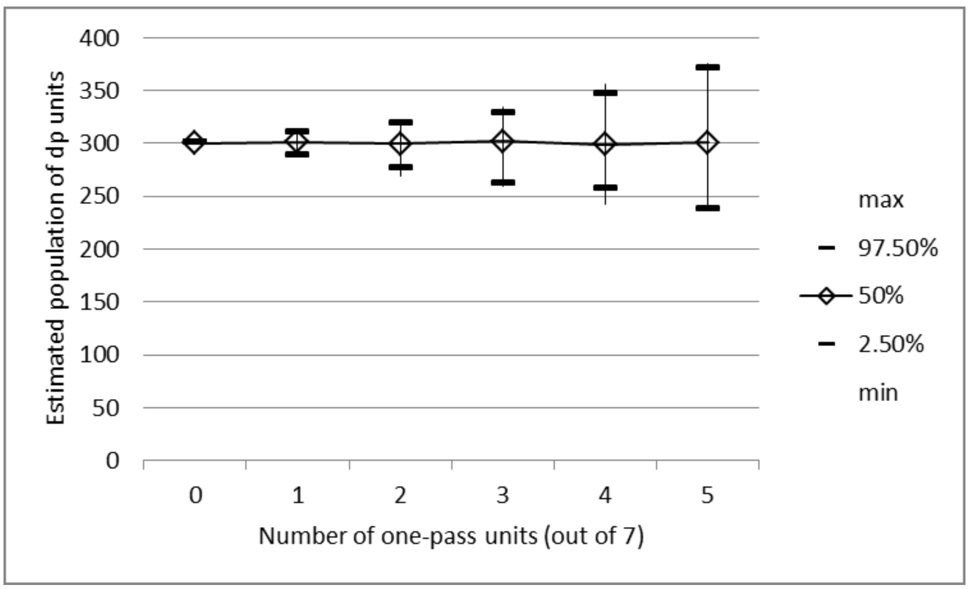


Figure 15. Example of potential consequence of only performing one-pass dives on some fraction of monitoring sites on estimate of fish abundance for deep pools (seven sites total).

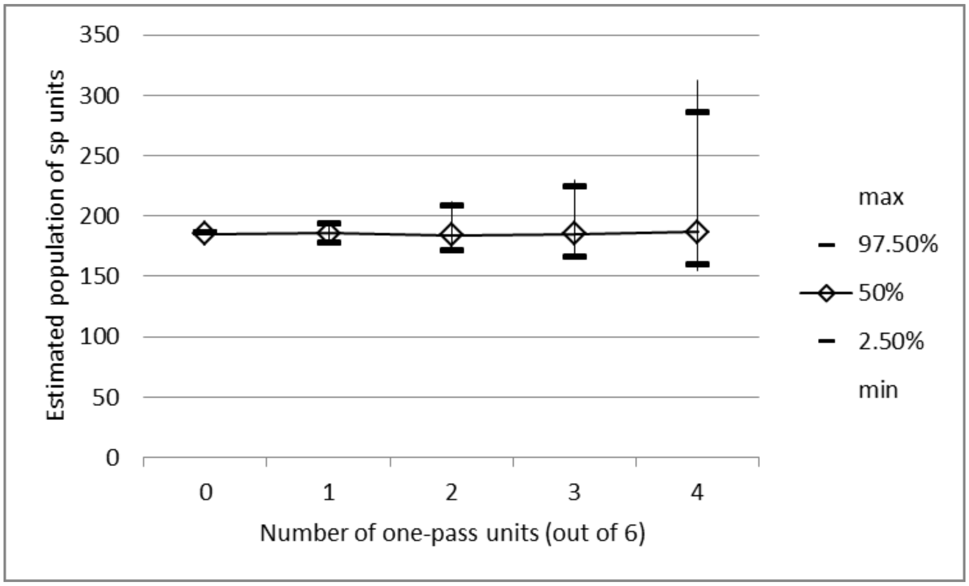


Figure 16. Example of potential consequence of only performing one-pass dives on some fraction of monitoring sites on estimate of total fish abundance, for shallow pools (six sites total).

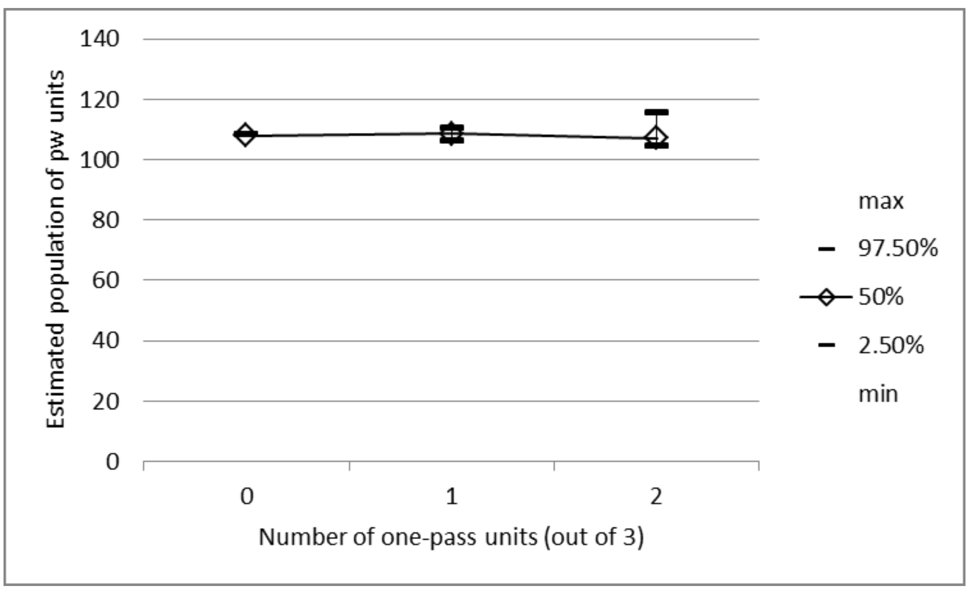


Figure 17. Example of potential consequence of only performing one-pass dives on some fraction of monitoring sites on estimate of fish abundance for pocketwater (three sites total).

5.5 Stream Flow

Flows recorded at the two stream flow monitoring stations in the Hetch Hetchy Reach, United States Geological Survey (USGS) gage 11276500 near Hetch Hetchy at the upstream end of the reach ("Hetch Hetchy gage"), and USGS gage 11276600 above Early Intake at the downstream end of the reach ("Above Early Intake gage"), are presented to provide an indication of conditions in the reach during Water Year (WY) 2014 relative to conditions in recent years (the past 10 years) (Figures 18 through 21). Flows in the Hetch Hetchy Reach are generally high during the spring and early summer (May–July) snowmelt runoff period, and low during the fall and winter (September–February). Short-duration high flow events occasionally occur during winter.

Throughout much of California, WY 2014 was the third year of the recent drought and was one of the lowest water years on record. Mean annual flow and average summer flow (May through mid-September) in WY 2014 were the lowest recorded in recent years at both gages. Stream flow during WY 2014 was noticeably low compared with recent years, particularly during February–September. There were no large-magnitude flow events during WY 2013 or WY 2014. A few low-magnitude flow events were evident at the Above Early Intake gage in WY 2014 during February–April (Figures 20–21).

Average daily flow in WY 2014 recorded at the Hetch Hetchy gage ranged from about 35 cubic feet per second (cfs) in February to 85 cfs in May. Average daily flow at the Hetch Hetchy gage from May through mid-September remained relatively stable at about 75–80 cfs (Figure 19). At the Above Early Intake gage, average daily flow ranged from about 35 to 85 cfs, with both flows occurring in February. Average daily flow at the Above Early Intake gage from May through mid-September remained relatively stable at about 95 to 105 cfs and indicates that about 20 cfs of accretion occurred in the reach during this period in WY 2014 (Figure 21).

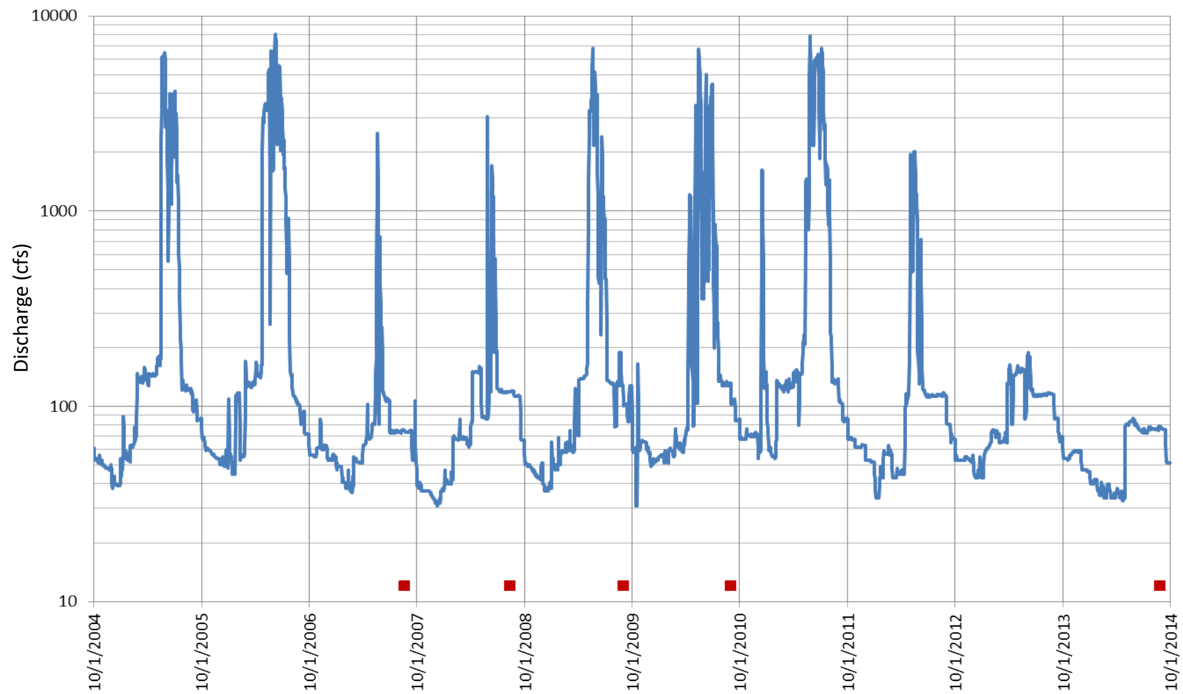


Figure 18. Mean daily discharge at the Hetch Hetchy gage (USGS 11276500) for WY 2005–2014 reported consecutively. Snorkel surveys by SFPUC, which occurred in August in 2007–2008, early September in 2009–2010, and late August 2014, are identified with red markers. Note that this figure includes provisional data for WY 2014.

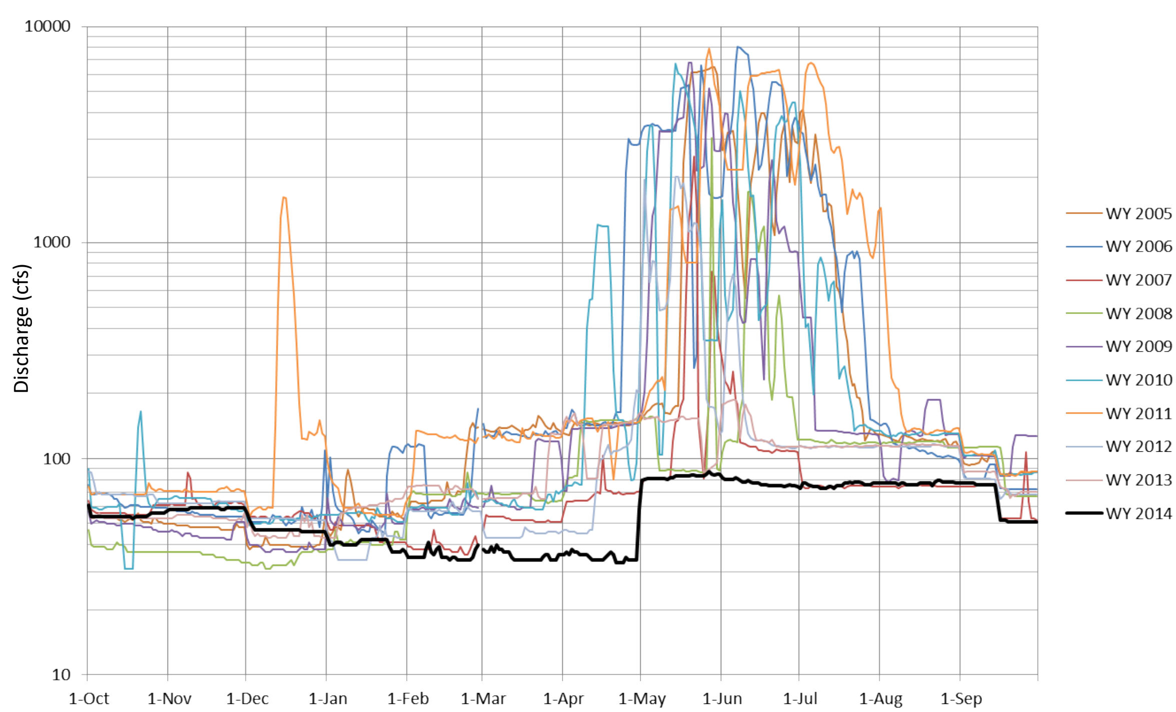


Figure 19. Mean daily discharge at the Hetch Hetchy gage (USGS 11276500) for WY 2005-2014 reported individually. Note that this figure includes provisional data for WY 2014.

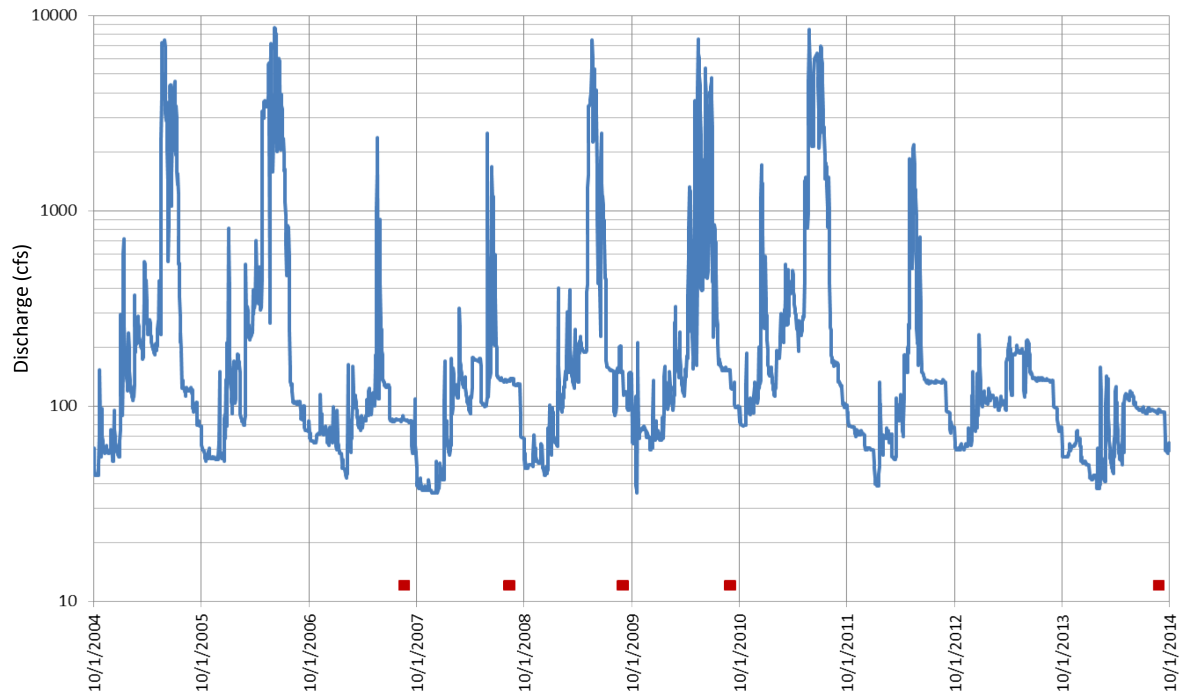


Figure 20. Mean daily discharge at the Above Early Intake gage (USGS 11276600) for WY 2005–2014 reported consecutively. Snorkel surveys by SFPUC, which occurred in August in 2007–2008, early September in 2009–2010, and late August 2014, are identified with red markers. Note that this figure includes provisional data for WY 2014.

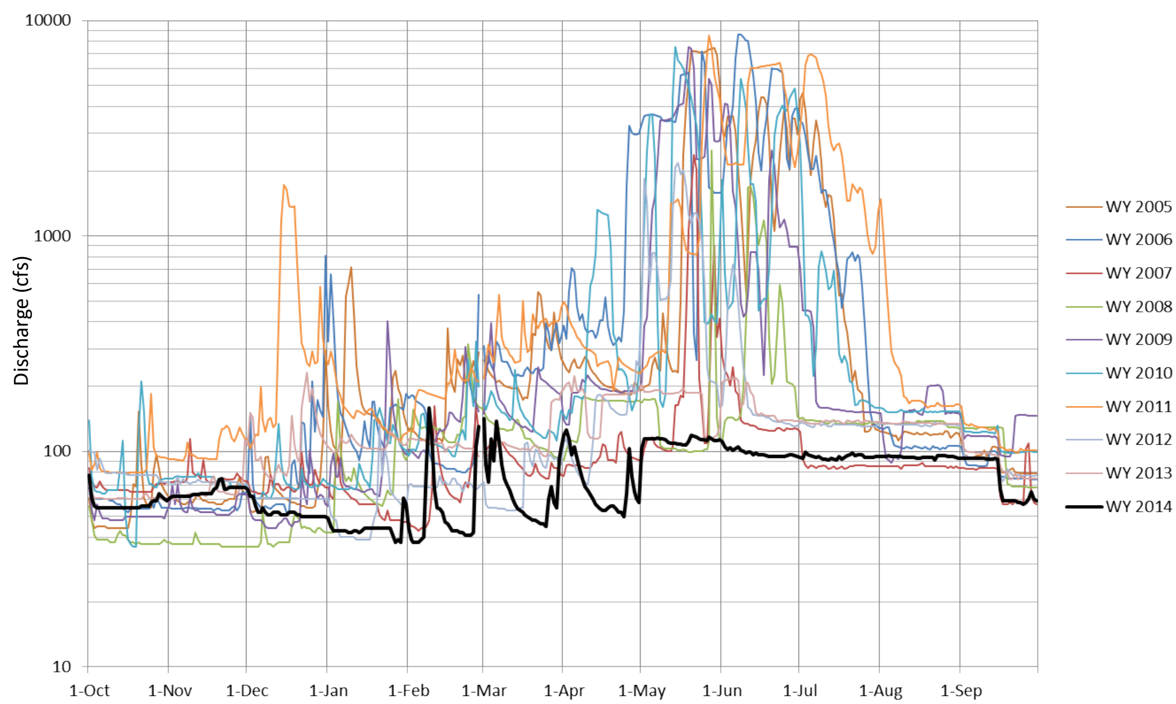


Figure 21. Mean daily discharge at the Above Early Intake gage (USGS 11276600) for WY 2005–2014 reported individually. Note that this figure includes provisional data for WY 2014.

5.6 Water Temperature

Daily water temperature data for the Hetch Hetchy gage and the Above Early Intake gage were plotted for WY 2005–2014, both consecutively (Figures 22 and 24) and individually (Figures 23 and 25) to illustrate annual patterns and compare WY 2014 relative to conditions in recent years.

Water temperatures at the Hetch Hetchy gage are generally lowest during January–April, climb to their highest during June–early August, and then decrease through late August and September as fall approaches. Water temperatures are generally relatively stable, although variable, during October–November, before decreasing in December at the onset of winter. The annual pattern at the Above Early Intake gage is a bit different, with lowest temperatures during December–January, climbing steadily to the highest temperatures in late-June to early-August, and then steadily decreasing again into winter.

Water temperatures at the Hetch Hetchy gage are relatively stable compared with the Above Early Intake gage due to the proximity to O'Shaughnessy Dam, with average daily water temperatures during WY 2005–2014 ranging from 41.7 degrees Fahrenheit (°F) to 65.7°F, and daily minimum and maximum temperatures ranging from 39.6°F to 66.9°F. For comparison, average daily water temperatures at the Above Early Intake gage during WY 2005–2014 ranged from 36.1 to 73.9°F, and daily minimum and maximum temperatures ranged from 33.4°F to 79.3°F.

Interestingly, the annual water temperature pattern appears to have more year-to-year variability at the Hetch Hetchy gage compared with the Above Early Intake gage, even though water temperatures at the Above Early Intake gage show greater extremes. WY 2014 was not close to being the highest daily maximum water temperature during WY 2005–2014 period at the Hetch Hetchy gage (Figure 22), whereas at Above Early Intake gage WY 2014 was by far the highest daily maximum water temperature during the WY 2005–2014 period (Figure 24).

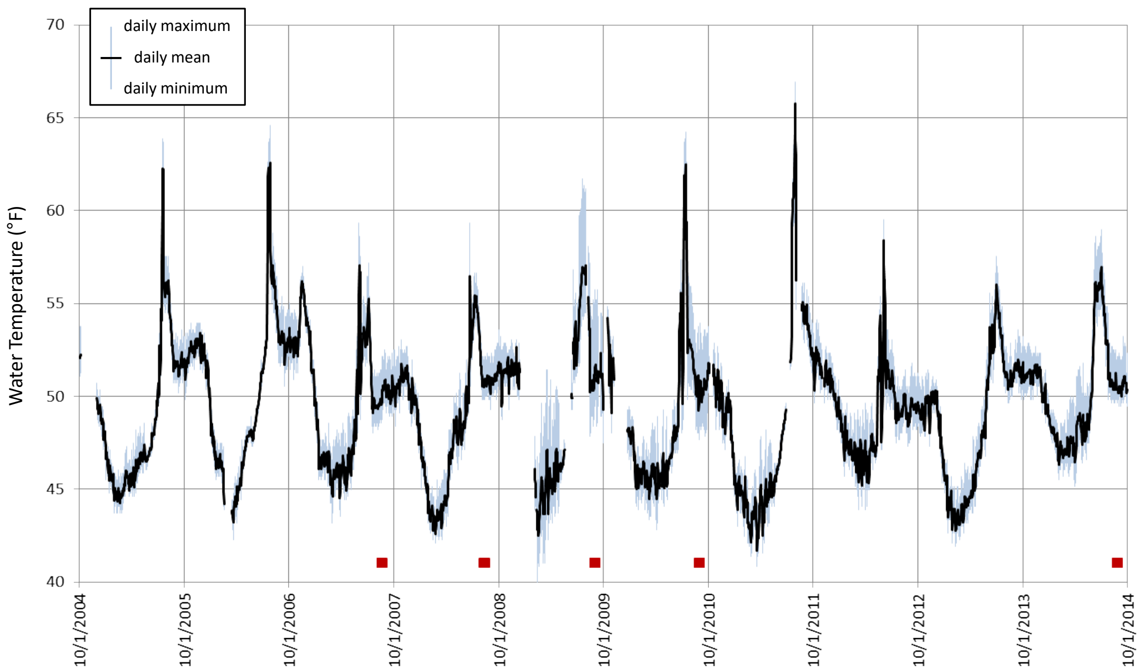


Figure 22. Daily average water temperature in the Tuolumne River measured at the Hetch Hetchy gage (USGS 11276500) for WY 2005–2014 reported consecutively. Snorkel surveys by SFPUC, which occurred in August in 2007–2008, early September in 2009–2010, and late August 2014, are identified with red markers. Note that this figure includes provisional data for WY 2014.

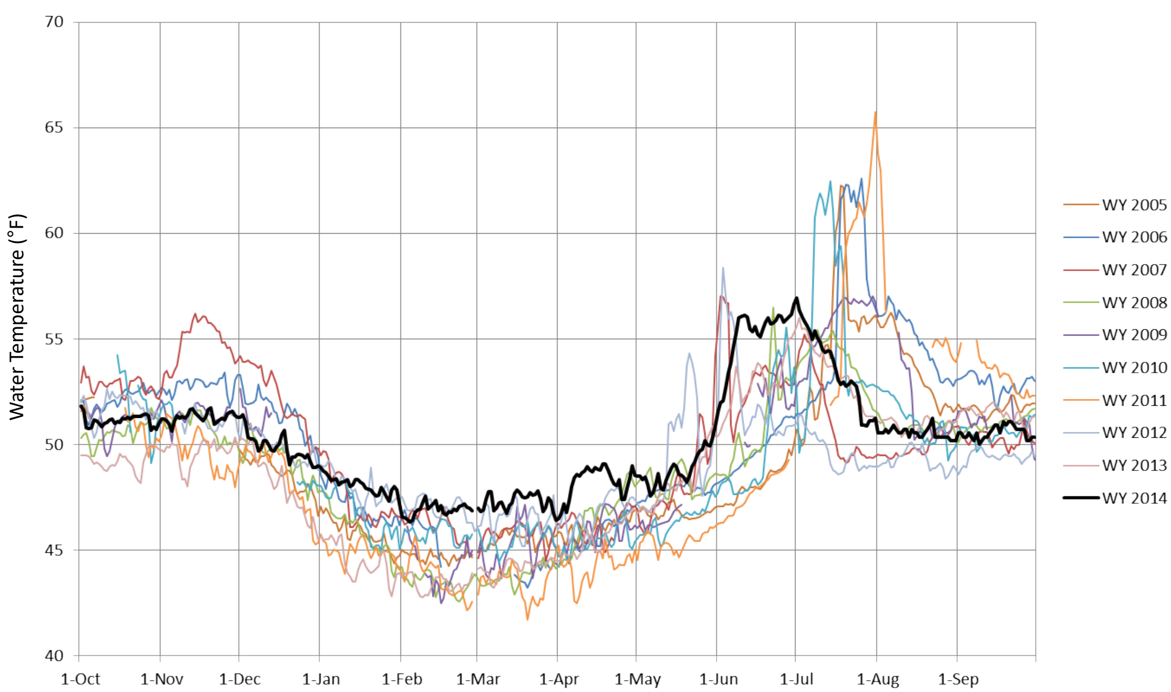


Figure 23. Daily average water temperature in the Tuolumne River measured at the Hetch Hetchy gage (USGS 11276500) for WY 2005–2014 reported individually. Note that this figure includes provisional data for WY 2014.

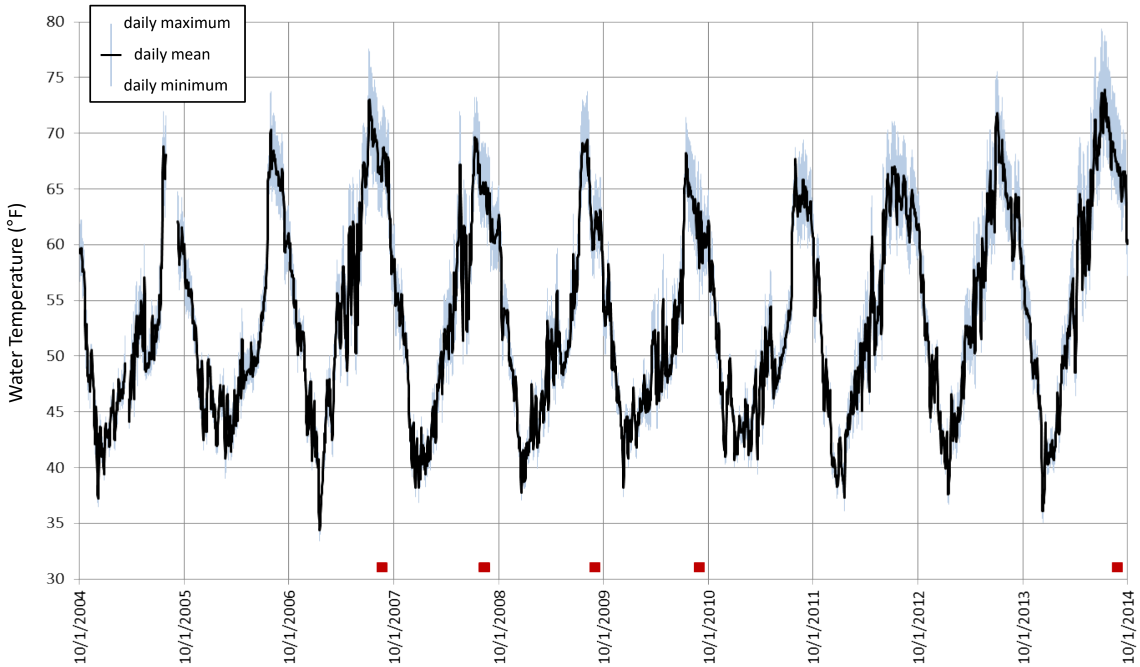


Figure 24. Daily average water temperature in the Tuolumne River measured at the Above Early Intake gage (USGS 11276600) for WY 2005–2014 reported consecutively. Snorkel surveys by SFPUC, which occurred in August in 2007–2008, early September in 2009–2010, and late August 2014, are identified with red markers. Note that this figure includes provisional data for WY 2014.

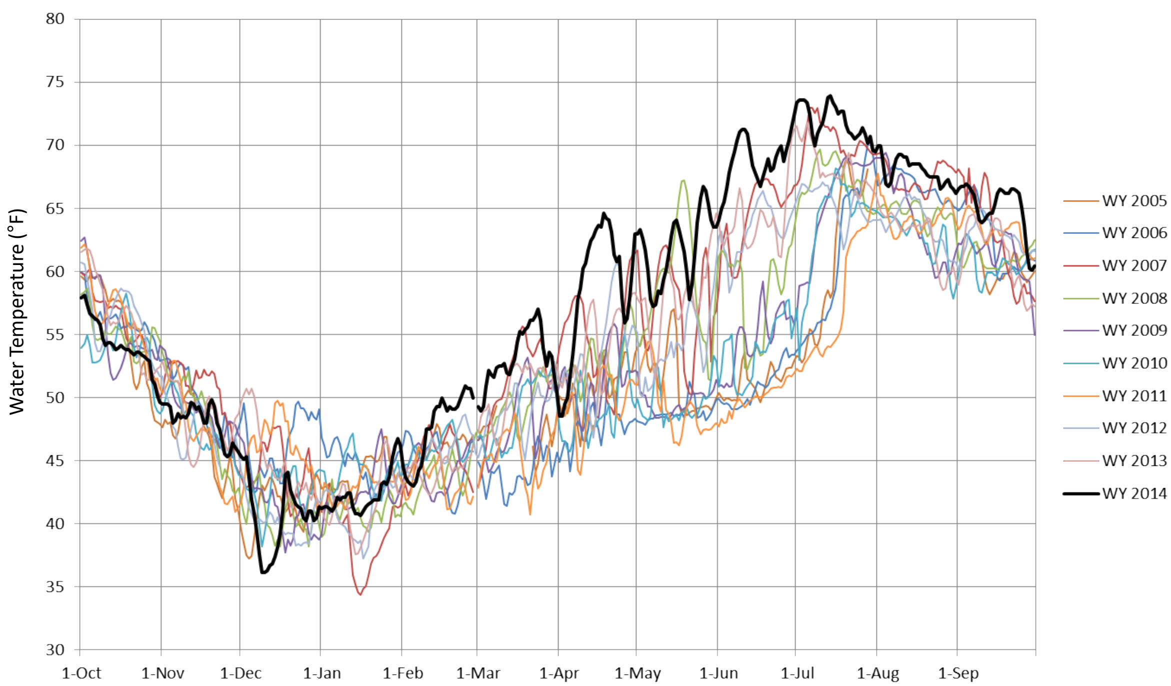


Figure 25. Daily average water temperature in the Tuolumne River measured at the Above Early Intake gage (USGS 11276600) for WY 2005–2014 reported individually. Note that this figure includes provisional data for WY 2014.

6 CONCLUSIONS

The fish population monitoring approach developed and implemented in 2014 was apparently successful at developing a focused sampling framework and protocol to efficiently and effectively sample fish populations in key subreaches of the Hetch Hetchy Reach of the Tuolumne River. Results from the 2014 monitoring indicate that abundance estimates have relatively low variance and will likely be sufficient to assess population trends and detect meaningful differences from year to year, and over longer periods of time.

WY 2014 was a unique year for fish populations and habitat conditions in the Hetch Hetchy Reach, as it immediately followed the Rim Fire and was one of the driest years on record following another dry year in WY 2013. These types of events can have a strong influence on habitat conditions and fish populations over varying time scales.

7 RECOMMENDATIONS

Whenever feasible, using the three-pass approach at all monitoring sites is recommend, understanding that if field logistics and/or time constraints indicate the three-pass protocol cannot be implemented safely, or would require adding an extra field day (for example), but a one-pass protocol could be completed, the one-pass protocol should be implemented at that site.

Adding a pocketwater habitat site to the monitoring sites in the O'Shaughnessy subreach is recommend to incorporate this habitat type into the sampling framework for this subreach. Pocketwater habitats comprise approximately 10 percent of the subreach by length (Table 2). Adding a pocketwater monitoring site would presumably require dropping an existing site to maintain effort at a similar level to 2014. Reducing the number of shallow pool monitoring sites (e.g., site 267) would be appropriate based on the relatively frequency by length of habitat types in the reach.

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