American River Steelhead (*Oncorhynchus mykiss*) Spawning 2001 – 2003


steelhead redd at lower Sunrise side channel


steelhead holding on a redd at lower Sunrise

by

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Abstract

We conducted steelhead redd surveys in the lower American River during the spawning season in 2001, 2002, and 2003. Redd locations and various attributes were mapped with GPS and entered into a GIS database. During 2001, two surveys were conducted to assess effects of flows below 1,500 cfs on steelhead redds. However, flows were not lowered below 1,500 cfs during the 2001 spawning period so effects were not assessed. The shallowest redds measured at 1,500 cfs had 20 cm of water over them.

Surveys during 2002 were conducted to develop an index of in-river spawning steelhead abundance by enumerating redds. We found 159 steelhead redds between February 7 and April 2, 2002. Redd density was 8.8 redds per mile in the area of river with available spawning habitat. Redd density was highest in the upstream seven mile reach with a density of 16.1 redds per mile. The 2002 estimate of in-river spawning steelhead, based on one to two redds per female and using the hatchery male per female ratio of 1.52 : 1.00, was 201 to 400 steelhead. The peak in spawning activity occurred in early March.

During 2003, we found 215 steelhead redds from January 7 to April 4. Spawning flows were higher in 2003 and redds were more dispersed in the upper river. No spawning occurred below Watt Avenue due to the pooling effect of high Sacramento River flows. Redd density was 11.9 redds per mile throughout the spawning section of river down to Paradise Beach. Redd density was again highest in the upstream seven mile reach at 19.6 redds per mile. The middle seven mile reach had 17.7 redds per mile in 2003 vs. 4.4 redds per mile in 2002. The redd based population estimate was 243 to 486 in-river spawners. An area under the curve population estimate based on fish observations was 343 steelhead spawning in the river and 967 steelhead in the river within the survey period but not spawning in the river. The peak in spawning activity occurred in mid-February. We closely monitored redds in jeopardy of being lost to dewatering to determine the fate of the eggs in those redds and the extent of dewatering.

Introduction

Steelhead returns to Nimbus Hatchery provide the only index of steelhead abundance in the American River (Figure 1). Only the naturally spawning steelhead in the American River are considered to be part of the Central Valley Steelhead ESU. Populations of naturally spawning steelhead are unknown. Staley (1976) estimated steelhead populations in the American River in the 1971-72 run to be 19,583 fish and in the 1973-74 run to be 12,274 fish. Numbers of steelhead entering the hatchery during these years were 2,256 and 3,237 respectively. He used three to five hexagonal wire fyke traps between Watt and Howe Avenue to capture and mark steelhead. Recaptures were made from fish entering Nimbus Hatchery. These may be the only steelhead run size estimates made for the American River other than the hatchery returns. During Staley's studies he found steelhead in the American River that had been marked from the Feather River, Coleman Hatchery, and Mokelumne River.

Our primary objective in this work is to devise a method for providing yearly estimates of in-river spawning steelhead abundance or an index of abundance that will be comparable from year to year. Secondary objectives include determining how flows affect steelhead spawning locations, timing, and egg to fry survival and determining what proportion of in-river spawning steelhead are of natural (vs. hatchery) origin.

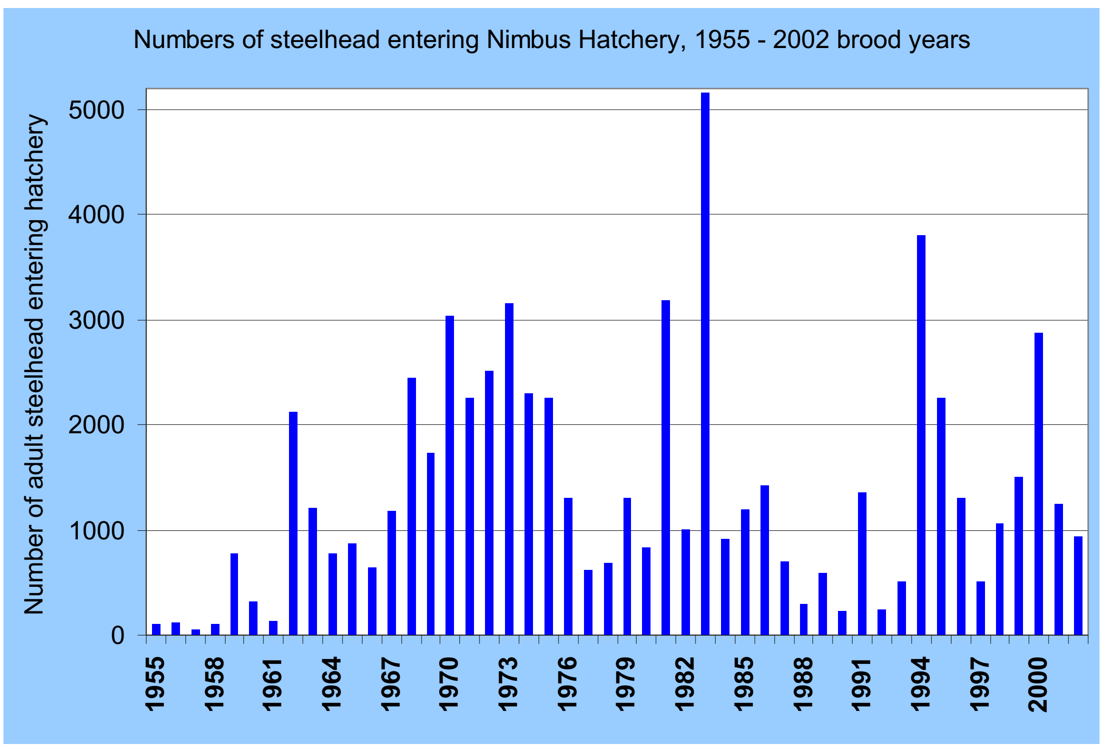


Figure 1. Number of steelhead entering Nimbus Hatchery, 1955 – 2002 brood years. Note: The brood year refers to the fall/winter when fish are preparing to enter freshwater, for example the 2002 brood year refers to those fish spawning primarily in 2003.

The California Department of Fish and Game (CDFG) conducted aerial photography of the American River during chinook spawning activities for many years up to 2000 (Snider, Titus, and Vyverberg 2001). We reviewed recent aerial photos with CDFG biologists and decided that resolution was not good enough to accurately discern steelhead redds in the photos. Therefore we decided to attempt ground based steelhead redd surveys.

Steelhead redd counts were conducted in the American River during 2001, 2002, and 2003. Two counts were performed during 2001 to determine effects to steelhead redds if flows needed to be lowered below 1,500 cfs. More effort was devoted to redd counts in 2002 to estimate the number of steelhead redds in the river and to begin development of a protocol for estimating steelhead spawning escapement for subsequent years when flow and water visibility are suitable. In 2003 we added detailed redd measurements and fish observations to more accurately identify steelhead redds and produce the population estimate.

Materials and Methods

Field Surveys

The American River was surveyed for steelhead redds using either a jet boat, drift boat, canoe, or by snorkeling or wading. The survey reach encompassed the entire Lower American River from Nimbus Dam (top of anadromous habitat) down to Paradise Beach (bottom of potential spawning habitat), mile 5 to 23 (Figure 2). The boat (canoe, drift boat, or jet boat) was oriented pointing upstream against the current and maneuvered diagonally back and forth across the river from one bank to the other working in a downstream direction (Figure 3). Surveyers wore polarized sunglasses and baseball caps to help see through glare on the water surface. The boat was maneuvered so that nearly all areas that appeared to be potential spawning habitat could be viewed. Crew members stood in the boat with one person standing on the bow to increase visibility. When water was too shallow for the boat (generally in side channels) the section was waded or snorkeled. During the first two years single strand channels for all surveys were more thoroughly surveyed for steelhead redds than areas with multiple channels (side channels) because of difficulty in getting the canoe or drift boat back upstream. Generally only one channel of multiple thread channel areas was surveyed with the boat in 2001 and 2002. During 2003 most of the spawning habitat was observed during each survey, either by boat or on foot. Spacing between transects covered by the boat in potential spawning habitat was generally about 20 meters. Spacing was adjusted by the boat operater to maintain visibility of the river bottom between transects.

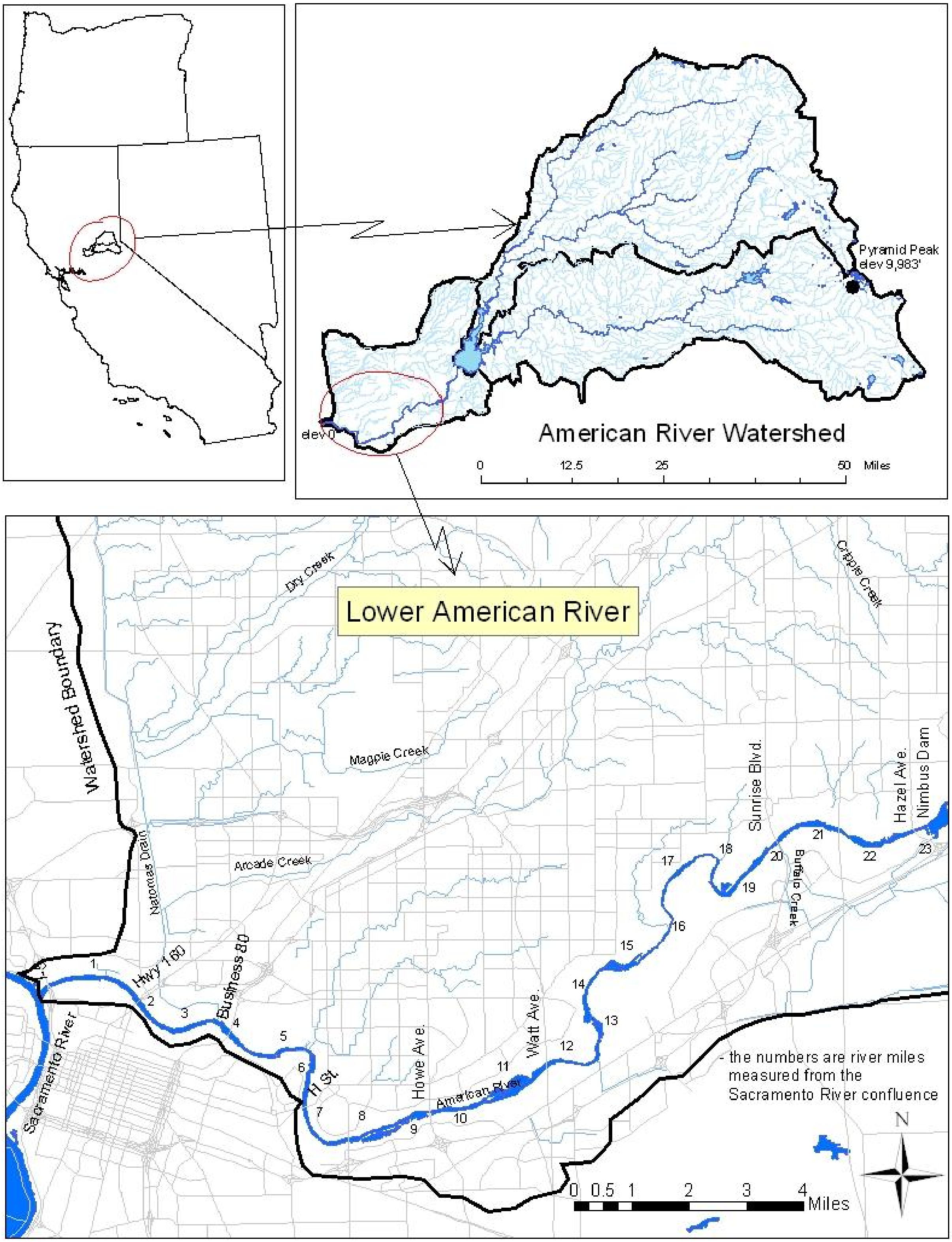


Figure 2. The American River watershed and Lower American River where steelhead redd surveys were conducted.

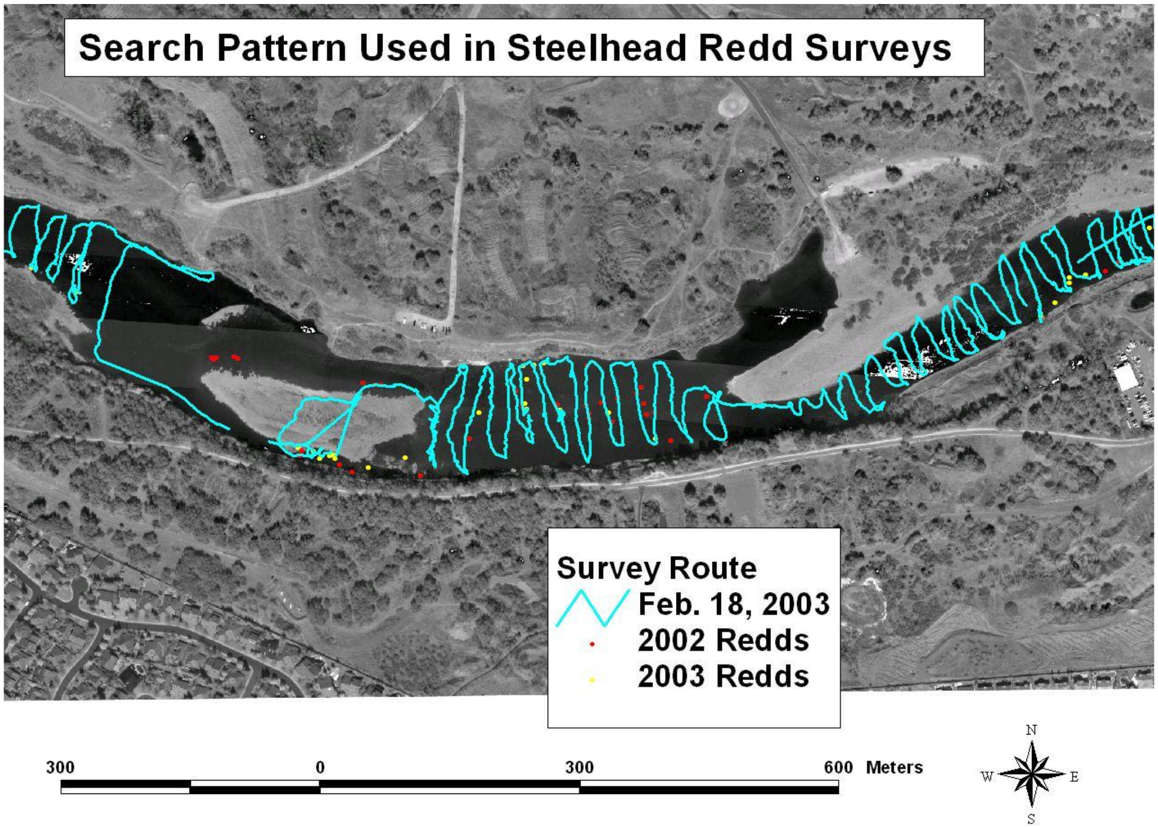


Figure 3. Typical survey route collected with GPS during one American River steelhead redd survey.

Redd Measurements

When a potential steelhead redd was observed it was marked with the GPS unit, measured, and dimensions entered. A Trimble Geoexplorer GPS unit was used to mark steelhead redd locations and record redd measurements. A data dictionary was created using Trimble Pathfinder Office software so that attribute data could be attached to each data point. Redd measurements were based on measurements used in California coastal spawning surveys (Gallagher 2002). We used a Global Water hand-held flow meter with 6foot expandable flow probe for taking measurements. The redd measurements were taken to the nearest centimeter with the water velocity meter rod and recorded on the GPS unit. Table 1 describes the redd measurements and Figure 4 shows a picture of a steelhead redd with the measurements denoted. For water velocity measurements the meter was held in the current until the average velocity reading stabilized, generally about 20 seconds. All the attributes collected on each redd are attached to the point in the GIS coverage so that data on each specific spawning location can be compared between years.

Table 1. Data recorded for redds during surveys.

Data Field	**Description**
Species	Steelhead, chinook, lamprey, pikeminnow, sucker, unknown
Depth	Water depth in centimeters measured near pot in a location to approximate depth prior to redd construction
Redd Age	0=test redd, 1=fish on, 2=new still clear, 3=older some algae, 4=old obscure, 5=marker only
Fish size	Estimated length of a fish on a redd, cm
Fish size 2	Estimated length of a second fish on a redd, cm
Velocity	Water velocity measured near the front of the redd in a location near the bottom where a fish would be when beginning to construct a redd (about 10-20 cm off the bottom)
Pot length (PL)	Length of pot parallel to flow
Pot width (PW)	Maximum width of pot perpendicular to flow
Pot depth (PD)	Maximum depth of excavation relative to the undisturbed stream bed = water depth in pot minus water depth to undisturbed stream bed
Pot substrate (PS)	Size of dominant substrate in pot, visually estimated after calibrating with measuring device
Tail spill length (TSL)	Length of tail spill parallel to flow
Tail spill width 1 (TSW1)	Width of tail spill perpendicular to flow at 1/3 of the distance down from the upstream end of the tail spill
Tail spill width 2 (TSW2)	Width of tail spill perpendicular to flow at 2/3 of the distance down from the upstream end of the tail spill
Tail spill substrate	Size of dominant substrate in tail spill, visually estimated after calibrating with measuring device
Marker	Denotes that a colored marker was placed on the redd
Flow	River flow in cfs released to the river from Nimbus Dam
Method	Motor boat, drift boat, canoe, snorkeling, wading, aerial

In addition to the data collected on the GPS datalogger we collected information on steelhead observations by reach, condition of steelhead observed, and attempted to determine presence or absence of the adipose fin.

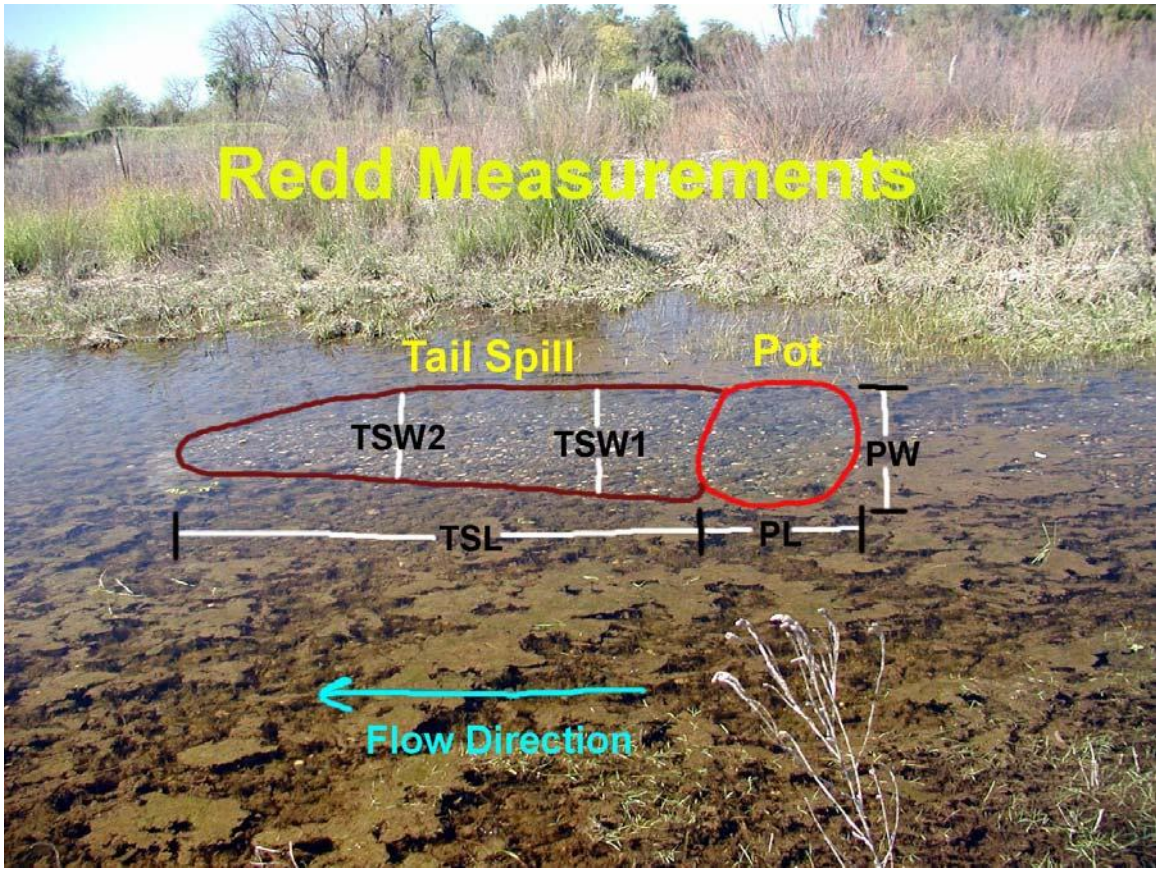


Figure 4. Illustration of measurements taken of steelhead redds. This redd was constructed under a higher flow than pictured. The lower flow made the redd show up well in the photo.

The redd locations with corresponding attribute data were saved as a point shapefile after differentially correcting the rover files collected in the field. The survey routes were stored as line shapefiles so that the specific areas of river surveyed could be viewed on a map. The mapped survey route allowed us to determine track areas that were surveyed and not surveyed. The survey route could be overlayed on a habitat-type map of the river to determine if all areas were adequately surveyed. Only partial survey route data was collected because the line file had to be closed whenever a redd was marked. In areas with multiple redds the line data was often not collected, since the redd locations indicate they were surveyed. When redds from two different surveys were marked in the proximity of each other (within about 5 meters of each other), the data was examined to determine whether these were the same redd. If it was believed to be the same redd from a previous survey, it was not used in the composite shapefile. Many redds in areas not frequented by wading anglers were marked on the ground with colored weights in 2003 to help determine how long redds remain identifiable. Data from each day was stored in a separate file, downloaded at the end of each survey period, and then exported into a composite GIS shapefile. Data was then differentially corrected using established and accepted methods by Trimble Inc.

The data was edited and displayed on orthophotos using ArcView and ArcMap. The shapefile is in UTM zone 10 NAD 27 projection. Redd data from the March 7, 2002 survey at Paradise Beach was not collected with GPS. Redd locations were instead estimated on aerial photos and then digitized manually. Eight redd locations were mapped in GPS at the upper Sunrise side channel on March 13, 2002 using the offset function while standing on the high bank above the river. This was to avoid working in the middle of numerous anglers casting to the fish on these redds.

Population Estimates

We estimated steelhead populations in 2002 and 2003 based on redd counts and steelhead observations. Susac and Jacobs (2003) tested the relationship between steelhead redd counts and spawner abundance over five years in Oregon streams. They compared redd counts to adult counts at fish ladders and weirs. Their relationship between adult abundance and redd counts is strong ($R^2 = 0.97$, $P<0.001$) suggesting that redd counts are a consistent indicator of run-size over the range of run sizes they observed, from 35 to 2,131 fish.

The 2002 spawning population estimate is based on the number of redds counted, the number of redds per female, and the ratio of males per female steelhead in the river. The ratio of male to female steelhead entering Nimbus Hatchery during the 2001 – 2002 run was used as the in-river ratio. The 2003 spawning population estimate was calculated using the same redd count based method. An additional area under the curve estimate (English et al 1992) was calculated in 2003 from observations of live steelhead in the river that were not holding on redds during surveys.

Because an estimate of the number of redds per female was not obtained for the American River, we used information from redd per female estimates in other rivers. Steelhead often build multiple redds, each redd immediately upstream of the prior one (Shapovalov and Taft 1954). This was observed for some redds in the American River, but the resulting contiguous area of disturbed gravel was counted and measured as only one individual redd. Comprehensive surveys of redds and steelhead passed through weirs in Oregon Rivers found that the ratio of redds to females averaged about one redd per female (Susac and Jacobs 1999). Susac and Jacobs (2001) observed 1.5 redds per female in the West Fork Smith River calibration site and believe it is the best available estimate for an Oregon coastal stream during low flow conditions. Freymond and Foley (1985) reported 1.2 redds per female in rivers surveyed in Washington. Gallagher (2001) calculated the number of redds per female in the Noyo River, California using population estimates produced by two methods. An estimate of 2.49 redds/female was calculated using the number of adults observed during each survey, the estimated residence time of steelhead in the river (area under the curve method), and the number of redds counted. An estimate of 2.30 redds/female was obtained based on the measured area of redds assuming that larger redds represented fish that constructed only one redd and smaller redds represented fish that made multiple redds. Steelhead snorkel escapement surveys conducted to index steelhead abundance in Prince of Wales Island Alaska streams consistently counted more than two times as many adult steelhead as redds although some steelhead were still unspawned as of the final survey each season (Hannon 2000 and Jones 2001). Pairs of redds just a couple meters apart were often observed during these snorkel surveys with steelhead present on only one redd of the pair, potentially indicating construction of more than one redd by a female. Farzan (2002) documented the highest ratio of redds per female found in any of the Prince of Wales surveys at 1.57 redds per female in Twelve Mile Creek (assuming one male per female and that all fish in the river were counted). It is likely that observer efficiency at detecting redds varies by river depending on type of substrate and water clarity and varies within a river over time with changing conditions. For the American River estimate we used one redd and two redds per female as the lower and upper bounds of the population estimate calculations. During 2002 surveys some redds were likely missed in un-surveyed side channels and prior to the first survey.

The area under the curve population estimate (Hilborn et al 1999) was based on live steelhead observations. We calculated this estimate by dividing the number of fish days (one fish in the river for one day = one fish day) during each survey period by the average number of days a steelhead is thought to remain in the river within the survey reach (survey life). This total was then divided by a correction factor for fish visibility (estimated observer efficiency, ie. what proportion of the fish in the river at the time of a survey that the surveyers see) to determine the area under the curve. The sum of all the area under the curve results was the population estimate. Population estimates were calculated separately for fish on redds (representing in-river spawning) and fish not on redds (fish that were in the river but did not spawn in the river). The in-river spawning population estimate was used to estimate potential fry production.

The thalweg profile of the river was constructed using two foot topography of the river bottom. The topography of the river was then used to estimate the elevation on the thalweg profile where groups of redds were located. We graphed locations of groups of redds along the longitudinal transect of the river constructed on the thalweg to illustrate where spawning occurred relative to channel gradient.

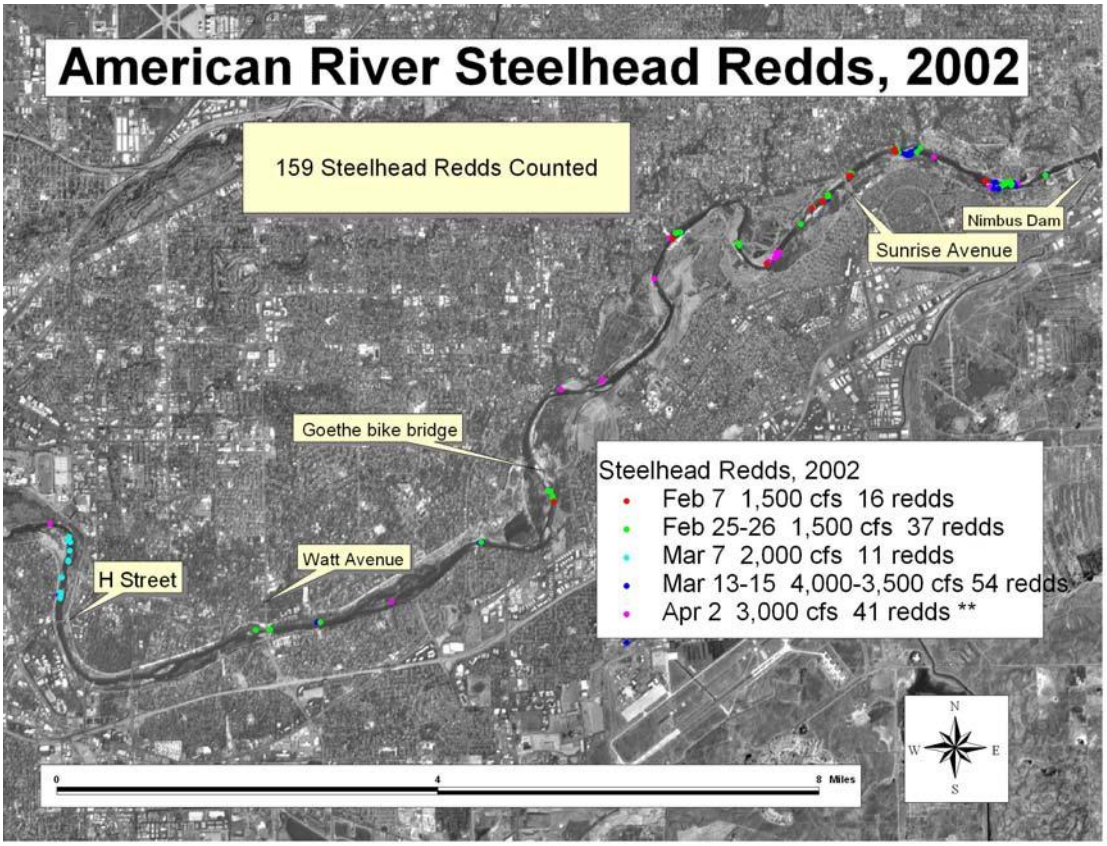
We predicted steelhead fry emergence dates based on the date redds were constructed and water temperature during the subsequent incubation period. Predicted emergence dates were compared to observations of newly emergent fry to help determine whether we were covering the entire spawning period with the redd surveys.

Midway through the spawning season when streamflow was lowered following creation of redds in side channels we monitored redds that were dewatered or in jeopardy of being dewatered to determine the condition of the eggs. Dewatered redds were excavated by hand and the condition of the eggs and fry was determined.

Results

We conducted steelhead redd surveys on the American River during the 2001, 2002, and 2003 spawning seasons. Data from the 2001 and 2002 surveys is in Hannon and Healey (2002).

During the 2003 survey we found a total of 215 steelhead redds and saw 208 adult steelhead between January 7 and April 4 (Figure 5). Spawning occurred over a 13.5 mile reach of the river from Watt Avenue to Nimbus Dam. Spawning was more evenly distributed between Watt and Nimbus in 2003 than in 2002. No spawning occurred below the first riffle downstream of Watt Avenue. The spawning habitat at Paradise Beach was not suitable for spawning during all but the last survey due to the backwater effect of high Sacramento River flows. Of the adult steelhead observations, 69 were observed on redds and 139 were not on redds. .



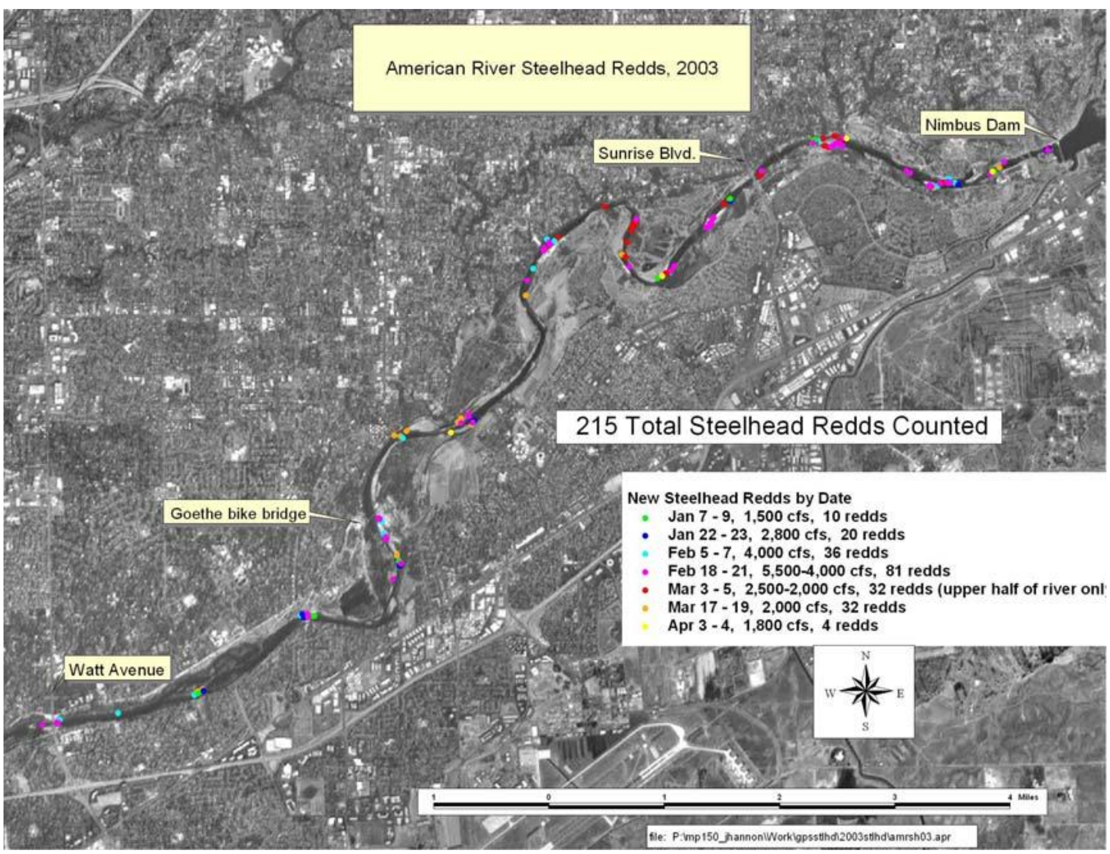


Figure 5. Map of American River steelhead redds in 2002 (top) and 2003 (bottom).

Spawning Distribution

Redd density in the 18 miles of the river with spawning habitat was 11.9 redds per mile in 2003 and 8.8 redds per mile in 2002 (table 2). Forty percent of the steelhead redds (85) occurred in the upper three miles of the river, above Sunrise Avenue at mile 20 in 2003. This equates to 28 redds per mile. Redds are concentrated in the upper section of the river, although not as concentrated as in the similar sized Feather River where Kindopp and Kurth (2003) found 48% of the redds constructed in the upper one mile of the Feather River. The redd distribution is broken down by common name of areas of the river in table 3 and in table 4 by reaches used in a planning model that evaluates Chinook salmon temperature related egg-to-fry mortality.

Although redds were concentrated in the upper river in 2002 and 2003, there was a greater proportion of spawning in the reach from Watt Avenue to Ancil Hoffman in 2003. Side channels appeared marginally suitable and were less likely used for steelhead spawning at flows of 2,000 cfs. However, steelhead appeared to select side channel spawning habitat at flows around 3,000 - 5,500 cfs. Areas of multiple thread channel had a high proportion of the steelhead spawning activity relative to their occurrence in the American River. For example, in 2002, 84 of the 159 redds (53%) occurred in river reaches with multiple channels while of 21% of the river (3.8 miles out of 18 miles with spawning habitat) contains multiple thread channels on a macro scale. In 2003 114 out of 215 redds (53%) occurred in multiple thread reaches.

Steelhead redd density during 2002 was 6.9 redds/mile from Nimbus to Discovery Park (23 miles). The first five miles of the American River from Discovery Park to just below Paradise Beach is deficient of steelhead spawning habitat because tides and Sacramento River flows back the water up to this point. Therefore, redd density in the upstream 18 miles of river was 8.8 redds/mile. Redd density by survey reach was 16.1 redds/mile in the upper seven mile reach from Nimbus Dam down to Ancil Hoffman Park, 4.4 redds/mile in the seven mile reach from Ancil Hoffman to just below Watt Avenue, and 3.75 redds/mile in the four mile reach from Watt Avenue to Paradise Beach (table 2).

Table 2. Redd density by river reach.

Steelhead Spawning Distribution Reach	River miles	Redds per Mile 2002	2003
Nimbus Dam to Sacramento River	1-23	6.9	9.3
Nimbus to Paradise Beach	5-23	8.8	11.9
Nimbus to Ancil Hoffman Park	17-23	16.1	19.6
Ancil Hoffman Park to Watt Avenue	10-17	4.4	17.7
Watt Avenue to Paradise Beach	5-10	3.75	0
Percent Associated with Multiple Thread Channel		53%	53%
Percent of River with multiple thread channel		4 miles out of 18 miles = 22%	

Table 3. Distribution of steelhead redds in 2003 (number counted) by common name of areas of the river, listed from upstream to downstream.

Location	Steelhead Redds, 2003
Nimbus	10
Upper Sailor	8
Sailor	10
Sailor side channel	11
lower Sailor	2
Sunrise above sc	5
upper Sunrise sc	28
upper Sunrise below sc	6
Sunrise Ave	5
lower Sunrise	5
lower Sunrise sc	16
El Manto	7
below El Manto	9
below San Juan rapids	1
Rossmoor	10
below Rossmoor/Ancil Hoffman top	4
cable crossing sc	22
upper Goethe sc	4
Goethe sc	11
lower Goethe sc	8
below Goethe sc	7
below Goethe	4
below Goethe sc outlet	1
Gristmill	7
above Watt sc	5
Watt	8
Watt sc	1

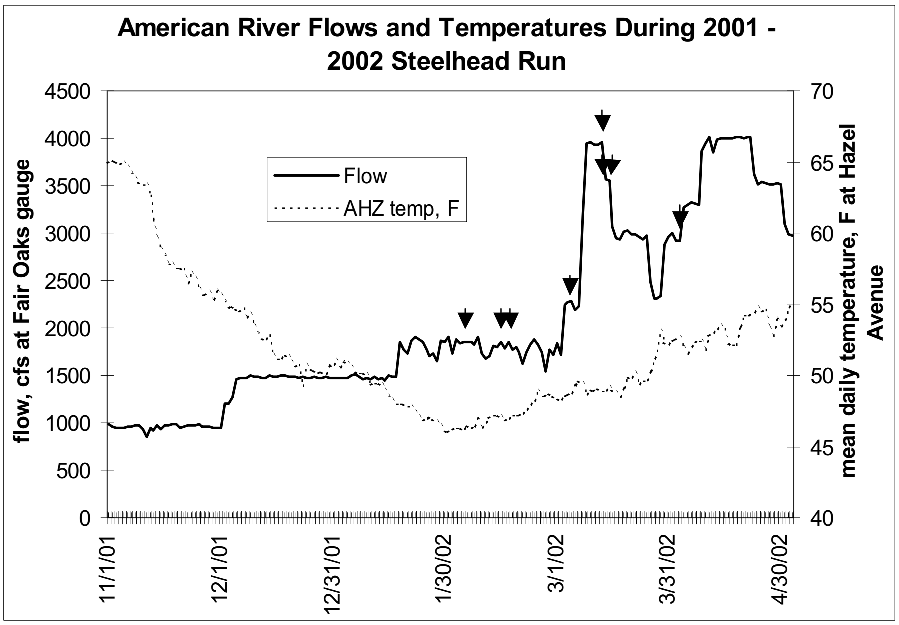
sc = side channel

Table 4. Steelhead redd distribution by reach used in the Chinook egg incubation planning model.

American River Steelhead redd distribution

Reach	Miles	2002 redds	2002%	2002 redds/mile	2003 redds	2003%	2003 redds/mile	Total 2002 + 2003	Total %
Above weir		no surveys			10	5%			
Nimbus to Sunrise bridge	2.86	80	51%	28	75	35%	26	165	**45%**
Sunrise to Ancil Hoffman	4.73	32	21%	7	52	24%	11	84	**23%**
Ancil Hoffman to Goethe bike bridge	1.89	3	2%	2	25	12%	13	28	**8%**
Arden Rapids (Goethe bridge) to Watt bridge	4.1	27	17%	7	51	24%	12	78	**21%**
Watt to Fairbairn water intake	2.02	1	1%	0	1	0%	0	2	**1%**
Fairbairn to H Street bridge	0.75	0	0%	0	0	0%	0	0	**0%**
H Street bridge to Paradise Beach	1.09	13	8%	12	0	0%	0	13	**4%**
Paradise Beach to 16th st	3.49		0%	0		0%	0	0	**0%**
16th st to Sacramento River	2.01		0%	0		0%	0	0	**0%**
Total	22.9	156	100%	7	214	100%	9	370	**100%**

Temperatures and flows during the 2002 and 2003 steelhead runs are given in Figure 6. During both years flows started out at about 1,500 cfs when spawning began. During 2002 flows remained near that level up into March when flood control operations began with two brief peak flow periods, in March and in April. During 2003 conditions were wetter earlier and flow increases began in January up to a peak spawning period release of 5,500 cfs to meet a Delta water quality standard in mid-February. Flows then ramped down to 2,000 cfs through the remainder of the spawning period before heavy precipitation began again and releases were later increased. The highest redd counts occurred during the peak flow periods in 2002 and 2003 and were a couple weeks earlier in 2003 than in 2002.



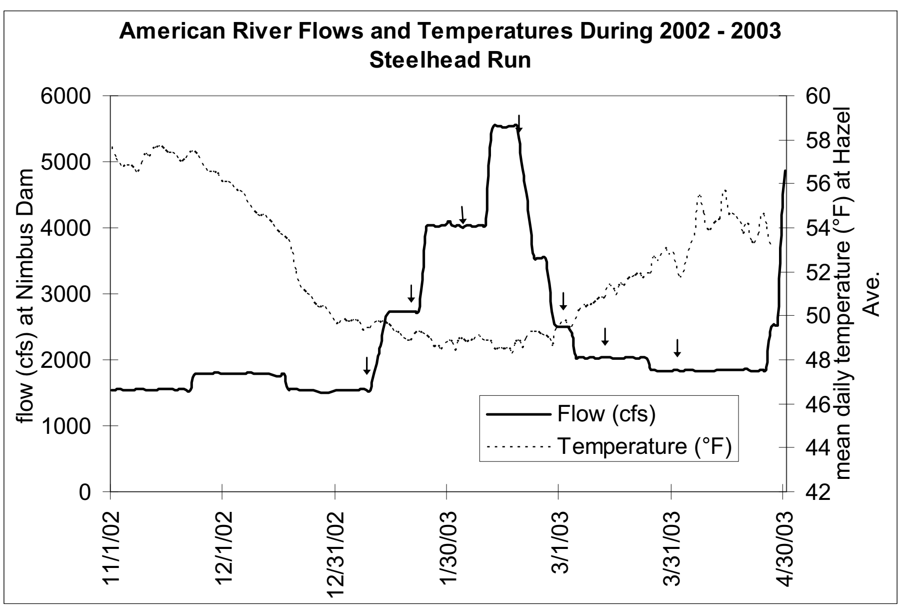


Figure 6. American River discharge from Nimbus Dam and average daily water temperature at Hazel Avenue during the 2002 (top) and 2003 (bottom) steelhead runs. Arrows denote when steelhead surveys were conducted.

Figure 7 shows a temperature comparison between Hazel Avenue and Watt Avenue, a distance of about 14 river miles. These two locations were used for calculating fry emergence dates. The warmer Watt Avenue temperatures later in the spring result in an incubation period a few days shorter than near Hazel Avenue. We checked regularly along the river margins for newly emerged steelhead fry throughout the survey period. We found the first fry on March 17 at upper Sunrise (Table 5). The first fry from redds we found were calculated to emerge, based on water temperature, on March 11. Therefore it appears we began redd surveys at about the time that the first steelhead were spawning and did not miss early spawners.

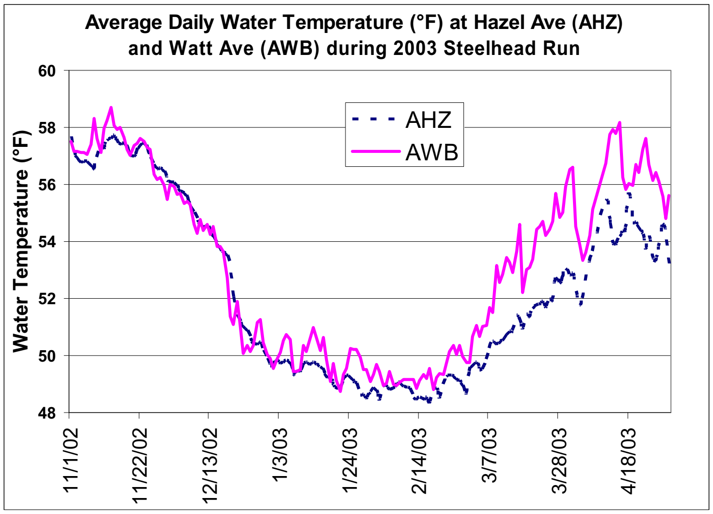


Figure 7. Water temperatures at Hazel and Watt Avenue used for calculating steelhead fry emergence dates from spawning date.

Table 5. Steelhead redd counts and adult observations and estimated fry emergence dates, 2003.

Date	Flow range, cfs	# new redds	# steelhead	ATU's at Hazel Ave, fry to emerge by[1]	ATU's at Watt, fry to emerge by[2]
January 7 – 9	1,500	10	20	3/13/03	3/11/03
January 22 - 23	2,800	20	28	3/25/03	3/22/03
February 5 – 7	4,000	36	42	4/6/03	4/2/03
February 18 – 21	5,500 - 4,000	81	53	4/20/03	4/15/03
March 3–5 (only down to Ancil Hoffman)	2,500 – 2,000	32	29	4/29/03	4/24/03
March 17 – 19	2,000	32	30	5/11/03	5/6/03
April 3 – 4	1,800	4	6	5/26/03	5/22/03

[1] Estimated emergence date based on 600 accumulated temperature units (°C) at Hazel Avenue

[2] Estimated emergence date based on 600 accumulated temperature units (°C) at Watt Avenue.

Date of first steelhead fry observation

Upper Sunrise	17-Mar
Watt Avenue	18-Mar
Nimbus basin	23-Mar
Sailor Bar	23-Mar
lower Sunrise side channel	3-Apr

Water clarity was generally suitable for conducting redd surveys during all surveys in 2001 – 2003. Secchi disc depths in the upper river (Fair Oaks bridge) and lower river (Fairbairn Water Intake) were taken in 2003 (Figure 8). The lowest water clarity (2.8 m) during a survey occurred on March 17 following 1.5 inches of rain over the prior two days. The water cleared after one day of no rain and the secchi reading was 3.8 meters the following day in the lower river. Redds seemed to be visible to a depth of about 1 to 1.5 meters less than the secchi depth readings.

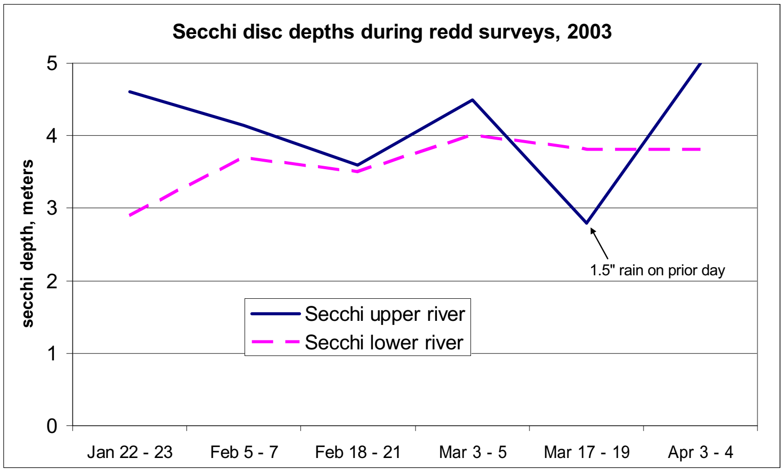


Figure 8. Secchi depth depths in the upper and lower river during 2003 surveys.

Six areas were identified containing side channels with habitat likely to support spawning steelhead, especially at flow levels above 3,000 to 4,000 cfs (Figure 9).

The biggest spawning concentrations occurred at Sailor Bar and upper Sunrise side channel. The area around the upper Sunrise side channel was heavily used by steelhead during both 2002 and 2003 (Figure 10). This same area is a favorite fishing area with easy access for wading anglers. Many steelhead anglers practice catch and release fishing. We observed steelhead on redds get caught, released, and then return to the redd within a minute or two of being released. Spawning steelhead often did not leave redds even with multiple anglers within about 20 meters. Steelhead and fresh redds were observed concentrated at the upper Sunrise side channel on March 13, 2002 following a flow increase from 2,000 to 4,000 cfs on March 8, 2002. The area is marginally suitable for spawning at 2,000 cfs but appeared to be preferred at 4,000 cfs based on an increase in the number of steelhead spawning in the channel following the flow increase.

Redd Dewatering

Steelhead constructed 15 redds in the lower Sunrise side channel between February 11 and 18, 2003 following a flow increase to 5,500 cfs (Figure 11). This side channel was unavailable for spawning in 2001 and 2002. Steelhead constructed 11 redds in a side channel below the Goethe bike bridge on the left bank of the river when flows were 4,000 to 5,500 cfs (Figure 12). Redds in these two locations were closely monitored through the rest of the spring because they appeared vulnerable to dewatering. Redds in these two areas appeared more vulnerable to dewatering under the 2003 flow regime than redds in other areas of the river.

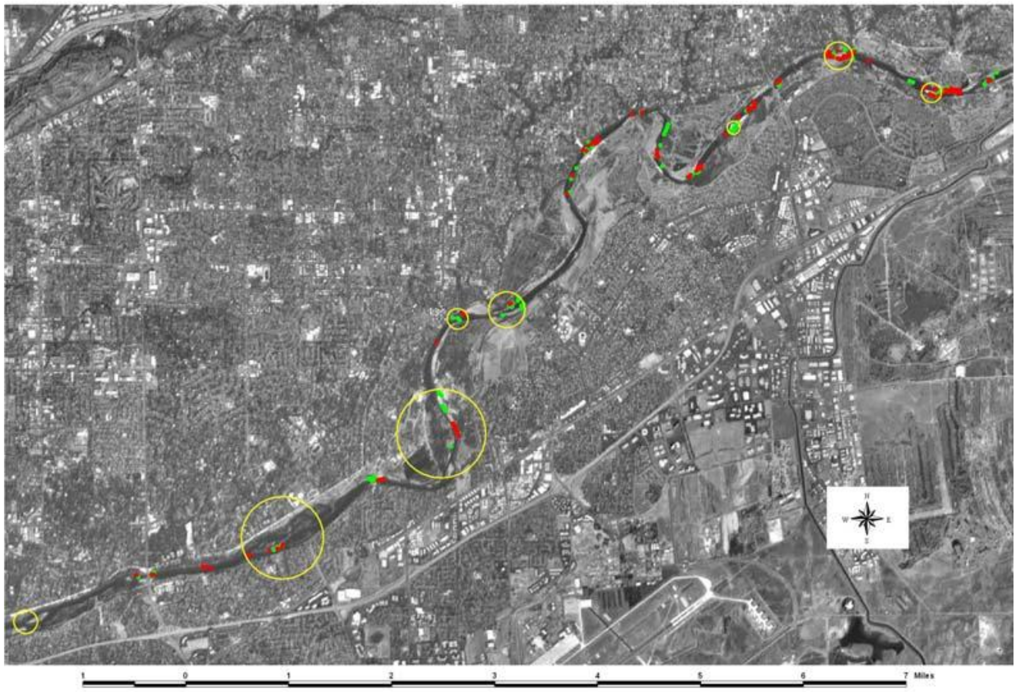


Figure 9. American River side channel reaches (yellow circled areas) where steelhead spawning is likely to occur. Red dots are 2002 redds and green dots are 2003 redds.

Five of the redds at the lower Sunrise side channel were dewatered of surface flow when flows dropped below about 3,000 cfs on February 27. The other ten redds in this side channel remained under water, but in a backwater pool with no water movement and heavy algae growth (figure 4). The redds at Goethe Park had surface flow throughout the incubation period with flows down to 1,800 cfs. The water surface elevation at the Goethe redds is controlled by three separate riffles across the river. The change in water surface elevation at Goethe is less for a given change in flow than at the lower Sunrise site.

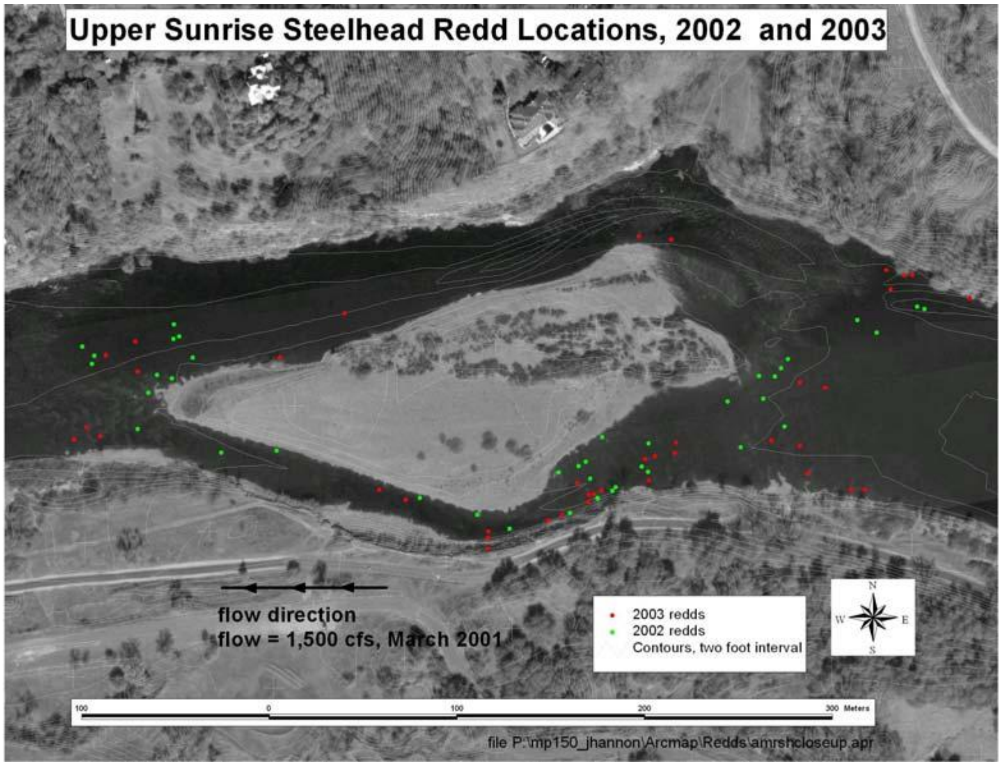


Figure 10. Upper Sunrise side channel steelhead redds in 2002 and 2003.

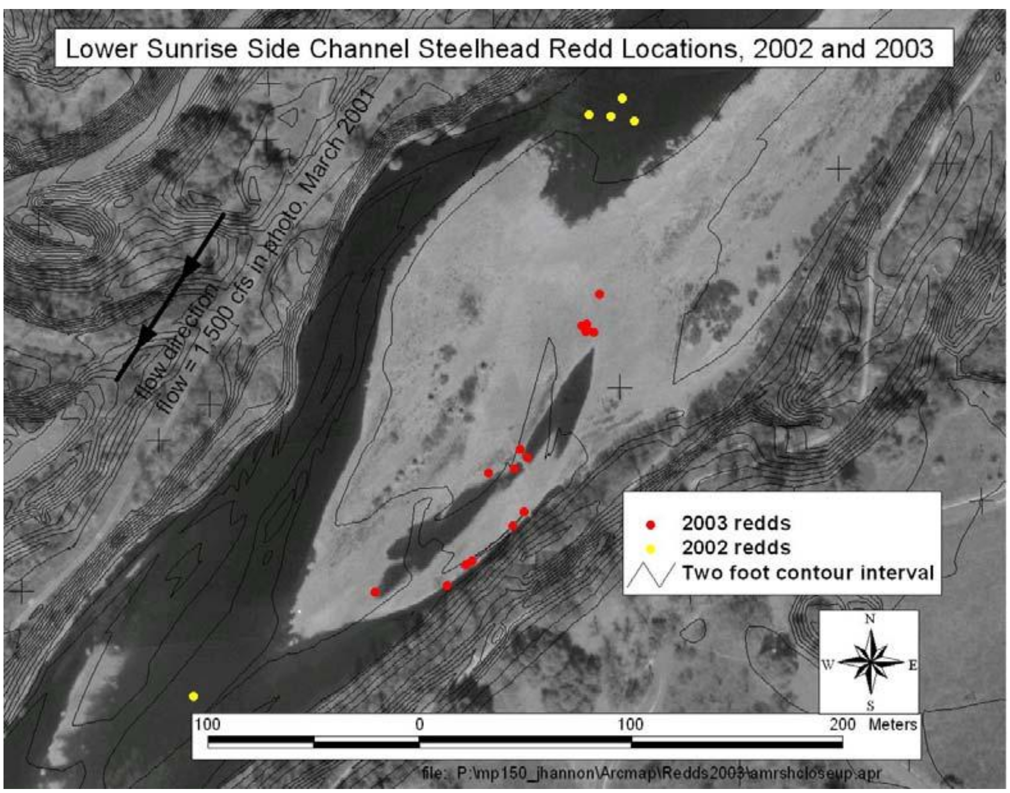


Figure 11. Steelhead redds at the lower Sunrise side channel. No flow is flowing through the channel in the photo at 1,500 cfs. Flow provides spawning habitat in the side channel (where 2003 redds are located) at greater than about 4,000 cfs.

Figure 12. Goethe Park Steelhead redd locations.

We partially excavated a dewatered redd away from the thalweg of the prior wetted side channel on April 3 after it had been dewatered of any surface flow for five weeks. When we found dead eggs we quit excavating. Later on April 5 we decided to attempt to count the number of eggs in the redd by excavating the entire redd. The dead eggs near the surface had apparently all been eaten by a raccoon and deeper ones had been consumed by invertebrates. Earthworms and other bugs were abundant within the redd. Immediately after the redd was excavated to a depth of about 10 cm where water was present steelhead fry began emerging into the open water. This redd was more or less completely excavated and 79 live steelhead fry were salvaged and moved to the main river channel. The yolk sacs in the fry in this redd were used up, indicating they were near the end of the time they could spend under the gravel.

A group of four other dewatered redds four meters from the above redd, in the thalweg of where flow in the side channel occurs was excavated one week later. Most of the fry in these redds still had yolk sacs. All of the excavated redds were constructed within about a one week period. The different level of development between the two locations indicates that the water was likely cooler in the redds closer to the thalweg, only four meters away from the first redd. Water in the redd away from the thalweg was 17C, although it may have been warmed slightly by the sun. Two hours of work by four biologists salvaged 900 steelhead fry from these dewatered redds and placed the fry into the edge of the main river channel. These redds were not completely excavated and more fry still remained stranded under the gravel. When we dug down to standing water, greater than about 10 cm below the gravel surface, there was water visibly flowing through the gravel. The subsurface flow was great enough that the steelhead fry that came out of the gravel immediately oriented into the current (Figure13). Dead eggs were not found in the redds in the thalweg. Some newly emergent fry were observed near the redds downstream in the backwater pool, although survival from these redds was likely not high. A thermograph was placed in one of the redds but was lost during high flows later in the spring.

Figure 13. Excavating dewatered steelhead redds and salvaging the fry (left photo) and steelhead fry orienting into the current (right photo) within one of the excavated pools in the left photo.

Nimbus Basin Spawning

We did not survey the area upstream of the hatchery weir (Nimbus Basin) in 2002 because we were unable to access it with the boat. Adult steelhead are known to be abundant in the area based on angler success. The spawning habitat in the area is poor at the lower flows (below about 8,000 cfs) because much of the smaller gravel has been scoured away. During 2003 we surveyed Nimbus Basin by wading and snorkeling. New steelhead redds were found during all but the first and last surveys (Figure 14). The gravel being used by most of the steelhead for spawning was large making it difficult to dig a very deep redd. Similar habitat conditions lower in the river would not likely be utilized for spawning but probably because this is the upstream extent of habitat access it does get used for spawning. Some redds were likely missed in Nimbus Basin during the flows above about 2,500 cfs because the velocity washed the snorkelers downstream before they could swim to the habitat furthest out in the main channel. Newly emerged steelhead fry were first observed in Nimbus Basin on March 23, confirming that at least some of the spawning was successful in the large gravel.

Lampreys appeared to be more successful at creating distinguishable redds in the Nimbus basin area than steelhead. The lampreys we saw spawning in Nimbus Basin appeared to be larger than the average size of the ones we saw lower in the river.

The top of the riffle at Nimbus basin is an area of the river that could likely be improved for steelhead and salmon by adding spawning sized gravel or reconfiguring gravel from some of the adjacent gravel bar deposits. There would be the chance that addition of smaller gravel could get washed out during high releases following spawning so that would need to be taken into consideration. Steelhead here, like in some other areas of the river are vulnerable to anglers but generally appear to do ok when caught and released. Handling live fish may contribute to the fungus development we observed although.

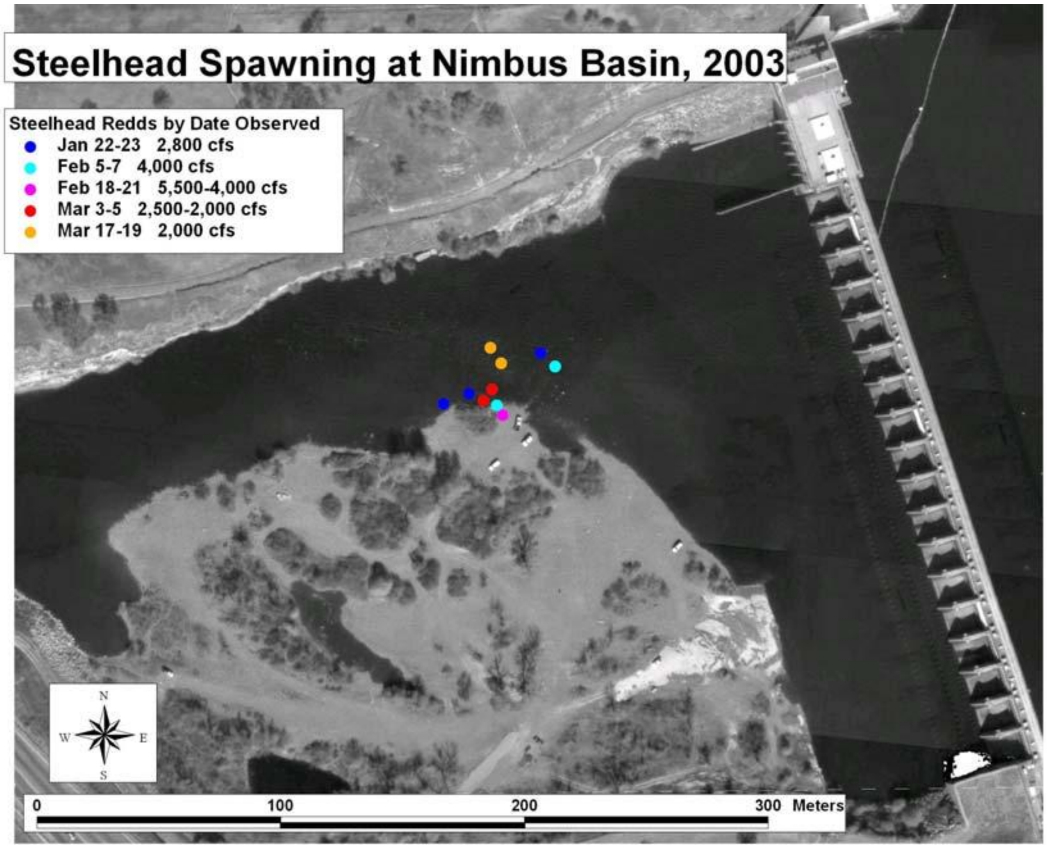


Figure 14. Steelhead spawning in Nimbus Basin in 2003.

The GIS and GPS mapping allows comparisons of spawning locations to be made at different flows between years. Figure 15 shows Sailor Bar spawning locations by flow. The redds constructed at the higher flows tended to be closer to the banks than those constructed at the mid or lower flows.

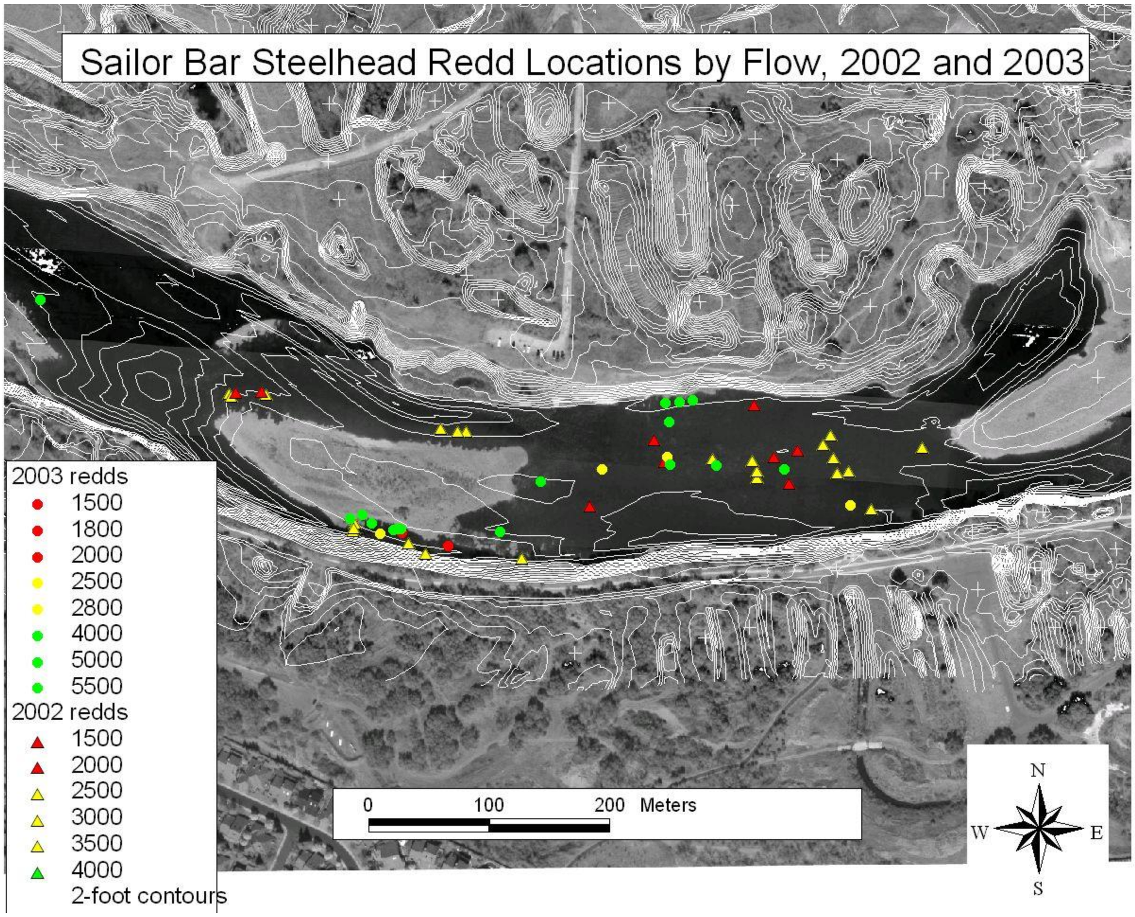


Figure 15. Steelhead spawning at Sailor Bar, 2002 and 2003.

Figure 16 shows locations of groups of redds on the thalweg profile. This coarse scale analysis shows that steelhead spawning occurred primarily near the major riffle crests in the river. Groups of steelhead redds were marked on 16 of the approximately 22 major riffle crests along the thalweg profile.

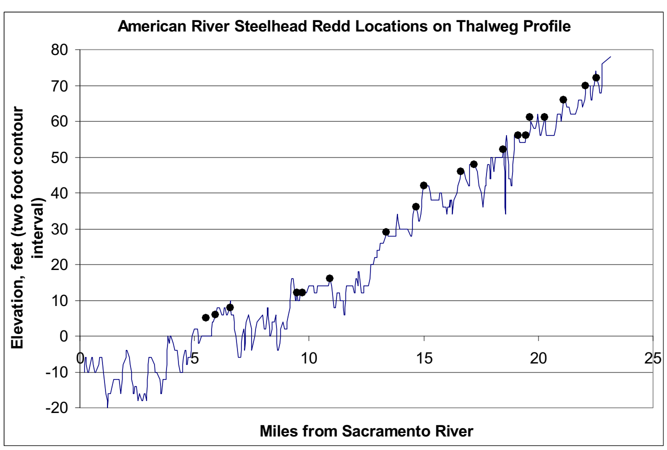


Figure 16. Locations of groups of steelhead redds (dots) along the American River thalweg profile.

Population Estimate
The redd based population estimate, based on number of redds observed, the male to female ratio (from the hatchery) and assuming 1 to 2 redds per female was 200 - 401 steelhead in 2002 and 243 – 486 steelhead in 2003 (Tables 6 and 7). The population likely lies somewhere in the range between the 1 redd per female estimate and the 2 redds per female estimate.

Table 6. Male to Female Ratio from Hatchery Returns

Year	Adults	Males	Females	Males/Female
2002	1,253	755	498	1.52
2003	935	521	414	1.26

Table 7. Redd based population estimate

Year	Redd Count	Males/Female	Pop. with 1 redd/female	Pop. with 2 redds/female
2002	159	1.52	**401**	**200**
2003	215	1.26	**486**	**243**

The live fish observation based population estimate (area under the curve) required an estimate of observer efficiency and residence time. Observer efficiency is the proportion of the fish in the river on the survey day that the observers see. Residence time is the amount of time (days) a fish remains within the survey area. In order to determine observer efficiency a known number of fish in the river from some other counting method is required. We did not have that known number so made a rough estimate based on fish entering the hatchery and angler interviews. We estimated that we were seeing 10% of the fish in the river that were not on redds. Steelhead holding on redds were much easier to observe than those not on redds. They tended to stay on the redd until the boat or walking surveyer approached well within eyesight. When they did leave the redd they could still often be seen lingering near the redd while we were taking measurements. We estimated that we were seeing 90% of the fish that were on redds during the survey days. We assumed no difference in steelhead holding on redds during the day when surveys were conducted versus during the night when no observations were attempted.

In order to determine residence time, individual marked fish with a counting station or radio telemetry are sometimes used (Korman et al 2002). Residence time for fish on redds can be estimated by repeated observations of individual redd sites with fish on them. Residence time for fish on redds was estimated to be three days based on return visits to redds when fish were observed on a redd. Steelhead were on 22% of the redds counted during the formal surveys and counts occurred every 14 days. If steelhead are on redds for three days then we would expect to see steelhead on 21% of the redds, agreeing closely with our 22% observational data. Estimates of residence time for fish not on redds were based on experience from repeated snorkel surveys conducted for indexing steelhead escapement in other rivers (Hannon 2000) and on weir counts from other rivers (Lohr and Bryant 1999) where residence time is variable with sporadic movements corresponding to changes in discharge. Based on these data from more northerly rivers we used 21 days as the average residence time in the survey reach for steelhead. This number may be on the low end. Other studies have found residence times for winter steelhead extending up to 100 days.

Based on the above estimates the in-river spawning estimate was 343 steelhead and the number in the river but not spawning in the river was 926 steelhead for a total escapement of 1,310 steelhead. Table 8 shows the area under the curve calculations. Steelhead observation timing is illustrated in figure 17 and redd observation timing is in figure 18. Steelhead observation timing is similar to that observed through a fishway on the Eel River (Shapovalov and Taft 1954). The area under the curve estimate for fish spawning in the river is likely more precise than the estimate for fish not spawning in the river because observer efficiency is high for fish on redds and the residence time is based on observations in the American River, whereas observer efficiency for fish not on redds is low and the residence time is based on steelhead in other rivers far from the American. When observer efficiency is low, as for steelhead in a large river, small changes in observer efficiency can make a big difference in the population estimate. The effect of changing observer efficiency and residence time on the population estimate is illustrated in table 9.

Table 8. Steelhead observations by location and date and area under the curve population estimates.

Steelhead observations 2003																			
Steelhead not on redds																			
	Day	Nimbus	Sailor up	Sailor low	Sunrise up	Sunrise low	El Manto	Rossmoor	Ancil Hoffman	Goethe	Grist mill	Watt	Paradise	clips checked	clipped	fungus	Fish Observed	Total Fish	AUC (Hillborn)
Jan 7 - 9	7		4	3	1	2			1	1	2	2		3	3	4	16	160	168
Jan 22 - 23	22	8	2	1	4	2	2			1		1		3	3	2	21	210	278
Feb 5 - 7	36		3	6	5	1	2			5		1	1			14	24	240	315
Feb 18 - 21	49		2	8	8	4		1		9						16	32	320	364
Mar 3 - 5	62		2	3	5	7		1						4	3	10	18	180	325
Mar 17 - 19	76	6	5	4	3	2			1			1		1	1	11	22	220	280
Apr 3 - 4	93	2	3		1									4	3	2	6	60	238
																			63
Total		16	21	25	27	18	4	2	2	16	2	5	1	15	13	59	139		2,031
												Escapement not spawning in river =							**967**
															observer efficiency = 0.1				
															residence time = 21 days				
Steelhead on redds																			
	Day	Nimbus	Sailor up	Sailor low	Sunrise up	Sunrise low	El Manto	Rossmoor	Ancil Hoffman	Goethe	Grist mill	Watt	Paradise	clips checked	clipped	fungus	Fish Observed	Total Fish	AUC (Hillborn)
Jan 7 - 9	7		2		1						1						4	4	6
Jan 22 - 23	22	3		1		2					1			1	1	1	7	8	83
Feb 5 - 7	36	1		5	4					3	2	3		2	2	6	18	20	175
Feb 18 - 21	49			1	5	2	4	2	2	5				2	2	4	21	23	254
Mar 3 - 5	62	1			7		1	2								3	11	12	208
Mar 17 - 19	76	3	2		3											2	8	9	133
Apr 3 - 4	93																0	0	68
Total		8	4	7	20	4	5	4	2	8	4	3	0	4	4	16	69		926
												Escapement spawning in river =							**343**
														observer efficiency = 0.9					
														residence time = 3 days					
										Total escapement = not on redds + on redds =									**1,310**

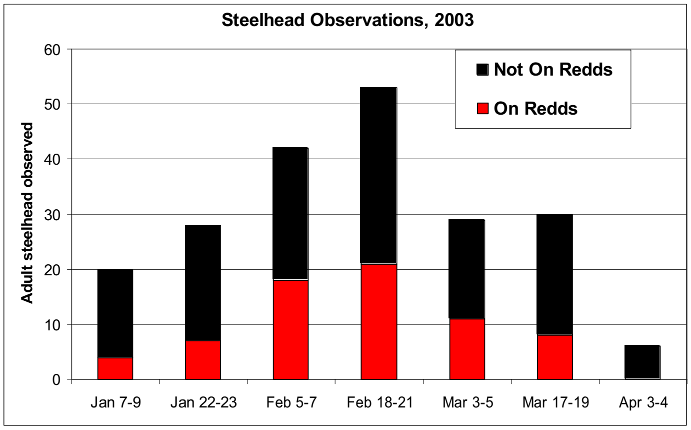


Figure 17. American River steelhead observations for fish on redds and not on redds.

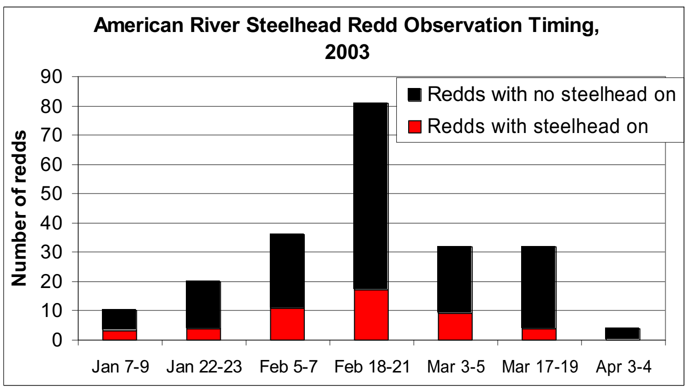


Figure 18. American River steelhead redd counts by date.

Table 9. Effects of different observer efficiency (OE) and fish residence time (RT) on population estimates (Pop).

	OE	**Pop**	**OE**	**Pop**	**OE**	**Pop**	**RT**	**Pop**	**RT**	**Pop**	**RT**	**Pop**
Not on redds	.2	483	.1	967	.05	1,934	28	753	21	967	14	395
On redds	0.95	325	0.9	343	0.8	386	5	207	3	343	2	513

Potential steelhead fry production based on 1.5 redds per female, an average fecundity of 6,300 eggs (this is the average fecundity at Nimbus Hatchery 1975 – 1987 (ADF&G 1987)[a]), 1.5 redds per female, and an egg to fry survival rate of 50% was 450,450 in 2003 and 333,900 in 2002 (Table 10). Based on snorkel observations and seining surveys high mortality of fry appears to occur during the first couple months following emergence.

[a] 6,300 eggs/female may be on the high side if early hatchery operations selected the larger females for spawning. The mean estimated size of 58 cm observed would yield a fecundity of 5,121 eggs/female according to the equation # eggs = 0.9471 X Length, cm $^{2.1169}$ Shapovalov and Taft (1954).

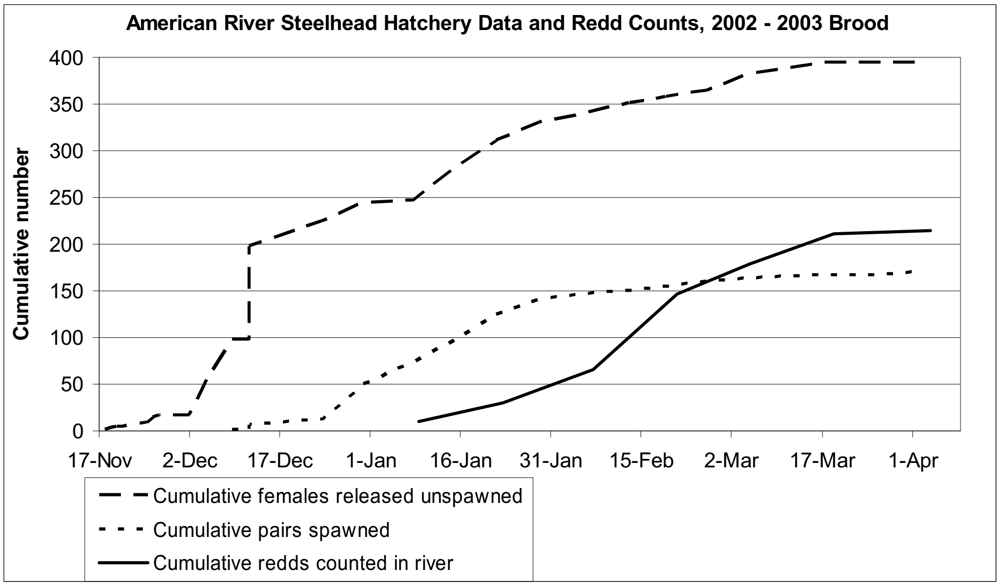
Table 10. Potential fry production estimated from redd count data in 2002 and 2003.

	2003	***2002***
Redds counted	215	159
Females spawning (at 1.5 redds per female)	143	106
Fecundity (Nimbus average 1975-1987, Ducey1987)	6,300	6,300
Total eggs spawned	900,900	667,800
Fry produced at 50% egg to fry survival	450,450	333,900

Timing of Steelhead Spawning

The last three pairs of steelhead in 2003 were spawned at the hatchery on April 2. The last redd count was conducted on April 4. No steelhead were observed over redds during the last survey, but six steelhead were observed in the river. No steelhead entered the hatchery between the last spawning on April 2 and when the ladder was closed on April 9. Straying or over-summering may occur in the American River. Individual steelhead collected by anglers during summer in past years had immature gonads. Large fresh steelhead were observed in the American into at least May in 2003 (Tom Cannon pers. comm.). Figure 19 shows hatchery spawning data versus redd observations in the river in 2002 and 2003. In-river spawning appears to occur a few weeks after the peak in hatchery spawning.

Staley (1976) provided a summary of American River steelhead management after the completion of Folsom and Nimbus Dams in 1955. During early years of hatchery operations (1955 – 1962) nearly all fish entered the hatchery from January through April and were considered winter run fish. Because returns were low during these early years supplements of eggs from the upper Eel River were made. Later, in 1969 – 1973, attempts were made to establish an earlier run to provide earlier steelhead fishing by stocking summer run steelhead from the Washougal River in Washington and Siletz River in Oregon. The fish came primarily from the Washougal River which has a run that enters the river from May through November and spawns March through June. Washougal River strain were again stocked in 1980 and 1981. In addition, early returning steelhead in the American and some trapped from the Sacramento River were isolated and spawned separately from later fish in an attempt to select for earlier returning steelhead for fishing. The goal was to have a large number of steelhead arrive in October. Anglers report immature adult steelhead in the American River during the summer. These could be remnants from the attempts to establish summer run steelhead in the American River.



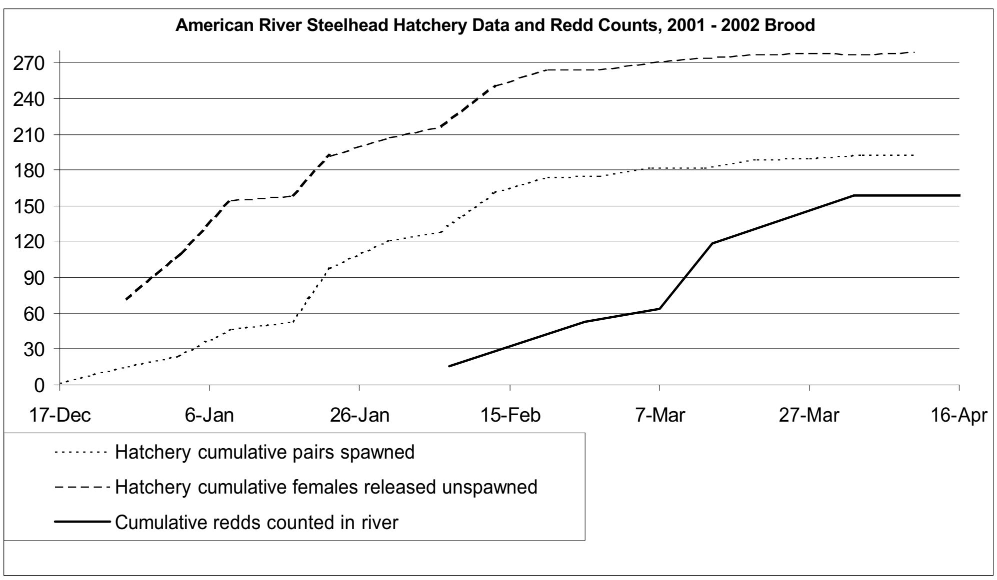


Figure 19. American River steelhead timing of hatchery spawning, unspawned female releases, and redd counts, 2002 – 2003 brood (top) and 2001 – 2002 brood (bottom).

Proportion of Returning Adults that were Naturally Spawned in River

All hatchery reared steelhead in the Central Valley now have the adipose fin clipped. When we observed steelhead in the river we attempted to determine whether the adipose fin was present or missing. During 2003, 9.5% of the steelhead we observed in the river were unclipped. We were able to determine status of the adipose fin of five steelhead on redds. These five steelhead on redds all had missing adipose fins. Of the steelhead entering Nimbus hatchery in 2003, 2.9% were unclipped. During 2002, 4.8% of the steelhead entering the hatchery were unclipped (Table 11).

Most of the observations when we were able to determine the status of the adipose fin were made when drifting by adult steelhead when snorkeling. These observations were primarily of steelhead that were not occupying redds. Steelhead on redds often left the redd when a snorkeler approached before the snorkeler could get a good look for the adipose fin. We seemed to be able to approach steelhead on redds closer in the boat or from the bank above than by wading in the river or snorkeling.

Table 11. Adipose clip status of steelhead observations in the river and of steelhead entering Nimbus Hatchery.

Year	Number able to determine presence/absence of adipose fin	Number unclipped (adipose present)	Percent unclipped	Number on redds able to determine presence/absence of adipose	Number unclipped steelhead observed on redds
2002	Adipose status not	determined			
2003	21	2	9.5%	5	0

Year	Steelhead Entering hatchery	Number unclipped	Percent unclipped
2001	2,877	50	1.7%
2002	1,435	69	4.8%
2003	935	27	2.9%

Individual Steelhead Characteristics

The length frequency of steelhead observed on redds is in figure 20. The average visually estimated size of steelhead observed was 58 cm and ranged from 36 to 80 cm (n=61, SD = 9). The average lamprey size was 44 cm and ranged from 30 to 70 cm (n=24, SD = 10). Summary statistics for measurements of redds that steelhead were observed holding on are given in table 12.

Many steelhead in the American River developed Saprolegnia fungus on the body in both 2002 and 2003. During 2003 we recorded the presence or absence of fungus on individual steelhead. We observed fungus on 36% of the adult steelhead observed (n = 208). Of steelhead not on redds, 42% were noted as having fungus and 23% of steelhead on redds had fungus. The white fungus stands out in the water and made steelhead more visible so the 42% value is probably high for the overall percentage of steelhead not on redds with fungus. Steelhead with fungus and not holding on redds were more likely to be seen and counted than those without fungus, likely inflating the percentage with fungus.

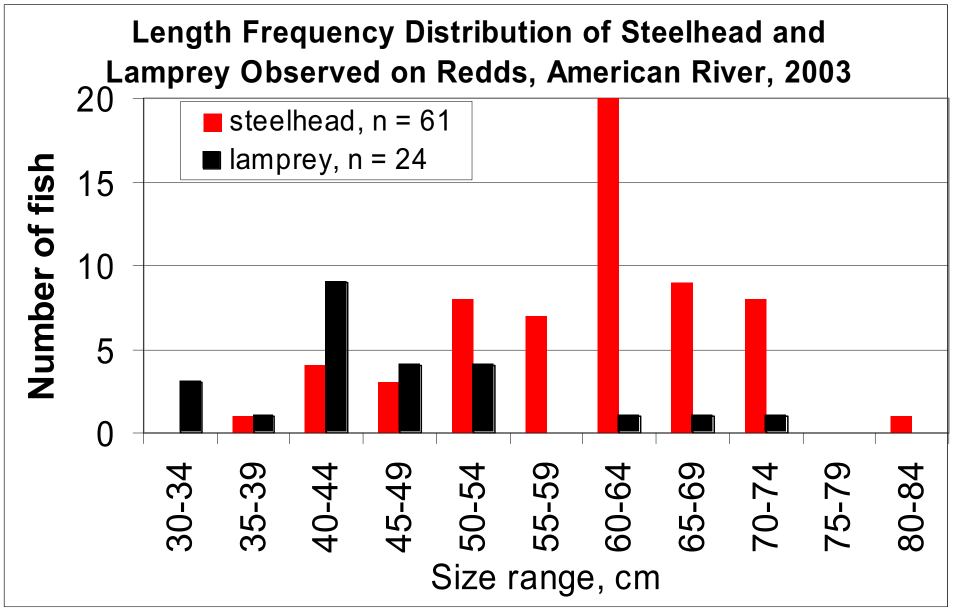


Figure 20. Length frequency of steelhead and lamprey observed spawning in the American River, 2003.

Table 12. Summary statistics for measurements taken of redds that were observed with steelhead ooccupying them.

	Mean Value	Range	Standard Error	Measurements
Fish Size, m	0.58	0.36-0.80	0.01	61
Redd Area, m2	1.97	0.6-4.8	0.13	44
Water Depth, m	0.66	0.30-1.12	0.03	45
Velocity, m/sec	0.80	0.15-1.75	0.05	45
Pot Length, m	0.83	0.4-1.8	0.04	44
Pot Width, m	0.94	0.5-2.0	0.04	44
Pot Depth, m	0.13	0.03-0.35	0.01	43
Pot Substrate, m	0.08	0.02-0.15	0.00	44
Tail Spill Len, m	1.39	0.5-3.0	0.10	44
Tail Spill Wid, m	0.97	0.55-2.0	0.04	44
Tail Spill Wid2, m	0.79	0.3-1.4	0.03	44
Tail Spill Sub, m	0.05	0.01-0.13	0.00	43

Differentiation of steelhead redds from redds of other species

Steelhead spawning in the American River overlaps somewhat with Chinook salmon, Pacific lamprey, Sacramento suckers, and Sacramento pikeminnows. During 2003 we observed live Chinook in late January. The last fresh Chinook redd we observed and measured was on January 22. The in-river spawning Chinook population was over 100,000 fish so Chinook redds were present throughout much of the river. Chinook spawning peaked in mid-November and most was completed by mid-December. The Chinook redds were clearly larger with deeper pots than steelhead redds. By the time steelhead spawning was occurring most Chinook redds were covered by epilithic algae so could be identified as not freshly constructed and were not counted. Many depressions from Chinook spawning were visible throughout the steelhead spawning period.

Sacramento suckers and Sacramento pikeminnows were often seen in concentrations near areas with algae cleared from the rocks in small diameter circles (~0.5 m diameter). There was generally little gravel displaced in these areas so they were clearly not steelhead redds and were not counted.

We observed Pacific lampreys spawning in January, February, March, and April in 2003. The peak in lamprey spawning was after the peak in steelhead spawning. During the final survey April 3 – 4, we counted 278 lamprey redds, 42 of them with lampreys actively spawning on them. Dead, presumably spawned out, lampreys were found in March and April. Figure 21 shows measurements of lamprey redds versus steelhead and unknown redds. Redds were classified as unknown if they were believed by the surveyers to be steelhead redds but accurate species identification (usually lamprey vs steelhead) was somewhat questionable. Lamprey redds were generally smaller and often had little or no tail spill. More fines were usually present in the pot of lamprey redds than in the pot of steelhead redds. When spawning, lampreys pick up the larger rocks with their sucker and carry them to the tailspill leaving much of the sand and small gravel in the pot. Some lampreys were observed scouring rock from the redd pot in a manner similar to steelhead. With their small bodies their scouring motions may not be as effective as steelhead and more fines tended to remain. Most of the unknown redds were ultimately classified as steelhead redds based on redd dimensions. Figure 22 shows the redd areas of steelhead, lamprey, and unknown redds from the initial field classification. Some lamprey redds were similar to steelhead redds and a few were possibly misclassified as steelhead redds (Figure 23). Gallagher (2002) used principle components analysis to develop a linear discriminant function that identified redds to species in the Noyo River. This could be pursued in the American. Experience gained by the survey crew during 2001 and 2002 surveys aided greatly in differentiating steelhead and lamprey redds. During the final survey in 2002 some lamprey redds were undoubtedly mis-classified as steelhead redds. At least one experienced survey crew member needs to be present for identification of species constructing the redds.

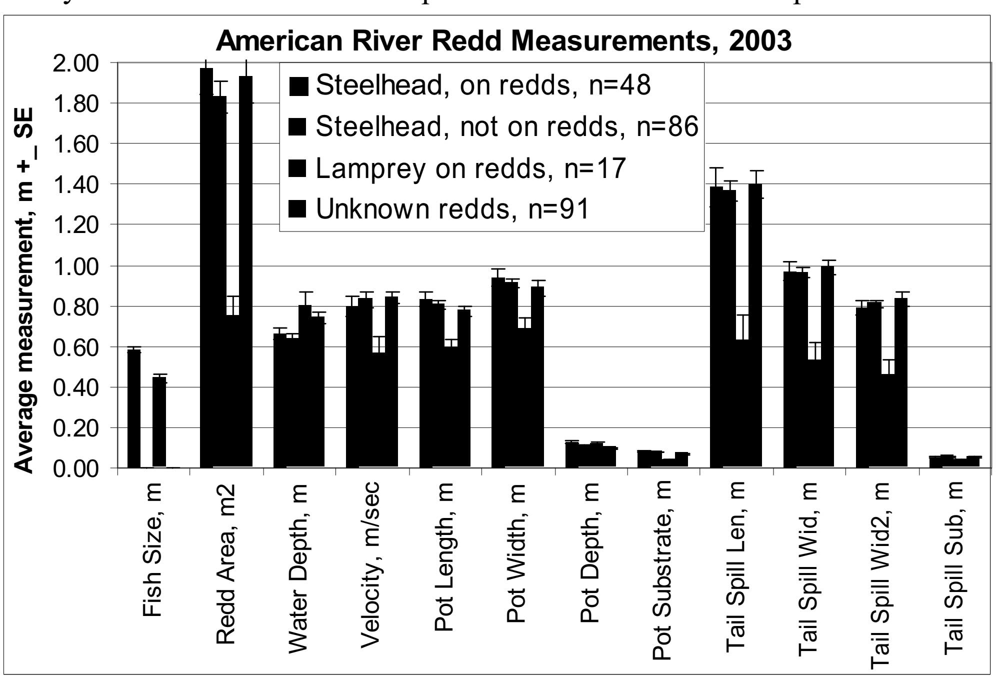


Figure 21. Average sizes of redds measured in the American River in 2003.

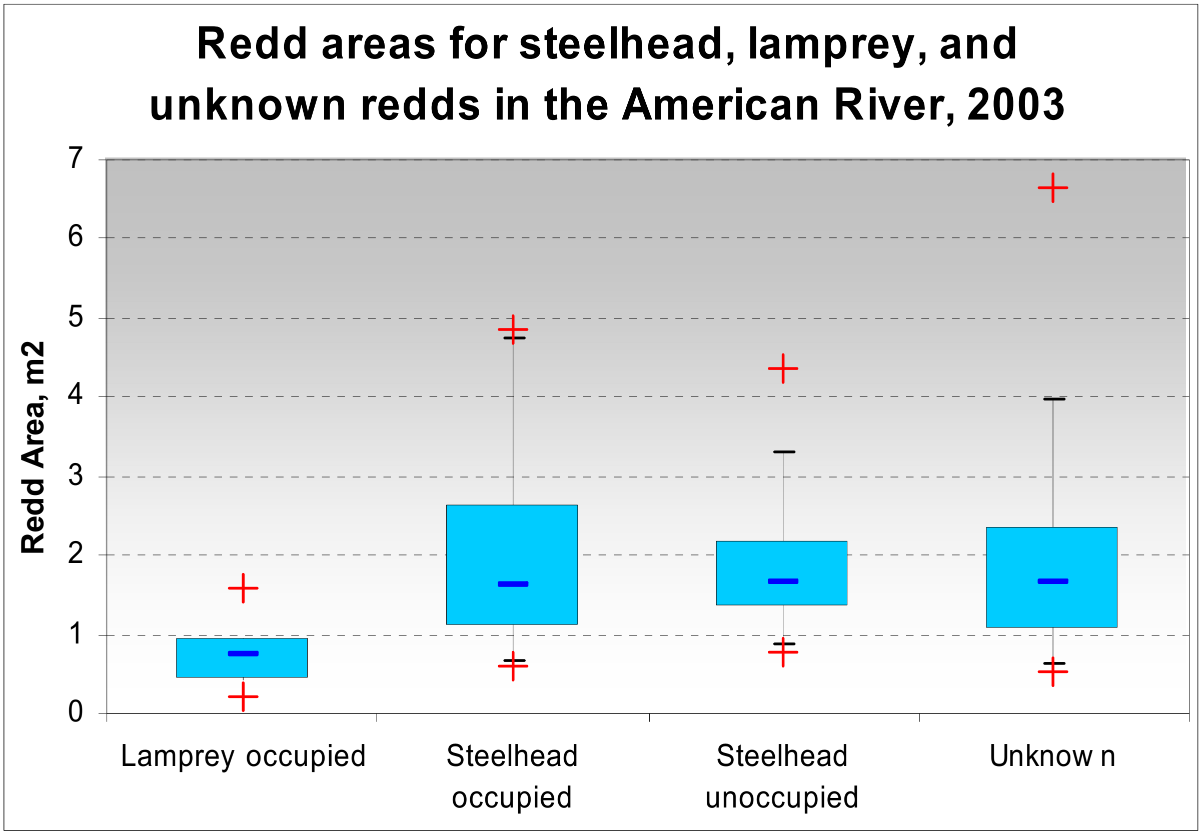


Figure 22. Redd area for steelhead, lamprey, and unknown species redds in the American River in 2003. The mid-point is the median value, the boxes encompass the 25th to 75th percentile values, error bars extend to the 5th and 95th percentile values and the crosses are the maximum and minimum values.

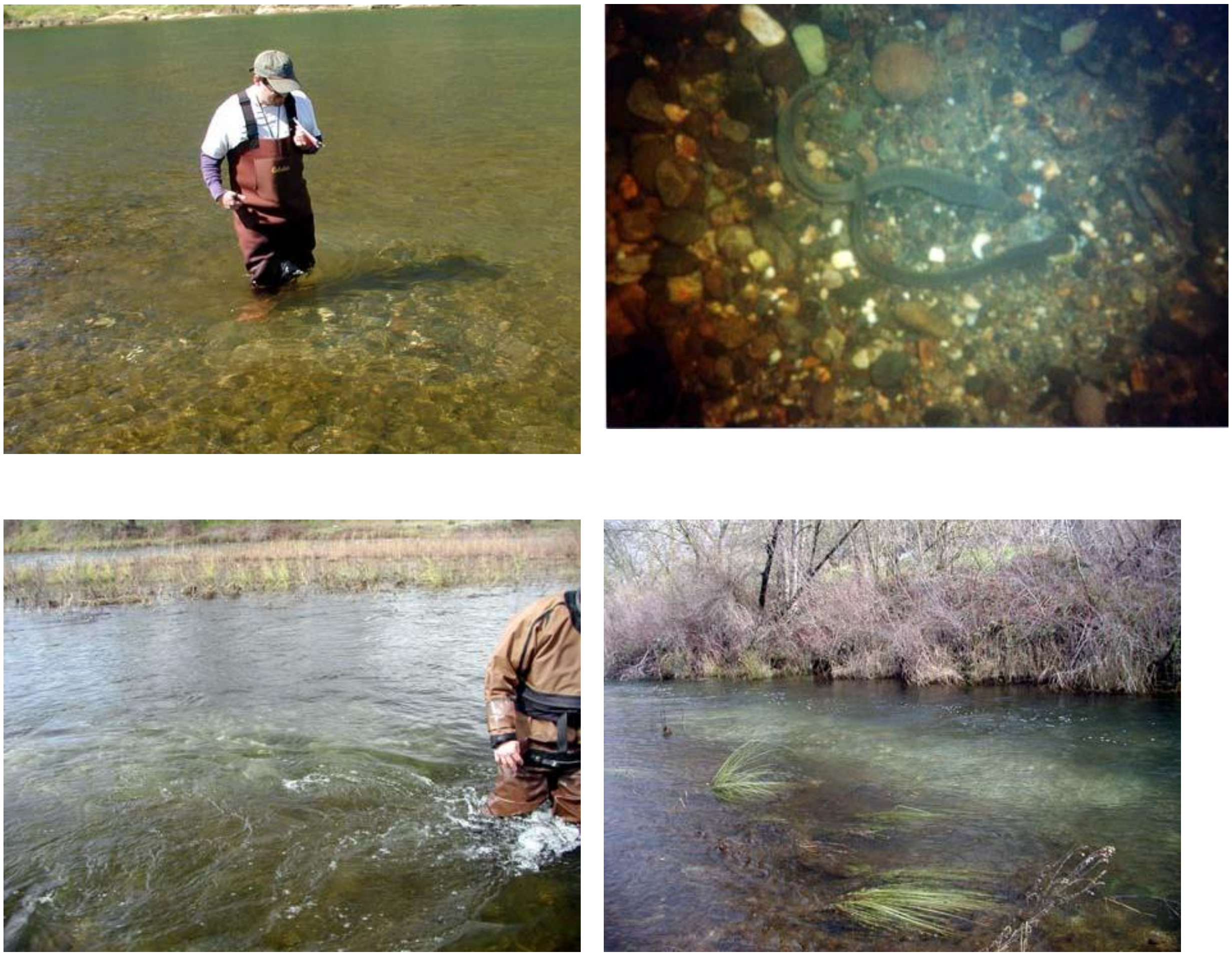


Figure 23. Pacific lamprey redds (top) and steelhead redds (bottom). Lampry redds were generally smaller with a round pit with more fines and smaller tail spill.

Conclusions

The following are some preliminary conclusions reached from the 2001 – 2003 steelhead spawning surveys.

1. Redd surveys in conjunction with visual counts can be used to monitor trends in in-river spawning steelhead abundance in the American River at flows up to at least 5,500 cfs.
2. Approximately 50% of steelhead spawning is associated with multiple thread channel (side channel) reaches.
3. The peak spawning period in the river occurs later than in the hatchery.
4. Many steelhead redds in the American River remain identifiable for not much more than two weeks.
5. Spawning is concentrated in the upper river but occurs throughout the area with suitable spawning habitat (down to Paradise Beach).

6. Many steelhead tend to develop fungus which may limit repeat spawning.
7. Eggs in some redds do survive periods of dewatered surface flow and fry can emerge from the redd provided surface flow is available for emergence.
8. Residence time for steelhead on redds in the LAR is estimated to be three days based on return visits to redds when fish were observed on a redd.

Recommendations for future surveys

The entire river can be surveyed in two work days with a flat bottomed boat with jet motor to navigate through shallow water areas. Surveys without a motor are more time consuming below Rossmoor because of the long slack water reaches.

The survey operation runs most smoothly with a three-person crew. One person should wear a dive suit to attempt to determine presence/absence of adipose fins, make measurements in deep water, and snorkel through side channel areas. A two-person crew can conduct the survey by boat if the third person is not available. If adequate staff or boat with motor are not available for a complete survey of the river, then the area from Sailor Bar to Ancil Hoffman Park or Rossmoor can be surveyed in a day by drift boat or canoe and used as an index reach. The GPS locations on GIS maps allow comparisons to be made between years in specific reaches of the river and on individual riffles.

Snider et al (2001) mapped documented steelhead and Chinook spawning areas throughout the river. The maps should be reviewed prior to conducting surveys to determine areas that should be most closely examined during the surveys.

The two week survey interval appeared to be adequate for detecting spawning activity, although a one-week interval would better reveal redd longevity, or how long individual redds remain identifiable. Susac and Jacobs (1999) found that longevity averaged nearly 30 days-in Oregon Rivers, but was variable within and between survey areas. Longevity in the American River appears to be less, possibly because warmer water temperatures and higher nutrient loads support epilithic algae, which quickly covers recently excavated redds. In addition, water velocity over redds, which changes with flow, influences how long the pit and tail spill are visible.

A more formalized steelhead survey protocol could be adopted after another year of surveys. A protocol will be needed to maintain long-term survey consistency to allow tracking of in-river steelhead spawning abundance over time.

Acknowledgements

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The GIS shapefile containing the data collected during redd surveys is available in UTM zone 10 NAD 27 from John Hannon at the Bureau of Reclamation Mid-Pacific Regional Office, 2800 Cottage Way MP-150, Sacramento, CA 95825 and is stored on the GIS server at P:\mp150_jhannon\Geolib\redds.shp.