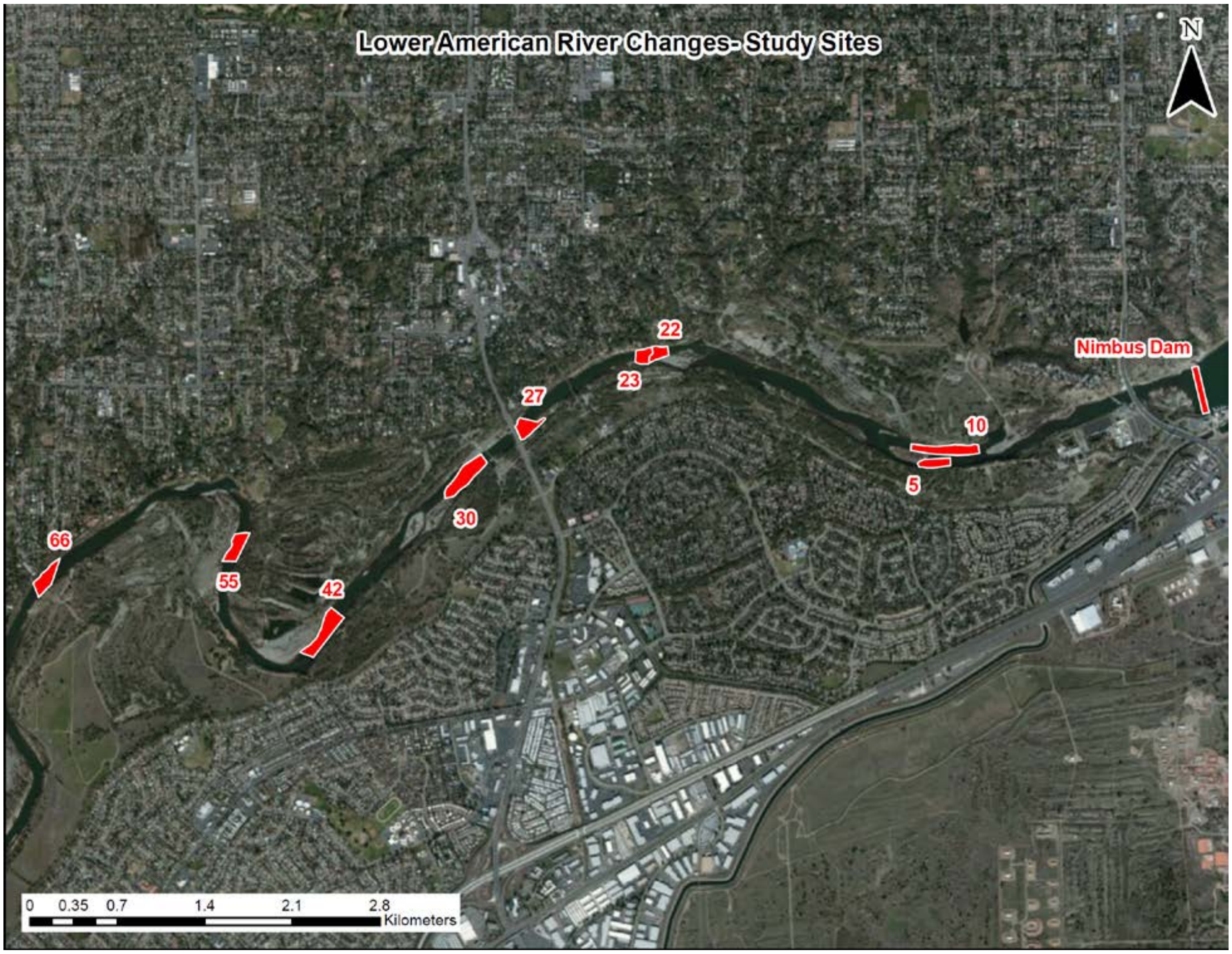
Degradation of natural Fall run Chinook salmon spawning sites on the American River



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June 23, 2014

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Objective

The objective of this project is to assess the rate of habitat degradation that is occurring at salmon spawning sites on the Lower American River. Folsom and Nimbus dams were installed on the American River in 1956, and upstream fish passage was blocked by Nimbus dam. A significant number of anadromous fish still spawn in the six miles of gravel bed river that lie below Nimbus Dam, so this last remaining available habitat is critical for preservation of the wild breeding stock.

Installation of the upstream dams has combined with other anthropogenic controls to change the Lower American River. The river has become incised and armored (Fairman, 2007). River flows have also changed dramatically, with water in the post-dam era stored or released for hydroelectric production, irrigation, recreation and flood control. This has produced a highly managed and regulated river, and in general the natural spawning habitat has degraded. This study assumes that fewer fish will spawn at a site if the habitat degrades. Rates of degradation were estimated by monitoring fish use at nine sites that are known for natural spawning (Figure 1).

Information about spawning use and degradation rates will be used to manage the American River. The Lower American River has many natural spawning areas that are used each year by returning adults, and resource managers are interested in the longevity or evolution of these sites. Results will be entered into a structured decision making model to evaluate the effectiveness of different management options for the Lower American River.

Background and study design

Many variables affect Fall run Chinook salmon spawning on the American River. River flow, timing of the salmon run, habitat zone, ocean escapement (number of returning adults) and climate (wet vs. dry years) were evaluated as factors that influence the number of adult salmon that spawn at specific sites. Sampling strategy and project design were discussed with Rob Titus and Mike Brown from CA Department of Fish and Wildlife. John Hannon (US Bureau of Reclamation) also provided guidance and air photos used in the study. Data collected for the project were primarily from air photographs, and the approach will be explained in the methods section (below). Strategies vetted through this peer review group resulted in the following study design:

- Ocean escapement and climate were treated as independent variables, and a range of climatic conditions and ocean escapement estimates were used to evaluate trends in spawning on the Lower American River.
- Available habitat, timing of the salmon run and habitat zones were standardized as much as possible to minimize the number of variables that affect spawning use at individual sites on the river.

The influence of each of these variables is discussed briefly:

Ocean escapement: The number of adult fish spawning in inland rivers is related to ocean escapement numbers. Large numbers of returning adult fish (ocean escapement) tends to boost spawning in all of northern California's rivers, while low escapement numbers correlate with low spawning in local rivers. For this project we selected six years that represented high, medium and low ocean escapement numbers (Table 1). Escapement to the American River ranged from 18,000 adults in 1991 to 180,000 adults in 1997.

Climate (wet/dry years): The American River watershed has wet, average and dry years. Wet years produce higher river flows, cooler river temperatures and inundate more habitat (see below). Higher flows also create a stronger attracting signal and help juvenile outmigration. Dry years have the opposite effect, and may not produce the attracting flows and temperatures required for spawning. This may result in smaller adult salmon runs and increased juvenile mortality. For this project we selected six years that show a range in river outflow, measured as "mean annual discharge". Mean annual discharge ranged from 1,200 cfs to 6,500 cfs for the six years selected in this study, and are representative of wet, average and dry years (Table 1).

Available habitat: The amount of suitable spawning habitat also changes with river flow, and stream features have different geomorphic function with more or less water. This has a shorter term and more localized effect than climate, and is related to dam releases, storage in upstream reservoirs and delta water quality requirements. A riffle or gravel bar that has little spawning at low flow may be inundated and have appropriate water depth and velocity at higher flows. River flows are changed on a daily or weekly basis during spawning season to deal with management constraints, so effect of short- term changes in available habitat could potentially be confused with the long-term climate signal. Available habitat was standardized as much as possible for this project by selecting photographs with similar river flow at the time the photograph was taken. River flows between 1,200 and 2,500 cfs were chosen as the acceptable window for the project, and a target of 1700 cfs was preferred (Table 1). Flows below 1,200 cfs generally create loss of suitable habitat and overcrowding, while redds (salmon nests) were difficult to distinguish when flows exceeded 2,500 cfs.

Timing of the salmon run: Adult salmon return to the American river in a pulse that approximates a bell curve, with early middle and late arrivals. Each year air photographs were taken during the beginning, middle and end of the Fall Chinook salmon runs. Redds tend to be well-defined in the photos from the early part of the salmon run, but few fish are spawning and total number of redds is low. In the middle of the salmon run greater numbers of fish are spawning and the total number of redds increases. By the end of the Fall salmon run, redd clustering and superposition make it very difficult to distinguish individual salmon redds on photographs. Timing of the salmon run was standardized as much as possible in this study by choosing air photographs from the peak or maximum of the run (Table 1). The majority of these photos were taken between November 23 and 26, except for the 1991 season. The photo taken in mid-November of 1991 was not clear enough to accurately estimate redds, so the photograph taken on December 9, 1991 was used instead.

Habitat zone: River channels or subreaches can be subdivided into different habitat zones. A habitat zone is a portion of the channel that has similar ecological function, and is usually tens to hundreds of meters long. Habitat zones were mapped on the Lower American River by Snider et al (1993). Common names for habitat zones are riffles, pools, glides and runs. Salmon spawn preferentially in riffles or pool/riffle sequences, so it is important to examine similar habitat zones when comparing spawning numbers. In this project habitat zones were standardized by only using riffle or riffle/run sequences that have historically had heavy spawning use. Habitat zones used in this project were vetted with our advisory group at CA DFW. The nine habitat sites for this study were selected from high use natural spawning locations originally identified by Snider et al. (1993) and evaluated by Vyverberg et al. (1997).

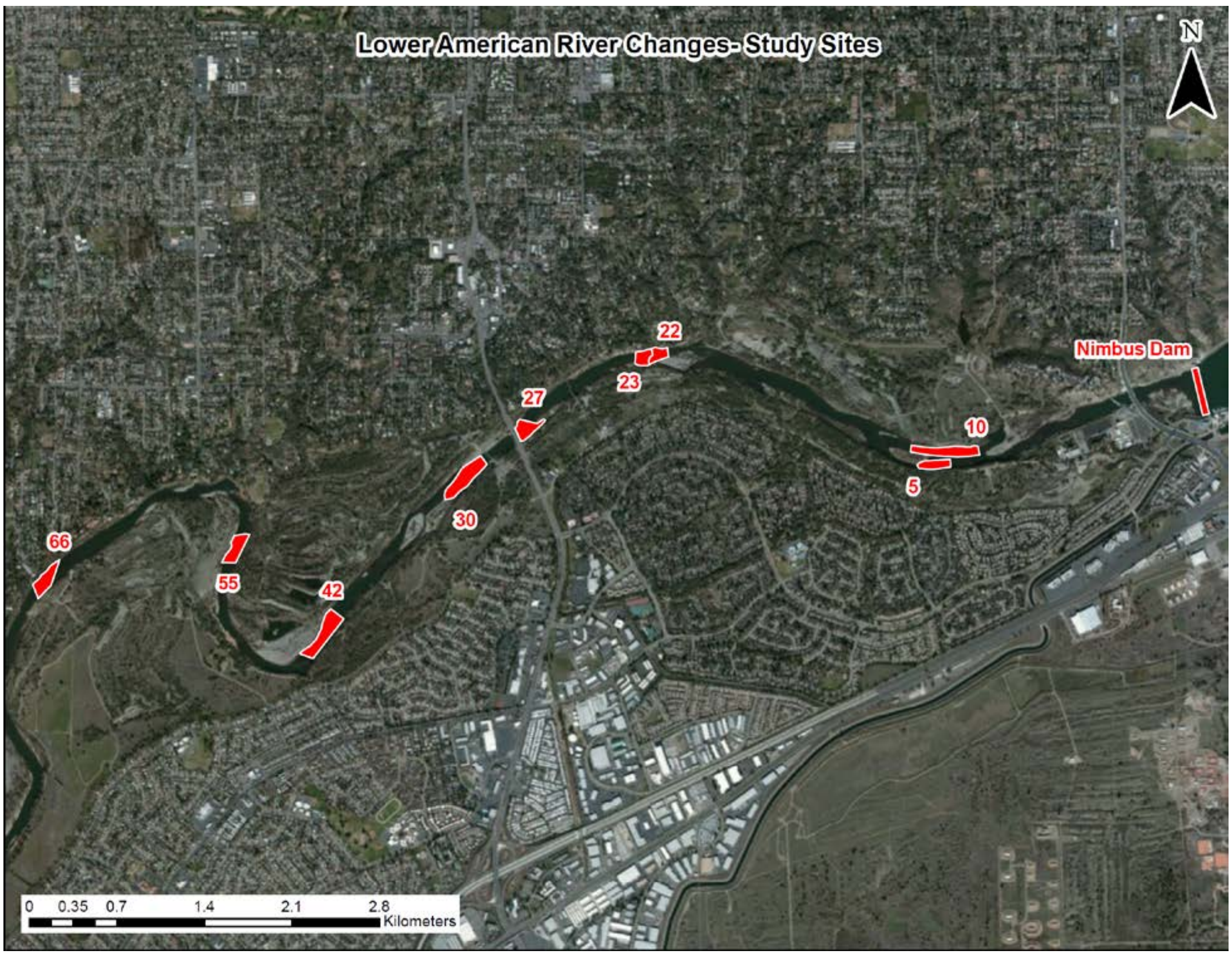


Figure 1: Location map and habitat numbers for nine natural spawning sites on the Lower American River. Habitat numbers are based on work by Snider et al. (1993).

Methods

The US Bureau of Reclamation and CA Dept. of Fish and Wildlife have contracted for special air photographs of the Lower American River every spawning season for the past 22 years. These are high quality, low level air photographs, and individual salmon redds (nests) can be identified on the photos. These air photographs provided the raw data for the study.

Nine habitat zones that have historically received heavy spawning use were chosen for this study (Figure 1). Our goal was to select natural spawning sites that are obviously effective at attracting returning adults, and look at changes in spawning use at those sites over time. The working hypothesis for the project was that the installation of Folsom and Nimbus dams has degraded the natural habitat and resulted in less natural spawning at these sites over a 22 year period. Restored areas were not considered in this project. Sites where flows changed because of nearby restoration projects were also excluded from the study.

Six years were chosen for this study out of the 22 years (1991-2013) of available air photographs. These years were selected because climate and ocean escapement varied, but available habitat and timing of the salmon run were relatively consistent. Habitat zone characterization did not vary from year-to-year. Climate (represented by mean annual discharge) and total escapement values were used as independent variables in this study. Low, moderate and high water years were chosen in combination with low, moderate and high escapement years. These variables are probably responsible for much of the annual change in fish use at each site. Table 1 lists the six years selected for this study (1991, 1993, 1997, 2002, 2007, and 2012) and data collected for each year.

Salmon spawning was measured in terms of total redd counts and redd density at the nine natural spawning areas. Higher redd counts and higher redd density are driven by greater numbers of adult fish and more natural spawning at a site. The 54 photographs chosen for this study (9 sites, 6 years) were uploaded to ArcGIS and georeferenced. Georeferencing defined the geographical location of objects in space based on a geographic projection (Hackeloeer, et al., 2014). Photographs were inspected, and the location of each redd was recorded by placing a geospatial marker on the photograph (Figure 2). Results were exported as habitat zone maps for each site. These maps are special layer-selectable .PDF files that contain separate results for each project year. Redd density was calculated by dividing the number of redds at a site by the total area of the site, as estimated using ArcGIS.

Table 1: Lower American River Data for the six years evaluated in this study.

Year	1991	1993	1997	2002	2007	2012
Date of Flight	12/9	11/23	11/25	11/25	11/23	11/26
River Flow (cfs)	1,260	1,756	2,425	1,750	1,250	1,900
Mean Annual Discharge	1,200	1,800	6,500	2,000	4,500	2,500
American River Chinook Salmon Escapement	18,145	26,786	46,888	118,114	14,670	34,900

Raw numbers of redds per site and redd density are heavily influenced by ocean escapement. This varies from year to year. To compensate for this, we also calculated the *percentage* of American River escapement for each site. This normalized the data for variations in ocean escapement. The percent of American River escapement was determined by dividing the total number of redds at a site by the annual American River escapement estimates from Phillips and Helstab (2013).

Results

Study results are available in tables and geospatially. Table 2 shows the total number of redds counted at each site using high-resolution aerial images from 1991, 1993, 1997, 2002, 2007 and 2012. Table 3 shows the number of redds per square meter calculated for each site and Table 4 shows the percent of American River escapement. This was calculated by dividing the total number of redds at the site by that year’s American River escapement number.

Table 2: Total redds counted at each natural spawning location.

Site	Redds					
	1991	1993	1997	2002	2007	2012
5	130	563	478	133	214	159
10	376	981	824	714	422	427
22	328	395	400	323	202	240
23	230	295	429	410	162	158
27	241	434	457	583	206	228
30	379	677	1550	885	468	824
42	324	528	729	581	49	377
55	77	238	277	547	19	149
66	239	868	741	929	63	370

Table 3: Redds per square meter was calculated by dividing the number of redds counted at the site by the area of the site.

Site	Site Area (sqm)	Redds/sqm					
		1991	1993	1997	2002	2007	2012
5	10,194	0.013	0.055	0.047	0.013	0.021	0.016
10	22,979	0.016	0.043	0.036	0.031	0.018	0.019
22	8,242	0.040	0.048	0.049	0.039	0.025	0.030
23	8,731	0.026	0.034	0.049	0.047	0.019	0.018
27	13,289	0.018	0.033	0.034	0.044	0.016	0.017
30	26,580	0.014	0.026	0.058	0.033	0.018	0.031
42	25,904	0.013	0.020	0.028	0.022	0.002	0.015
55	15,074	0.005	0.016	0.018	0.036	0.001	0.010
66	15,413	0.016	0.056	0.048	0.060	0.004	0.024

Redd counts confirm that spawning use is consistent at individual sites chosen for this study, despite variations in ocean escapement or climatic conditions (river outflow). In 1991, site 30 (Figure 3a) showed the highest usage (379 redds) and site 55 (Figure 4a) showed the lowest usage (77 redds) of all nine sites. Twenty-one years later, site 30 (Figure 3b) continued to show the highest usage (824 redds) and site 55 (Figure 4b) maintained the lowest usage (149 redds). These two sites also showed the highest and lowest *percent* of American River escapement in 1991 and 2012 (Table 4).

Results were more variable when we calculated redd density (Table 3). Site 55 showed the lowest density redds per square meter for 1991 (0.005) and 2012 (0.010), while site 22 showed the highest density in 1991 (0.040) and site 30 showed the highest redd density in 2012 (0.031). This calculation does not factor in population swings due to ocean escapement or climate, and small differences in available habitat may be reflected here too. For the purposes outlined in this project it is more appropriate to compare percent of escapement than redd density on the Lower American River.

Table 4: Percent of American River Escapement was calculated by dividing the number of redds counted at the site by that year's American River escapement estimate.

Site (habitat zone)	Percent of American River Escapement						Average escapement at site (%)
	1991	1993	1997	2002	2007	2012	
5	0.7	2.1	1.0	0.1	1.5	0.5	1.0
10	2.1	3.7	1.8	0.6	2.9	1.2	2.1
22	1.8	1.5	0.9	0.3	1.4	0.7	1.1
23	1.3	1.1	0.9	0.4	1.1	0.6	0.9
27	1.3	1.6	1.0	0.5	1.4	0.7	1.1
30	2.1	2.5	3.3	0.8	3.2	2.4	2.4
42	1.8	2.0	1.6	0.5	0.3	1.1	1.2
55	0.4	1.0	0.6	0.5	0.1	0.4	0.5
66	1.3	3.2	1.6	0.8	0.4	1.1	1.4
Totals:	12.8	18.6	12.6	4.3	12.3	8.4	

Complete geospatial results are available for each site as layer-selectable pdfs with a 1991 background image or a 2012 background image. Different backgrounds can be selected to observe changes to the river channel over the 22 year study period. Geospatial results for each site (habitat zone) and each year are imbedded in the links below. These links require access to the 18 files that contain these images.

Site 5 with 1991 background image
Site 10 with 1991 background image
Site 22 with 1991 background image
Site 23 with 1991 background image
Site 27 with 1991 background image
Site 30 with 1991 background image
Site 42 with 1991 background image
Site 55 with 1991 background image
Site 66 with 1991 background image

Site 5 with 2012 background image
Site 10 with 2012 background image
Site 22 with 2012 background image
Site 23 with 2012 background image
Site 27 with 2012 background image
Site 30 with 2012 background image
Site 42 with 2012 background image
Site 55 with 2012 background image
Site 66 with 2012 background image

Each pdf file represents a habitat site, and has imbedded layers that show redd locations for each of the six years analyzed in this study. Redd locations from each year can be viewed individually by turning layers on or off. To turn annual layer files on or off for a habitat site, click on the layer image at the left side of the pdf, expand the layers folder, and click on the "eye" icons to turn individual layers on or off (Figure 2).

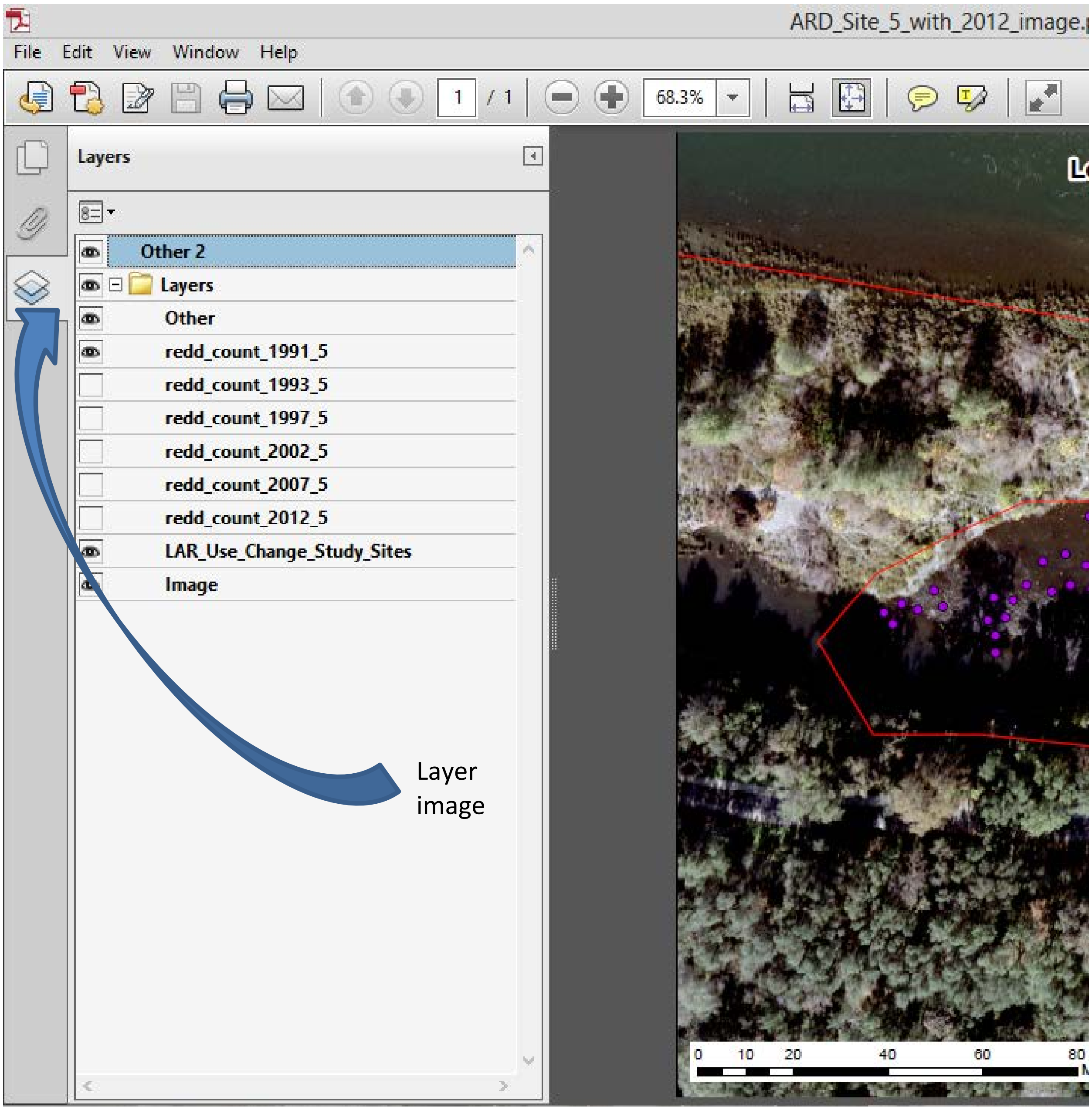
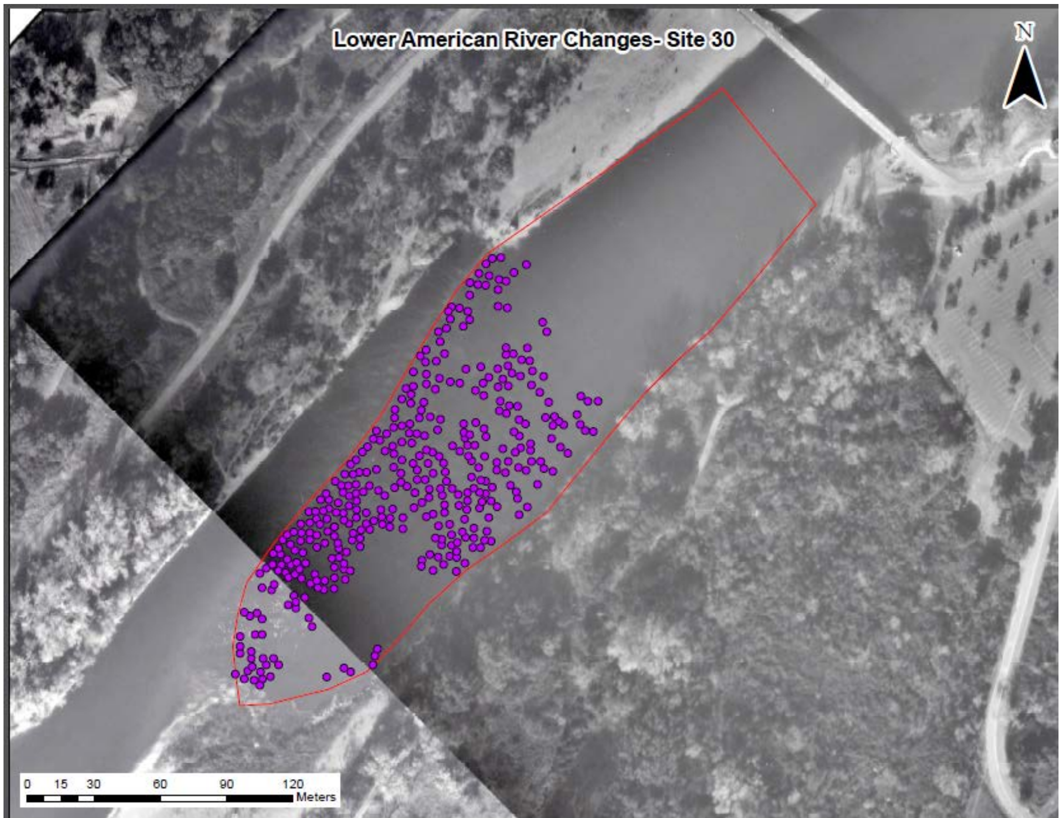
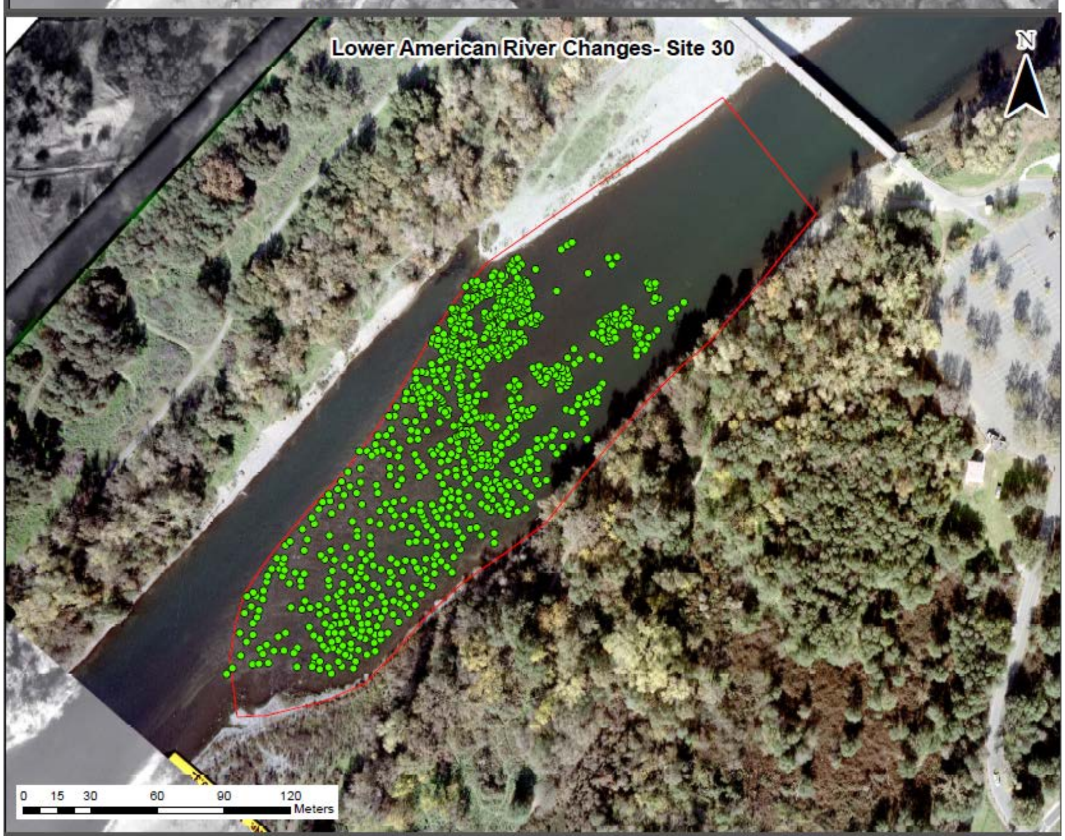


Figure 2: Screen shot of geospatial results in a layer selectable pdf. To turn layer files on or off, click on the layer image at the left side of the pdf, expand the layers folder, and click on the "eye" icon.

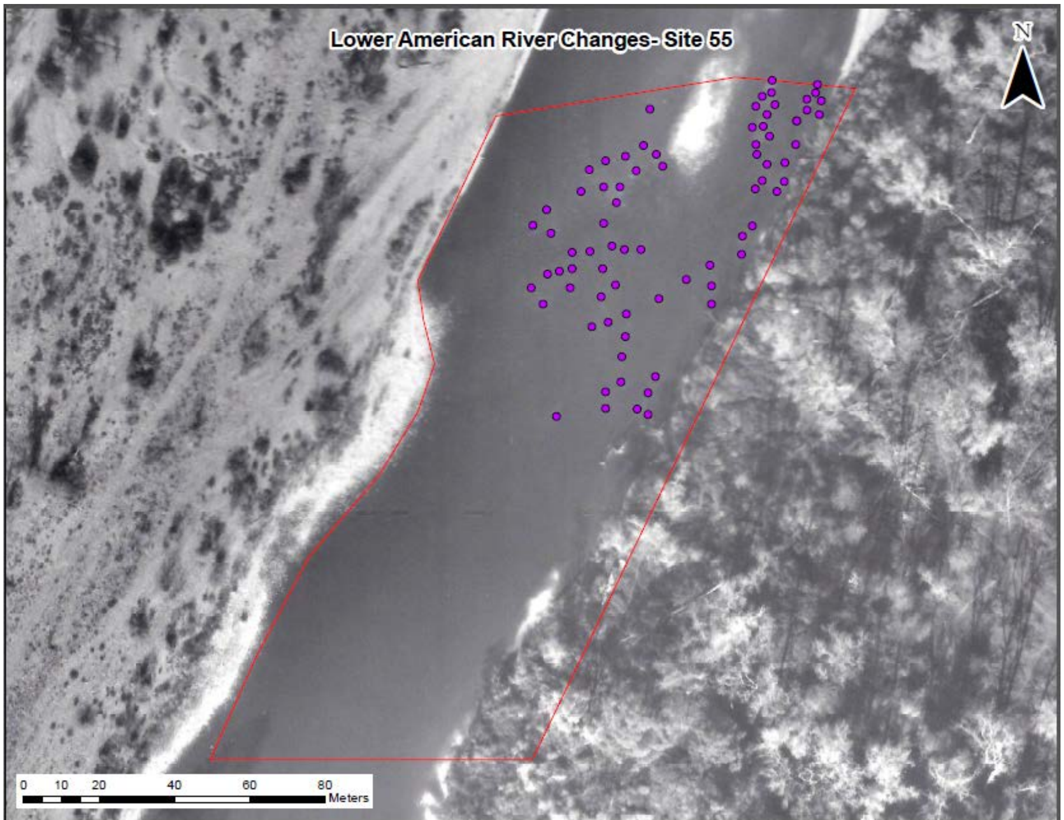


a.



b.

Figure 3: Redd counts for Site 30 in (a) 1991 and (b) 2012.

a.


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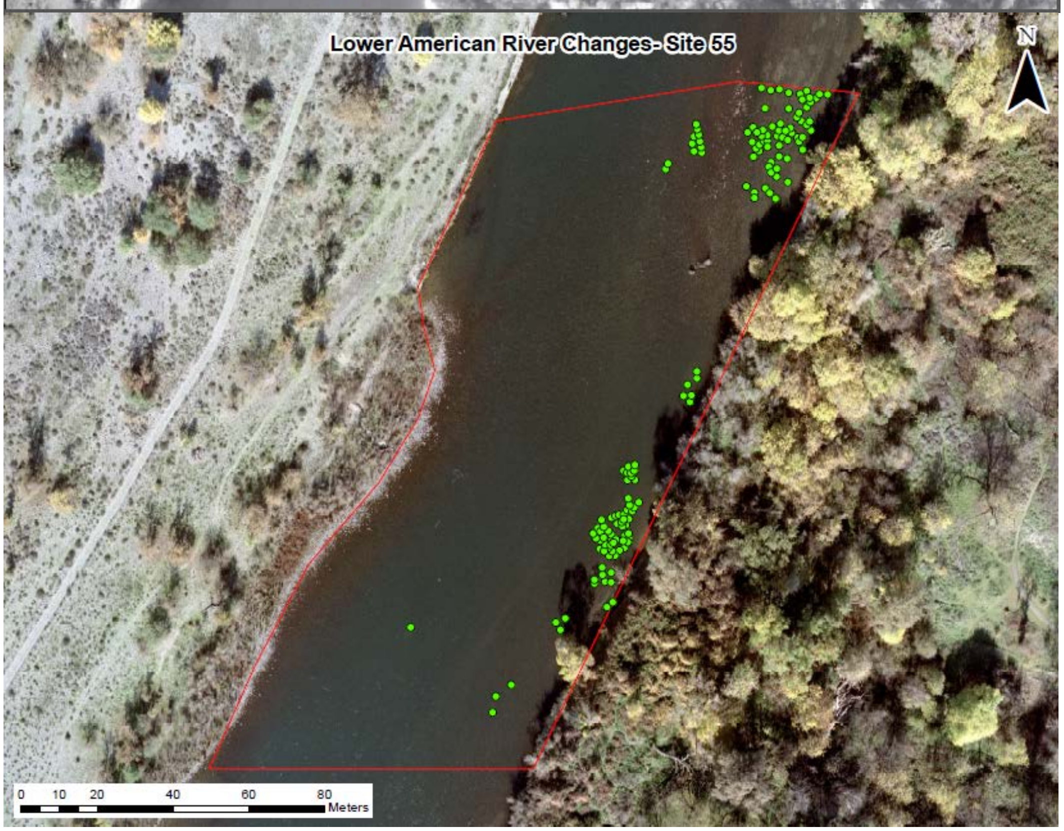

Figure 4: Redd counts for Site 55 in (a) 1991 and (b) 2012.

Analysis and Discussion

Several important trends emerged from this analysis. Data collected in this study show that nine high-use areas account for a significant portion of the natural spawning in the Lower American River. Fish use at these nine sites ranged from 4.3 to 18.6% of total spawning. This confirms that these natural spawning areas are a critical resource.

Ocean escapement explains much of the variability in the percentage of spawning use from year to year. Ocean escapement is inversely related to the percentage of American River spawning use at the nine habitat zones, and a linear regression for these data has an R^2 value of 0.54 (Figure 5). The *percentage* of American River spawning at these nine sites was lowest in 2002 when ocean escapement was highest (Figure 5). This provides strong evidence that habitat can be limiting, and some adult fish chose to spawn at less crowded sites during the high use year. Our data set does not identify the point where overcrowding becomes an issue, but it appears to be more than 47,000 adults and less than 118,000 adults. This point has been debated among fisheries biologists for many years, and we may finally have conclusive evidence that habitat can be limiting on the Lower American River.

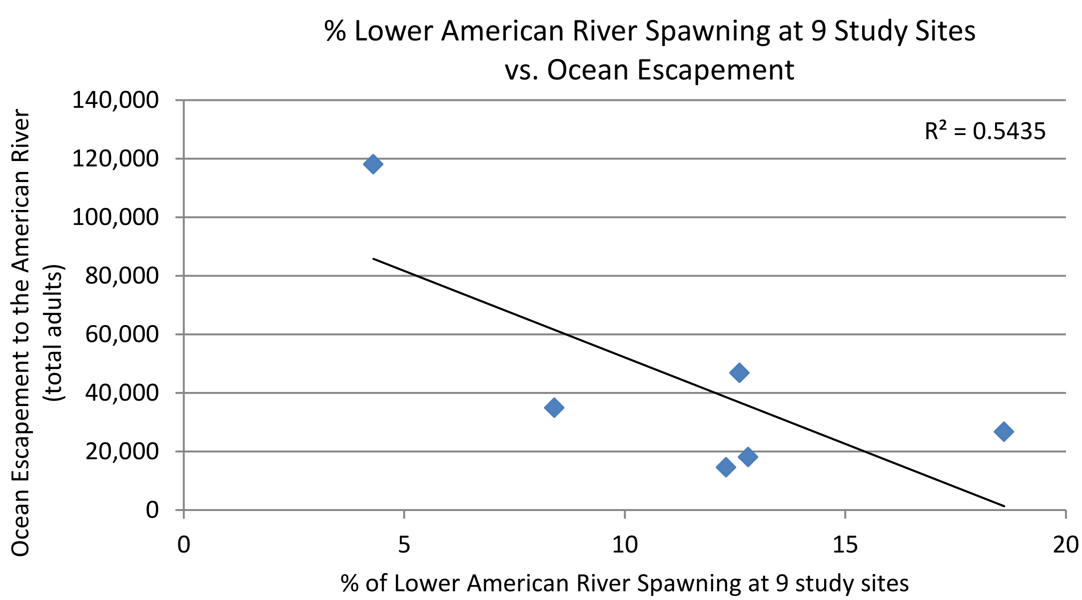

Figure 5: Percentage of Lower American River spawning at nine high-use spawning sites is inversely related to ocean escapement. Some fish select other sites when ocean escapement is high.

Some high use spawning areas are more functional than others. Figure 4 shows that habitat zones that had heavy natural spawning use 22 years ago are still the most heavily used spawning areas (habitat zones 10 and 30). Sites that were moderately used 22 years ago still have moderate spawning use (habitat zones 23 and 55). This implies that each site has inherent physical conditions that influence spawning. This could include factors like water depth and velocity, hyporheic flow and gravel quality.

Total numbers of spawning adults at each habitat site are highly variable from year-to-year (Table 2). There tend to be more redds at the study sites during wet years (1997) or years with high ocean escapement (2002), while dry years years (1991) or years with lower ocean escapement (2007) tend to have less spawning use. These statements only refer to *total* numbers of spawning adults. Percentages of adults at each site are discussed below.

Spawning use is relatively consistent *within* each habitat zone. All habitat zones in this study have the highest spawning numbers and highest spawning density at the the upstream edge of the site. This pattern is consistent over time and space, and is related to river geomorphology. Salmonids tend to spawn at pool/riffle transitions or at the upstream edge of a riffle sequence. This is the region where oxygenated surface water is forced into the gravel. Flow paths and residence times are short at the head of a riffle (Jones and Mulholland, 2000; Morita, 2005; Bean, 2013), and hyporheic conditions support egg and alevin development. This pattern persists regardless of ocean escapement or climatic conditions.

Some sites and some years have unexplained variations. Small variations in spawning use are probably due to social interactions or changes in habitat function. Salmonids are social animals, and early arrivals at a site may influence redd placement later in the spawning season. This probably explains many local anomalies where a small group of fish spawn on the middle or downstream edge of a site. Habitat function is another variable, and is related to river flow during spawning season. We attempted to standardize this study for daily or weekly changes in river flow during spawning season, but a site may function differently if flow is 1250 cfs one year and 1900 cfs the next study year.

Annual climatic variability (wet vs. dry years) does not explain the habitat zone use that we observed. There is no apparent correlation between spawning density and mean annual discharge for the six years that were studied (Figure 6). Figure 6 shows that a wet year, a moderate year and a dry year all have similar spawning use. At the broadest level it appears that wet years don't necessarily attract more adult fish to the high use spawning sites. It is important to note that this annual average does not account for shorter term pulses or changes to the river during the Fall spawning season. This also ignores any effect on juveniles as they migrate out of the system. We need to be careful not to over-interpret the climatic impact.

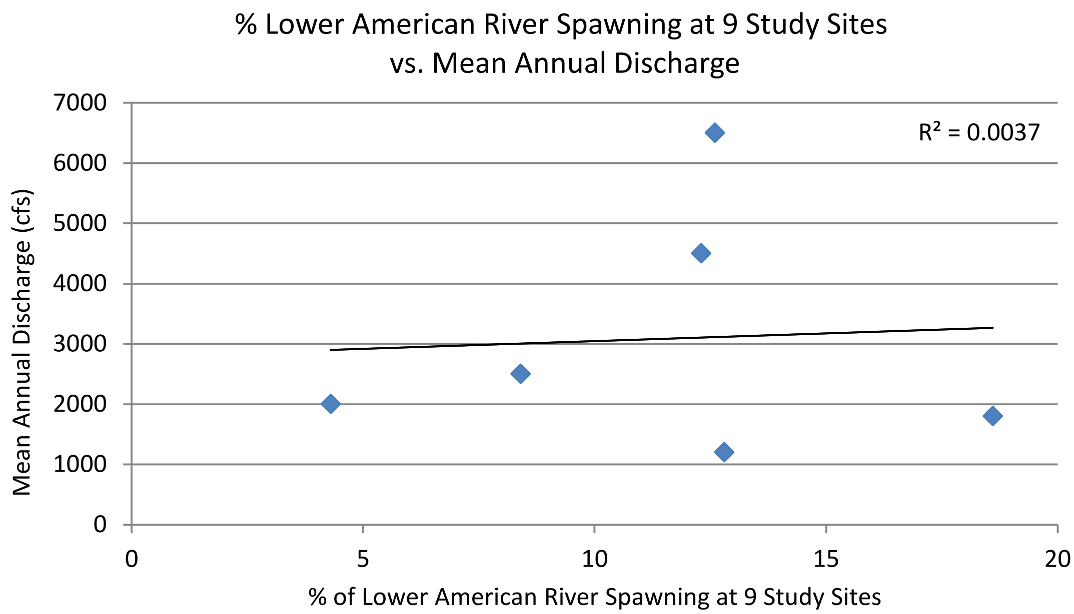

Figure 6: Percentage of Lower American River spawning at nine high-use study sites does not appear to be related to wet vs. dry years.

Rates of degradation

The goal of this project was to evaluate spawning use at 9 high-use habitat zones, and examine the sites for signs of degradation over a 22 year period. Figure 7 shows the percent of American River escapement for each site by year, with best-fit linear regression trend lines. Based on these trend lines, sites 5, 10, 22, 23, 27, 42, 55 and 66 showed a decrease in the percentage of natural spawning between 1991 and 2012. Site 29 is the only site to show a slight increase in the percentage of natural spawning between 1991 and 2012, and this relationship is weak. The coefficient of determination (R^2) for the sites ranged from 0.0021 to 0.4284.

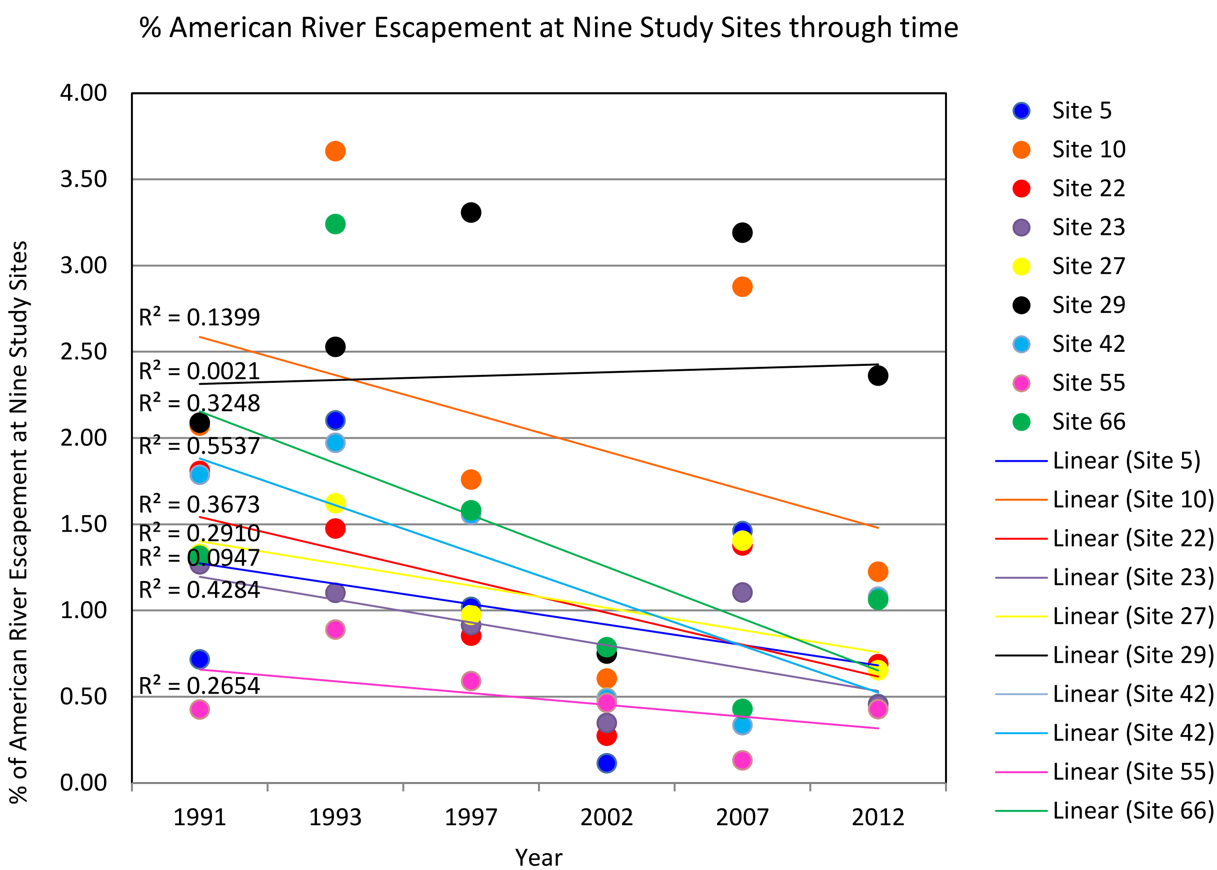

Figure 7: Plots of spawning use (expressed as percent of total American River escapement) show a decline at eight out of nine high-use habitat areas over the 22 year record.

The previous discussion of ocean escapement showed that habitat carrying capacity on the Lower American River is exceeded somewhere between 47,000 and 118,000 adult fish. This could influence the correlations in Figure 7, because the 2002 spawning year had a large number of adults. This resulted in over-crowding and use of less suitable sites by many returning fish in 2002. As a result, the percentage of spawning dropped at all high-use spawning sites in 2002. This could skew the data and drive some of the trend lines observed in Figure 7. To test this, we plotted the same data set again, but omitted the 2002 spawning season. Results are shown in Figure 8. All high-use sites except habitat zone 29 still show a decrease in the percent of total spawning over time. A comparison of linear correlation coefficients (R^2 values) from Figure 7 and Figure 8 shows that six out of nine correlations actually increase when the 2002 data are omitted (Table 5). This indicates that ocean escapement is not driving the trends observed in Figure 7, and the trends are interpreted to show degradation of the sites over time.

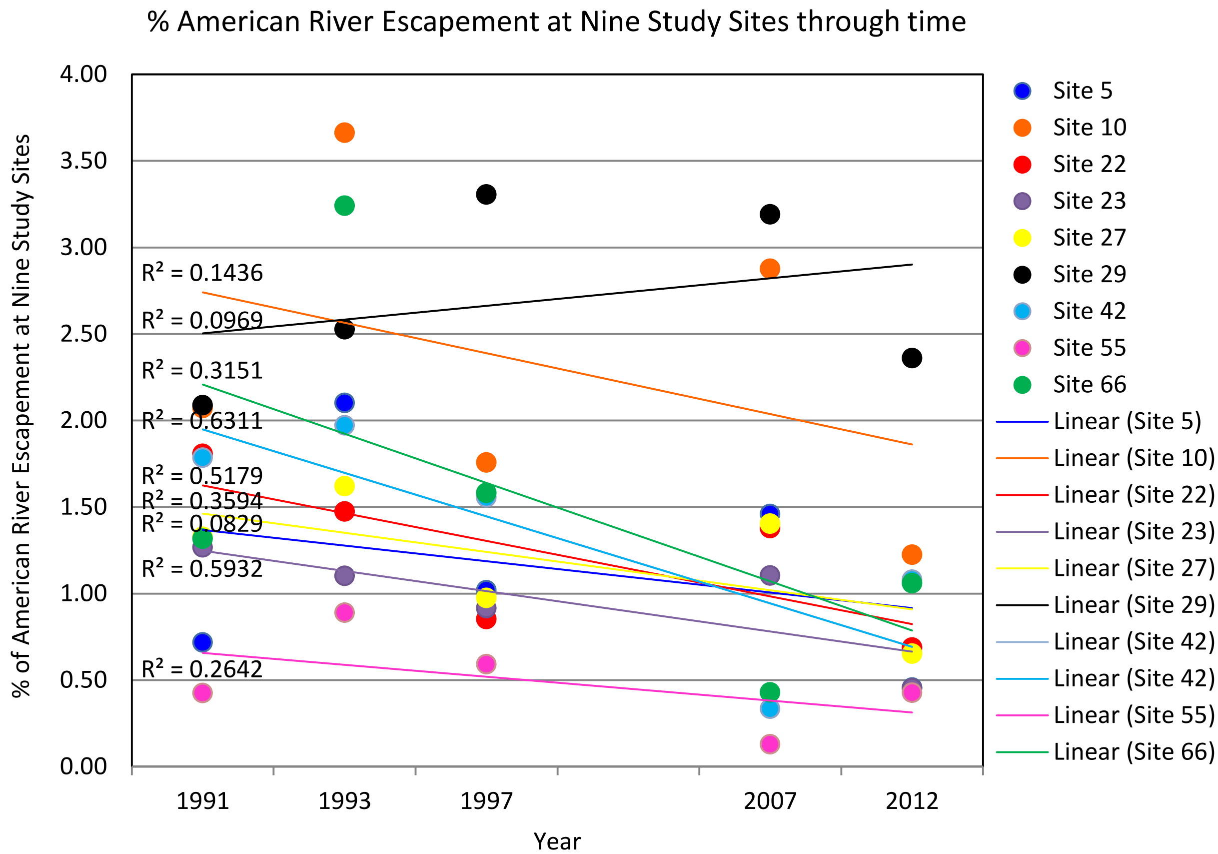

Figure 8: Results from Figure 7 were replotted without the 2002 spawning data. Trends are similar to Figure 7 and correlations are sometimes higher, indicating that ocean escapement and overcrowding in 2002 did not drive the trend toward lower spawning use at eight out of nine high-use spawning areas.

Table 5: Correlation coefficients (R^2 values) show that eight out of nine high use habitat sites have less spawning use over time, even when 2002 data are omitted.

Site (Habitat Zone)	R^2 value for all years analyzed	R^2 value with 2002 omitted
Site 5	0.0947	0.0829
Site 10	0.1399	0.1436
Site 22	0.3673	0.5179
Site 23	0.4284	0.5932
Site 27	0.2910	0.3594
Site 29	0.0021	0.0969
Site 42	0.5537	0.6311
Site 55	0.2654	0.2642
Site 66	0.3248	0.3151

The remaining step with this new information was to estimate rates of degradation. This was accomplished by averaging spawning use at all nine high-use sites for the 22 year study period. We omitted the 2002 spawning data because of the overcrowding issue. A linear regression of these data estimates that spawning at the study sites started at 15.8% of the total on the Lower American River and decreased to 9.2% over 22 years (Figure 9). This correlation appears to explain a significant amount of the variability in the data set (R^2 = 0.5241), and the 6.6% reduction is a significant change. Stated differently, the 9 study sites appear to have lost 38% of their spawning capacity over 22 years (6.6%/15.8%). This could be interpreted as a degradation rate of 1.7% per year (38%/22 years).

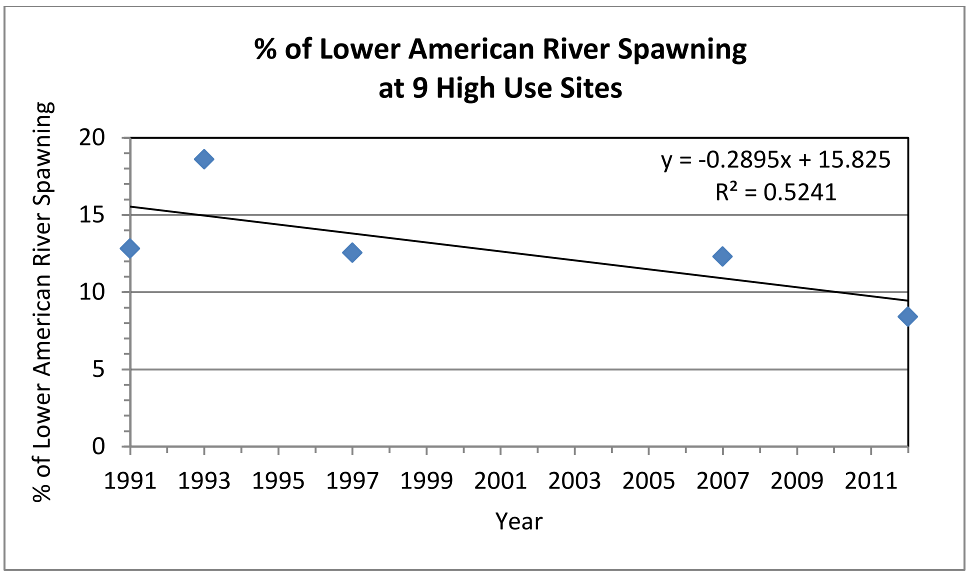

Figure 9: Nine high-use spawning sites were averaged to estimate a rate of degradation.

Other factors enter into this discussion. Habitat restoration started in 2008, and the restored sites were not included in this analysis. Restoration projects in 2008, 2009, 2010/11 and 2012 all attracted large numbers of returning adult fish. These fish might previously have spawned at the nine natural high-use study sites, but instead spawned at newly restored areas. For this reason the projected degradation rate was estimated again, but was limited to pre-restoration data (Figure 10). This correlation does not explain much of the variability in the data (R^2 = 0.1902). The linear regression of nine high-use sites starts with 15.36% of the spawning in 1991 and ends with 12.3% of the spawning in 2007. This is a 3.1% decrease in spawning over

16 years, or 19.9% of the total (3.1%/15.35). This gives a degradation rate of 1.2% per year (19.9%/16 years), with extremely low confidence in the correlation and the trend.

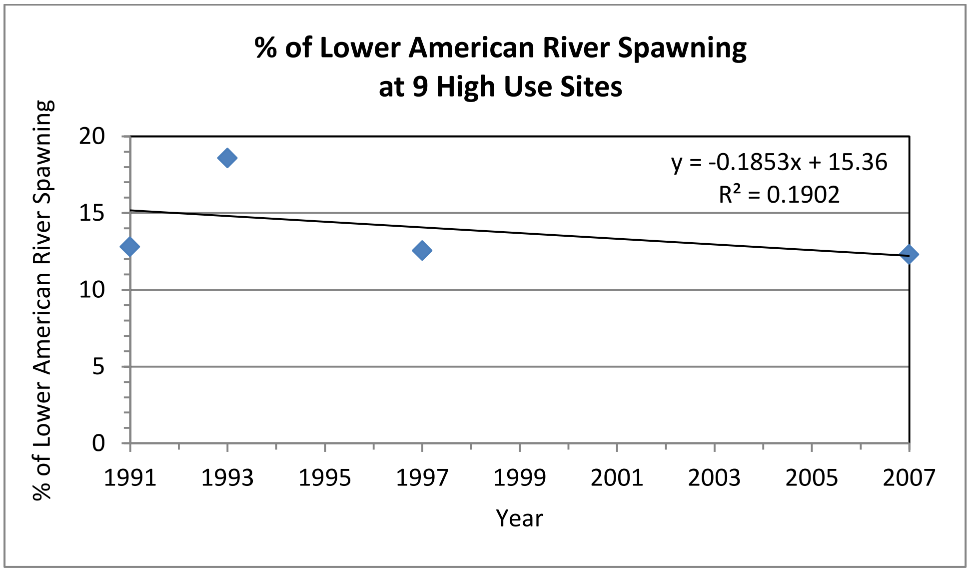

Figure 10: Data points that overlap with restoration efforts were removed, and nine high-use spawning sites were averaged to estimate a rate of degradation. This analysis has very low stastical significance (R^2 = 0.1902).

In summary, degradation rates at nine high use spawning areas were estimated to range from 1.7% per year to 1.2% per year. Confidence in these estimates is very low due to statistical uncertainty and limitations of the data set. Streams are complex systems, and outside factors like ocean escapement and restoration efforts have obvious influence on these estimates.

Summary

- Nine natural spawning sites on the American River are responsible for 8-19% of the total escapement in the years studied.
- The total number of redds at each habitat site varies from season to season. The percentage of redds at each habitat site is more consistent.
- Wet years and dry years do not appear to have much effect on Fall run Chinook use of the nine high use areas.
- Ocean escapement has a strong control over this system.

- Habitat restoration efforts that started in 2007 may have caused a decrease in spawning at nearby natural spawning sites.
- Spawning use declined at most high-use sites from 1991 to 2012. The rate of degradation appears to range from 1.7% to 1.2% per year. Statistical confidence in these estimates is low.

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