Redwood Creek Life Cycle Monitoring – DIDSON

March 1, 2011

Final Project Report

Humboldt State University, Sponsored Programs Foundation

Agreement No. P0810310

Prepared for:

California Department of Fish and Game

Fisheries Restoration Grants Program

by

Walter G. Duffy

California Cooperative Fish Research Unit

Humboldt State University

Arcata, CA 95521

Description of the Sub-basin

Prairie Creek is a fourth-order tributary to Redwood Creek which drains a 34.4 km^2 watershed. Prairie Creek is approximately 20 km long. It is located in the Northern California coastal zone within Redwood National and State Parks, Humboldt County, California, in old growth redwood (*Sequoia sempervirens*) forest. Prairie Creek supports four species of salmonids: Chinook salmon, coho salmon, steelhead, and coastal cutthroat trout (*O. clarki clarki*), as well as threespine stickleback (*Gasterosteus aculeatus*), Sacramento sucker (*Catostomus occidentalis*), prickly sculpin (*Cottus asper*), coast range sculpin (*C. aleuticus*), Pacific lamprey (*Lampetra tridentata*), and Pacific brook lamprey (*L. richardsoni*).

Study areas were based upon survey reaches previously established by the USGS California Cooperative Fish and Wildlife Research Unit (CACFWRU). These began 50 m below the confluence of Prairie Creek and Streelow Creek, which is 6.7 km upstream of the mouth of Prairie Creek, and continue upstream for 13.3 km. Population estimation and monitoring of juvenile and adult Pacific salmon on these reaches have been conducted since 1998. From 2008-2011, monitoring has also been conducted on Lost Man Creek, beginning at the confluence with Prairie Creek and extending upstream 4.0 km to the first apparent barrier to migration.

Methods

Estimating Adult Escapement

Escapement of adult coho and Chinook salmon, steelhead and coastal cutthroat trout was estimated from 1998/99 through 2010/11 from walking surveys to enumerate live fish and redds and from carcass mark-recapture studies. In 2005 through 2010, we also operated a weir on Prairie Creek and in 2008-2010 on Lost Man Creek. Here we report escapement results from observations of live fish. Results from other methods will be presented in a forthcoming report.

We estimated escapement live fish counts made on spawning surveys were used to estimate escapement using the trapezoidal AUC method (modified from Parken et al. 2003). This approach calculates stream population estimates at each survey time, the area under the population curve, and the AUC escapement. The population of Chinook and coho salmon, steelhead and coastal cutthroat trout in the survey reach on the day of each survey (x_i) was estimated by dividing the number of each species observed (fo) by the observer efficiency factor (oe):

$$x_i = \frac{fo}{oe}$$

An observer efficiency of 35% was used to expand the observed number of salmon to an estimate of the actual number of salmon present during each sampling period. This expansion value was based on a study of observer efficiency in Prairie Creek during 2008/09-2009/10 (Poxon in prep.).

For purposes of surveys, Prairie Creek was divided into four reaches, each about 2 km long. Individual reaches were surveyed on separate days, and the data from each of these surveys was then summed to calculate the total number of each species observed during each sampling period. We assumed that live fish did not move among reaches during each sampling period. The mean date of the four surveys was recorded as the survey date. The sampling period population estimates were plotted against time and the area under the population curve (auc) was estimated by summing the rectangular areas that approximate the area under the escapement curve:

$$auc = \sum_{i=2}^{n} \left(t_i - t_{i-1}\right) \cdot \frac{\left(x_i + x_{i-1}\right)}{2}$$

where t_i is the water year day of the i^{th} survey day where the water year is defined as beginning on October 1, when t=1, and ending on September 30, when t=365.

Escapement ($\hat{E}_{auc}$) was then estimated by dividing the auc by the species' residence time (rt):

$$\hat{E}_{auc} = \frac{auc}{rt}$$

Residence time estimates were calculated for the Prairie Creek survey area through the recovery of carcasses of salmon that had been tagged upon live capture at the weir (Table 1). Residence time was estimated as the number of days between a salmon's initial capture at the weir and its recapture as a carcass. Only carcasses found in a fresh condition (i.e. carcass condition of 1: fresh (eyes clear and flesh firm)) were used to calculate residence time.

Juvenile Abundance

We used a two-stage sampling design to estimate abundance of juvenile salmonids in Prairie Creek each year. Area of habitat available to fish was estimated in July or August of each year. Surveyed stream habitats were delineated into six habitat strata: pools, runs, riffles, edgewater, complex and "other". Criteria described Flosi et al. (1998) were used to distinguish habitat types and geomorphic unit breaks. Small habitat units characterized by a length to average wetted width ratio of less than one, were included as part of the next upstream unit. Habitat units classified as complex or "other" were considered unsuitable for estimation of fish abundance using diver observation or electrofishing removal methods. Complex habitat units were generally characterized by extreme physical habitat complexity due to extensive undercut banks and (or) abundant woody debris. "Other" habitat units were mostly minor side channel habitat of marginal width and depth. Physical measurements of thalwag length, wetted widths, and average and maximum depth were recorded for all surveyed habitats. In pools, wetted width measurements were taken at the upstream, middle and lower portions of habitat units, whereas in runs and riffles width measurements were taken at the upstream and downstream portions of habitat units. Surveyed habitats were numbered sequentially allowing for subsequent identification of individual habitat units.

We used a modification of the Hankin and Reeves (1988) method to estimate juvenile coho salmon, and other salmonid, abundance in pools and runs. An adaptive sequential independent sampling scheme (ASIS) was used to select first phase sample units with expected inclusion probability equal to 0.5. First phase sample units were selected after habitat units (pools or runs) were classified and measured. Pool and run habitat units selected during the first phase were flagged by a habitat survey crew at the upper and lower habitat boundaries. Shortly thereafter, a two-person dive crew conducted single dive counts in flagged first phase units. Individual units were sampled by a single diver, with two divers working upstream while sampling alternating habitat units. Divers recorded numbers of juvenile coho salmon and other species observed within habitat units. After a single dive count was made in a given first phase unit, ASIS was used to determine whether or not the sampled unit was selected at the second phase of sampling. Nominal ASIS selection probabilities for the second phase of sampling were set at 0.25 for the pool habitat strata and 0.33 for the run habitat strata. All deep pool ($\geq$ 1.1 m) habitat units were flagged for sampling. For second phase units, the following decision rule was used to determine mode of calibration: (a) If the count of juvenile coho salmon was less than or equal to 20, then the method of bounded counts (MBC) was used to calibrate the first phase dive count; or (b) If the count of juvenile coho salmon exceeded 20, then 3 to 5 pass depletion electrofishing was used to calibrate the first phase dive count.

When the method of bounded counts was used for calibration of second phase units, three additional single-pass dive counts were immediately conducted. Abundance of juvenile coho salmon in units selected for MBC calibration were determined using the formula:

$$\hat{Y} = X_m + \left(X_m - X_{m-1}\right)$$

with X_m being the highest count, X_{m-1} the second highest count.

In the deep pool strata, all surveyed deep pool units were selected for abundance sampling. Four repeated dive counts were made in deep pool units. If densities of juvenile coho salmon were low, then valid MBC estimates of abundance could be generated for these units. When densities were high, however, the MBC assumptions (no double counting of fish) could not be met. Therefore, reliable estimation of abundance was not consistently possible for this strata.

Depletion electrofishing was used in selected second phase units where first phase dive counts exceeded 20 or more juvenile coho salmon. All second phase units selected for electrofishing calibration were sampled within one day of corresponding first phase dive counts. Units sampled using electrofishing methods were blocked with 6 mm mesh netting at the upstream and downstream unit breaks. Blocked units were sampled using two battery backpack electroshockers (Smith and Root Model 12) with multiple removal passes of timed equal effort. Number of juvenile coho salmon and other species caught was recorded for each electrofishing pass within a sampled unit and fish abundance determined using a jacknife estimator (Pollock and Otto 1983):

$$\hat{y}_J = \sum_{i=1}^{m-1} C_i + mC_m$$

where C_i denotes the number of fish caught on pass *i*, and *m* denotes the number of passes. The jacknife estimator has favorable properties when true fish abundance is low and probabilities of capture are low (Hankin and Mohr 2001).

We used the multistage design of Hankin (1984) to estimate abundance in riffles. In the riffle stratum, an initial random start between 1 and 12 was selected, and then every 12th riffle unit thereafter was flagged and subsequently sampled using 2 to 4 pass depletion electrofishing.

The estimation of total abundance of juvenile coho salmon and other salmonids incorporated measurements of habitat unit surface area (A) as a predictor of fish abundance. Notation used was as follows:

U = sampling universe

N = total number of units in habitat strata

k = unit index; k = 1,2,…, N

$k_{\hat{y}}$ = estimated abundance (MBC or jackknife estimate) in unit k

x_k = diver count of fish in unit k

z_k = area of habitat unit k

$t_y = \sum_{k=1}^{N} y_k$ = total abundance over all N units

$t_z = \sum_{k=1}^{N} z_k$ = total area of all N habitat units

n_1 = first phase sample size

n_2 = second phase sample size

Abundance of juvenile coho salmon and other juvenile salmonids was estimated using:

$$\hat{t}_y = N\overline{y}_2\left[\frac{\overline{x}_1}{\overline{x}_2} + \frac{\overline{z}_u - \overline{z}_1}{\overline{z}_2}\right]$$

where $\overline{z}_u$, $\overline{z}_1$ and $\overline{z}_2$ are mean habitat surface areas for the stratum, and for first and second phase samples. Sampling variance for habitat adjusted abundance was estimated as:

$$\hat{V}(t_y) = N^2\left(1-\frac{n_1}{N}\right)\left(\frac{\overline{z}_u}{\overline{z}_1}\right)^2 \frac{s_e^2(\overline{y}_{2,z})}{n_1} + N^2\left(1-\frac{n_2}{n_1}\right)\left(\frac{\overline{x}_1}{\overline{x}_2}\right)^2 \frac{s_e^2(\overline{y}_{2,x})}{n_2}$$

where $s_e^2(\overline{y}_{s,z}) = \sum_{k=1}^{n_2}\left(y_k - \hat{B}_z z_k\right)^2 / (n_2 - 1)$, and $\hat{B}_x = \frac{\overline{y}_2}{\overline{x}_2}$.

In riffle habitats we used only electrofishing and total abundance was calculated, again using surface area data as:

$$\hat{t}_{y,R} = t_z \left. \sum_{k=1}^{n} \hat{y}_k \middle/ \sum_{k=1}^{n} z_k \right.$$

A variance estimator for estimated abundance in riffle habitats was calculated as:

$$\hat{V}\left(t_{y,R}\right) = N^2 \frac{\left(1 - n/N\right)}{n} \cdot \frac{\sum_{k=1}^{n} z_k^2 \left(\hat{\hat{y}}_k - \hat{\bar{\bar{y}}}\right)^2}{n-1} + \frac{N}{n} \sum_{k=1}^{n} \hat{V}\left(\hat{y}_k\right),$$

Where $\hat{\hat{y}}_k = \hat{y}_k / \hat{z}_k$ and $\hat{\bar{\bar{y}}}_k = \sum_{k=1}^{n} \hat{y}_k \Big/ \sum_{k=1}^{n} \hat{z}_k$.

Smolt Production

A downstream migrant trap (DSMT) was installed in Prairie Creek each year immediately below the confluence with Streelow Creek. The trap operated for variable periods each spring, but typically were installed in March and operated through early June. The DMST consisted of a fyke net installed so that the mouth faced upstream in the thalweg. A 15.24 cm diameter PVC pipe was attached to the cod end of the DSMT net which connected to a live box 1 m wide, 1 m high and 2 m long. Traps were checked for fish and cleared of debris daily.

A subsample migrating coho salmon smolts captured in the live box were anesthetized with MS-222, their fork length (mm) and wet weight (nearest 0.01 g) recorded and they were marked and released upstream. Recapture of these marked fish on subsequent sampling dates allowed for estimating capture efficiency of the DMST. Number of coho salmon smolts captured weekly was expanded to an estimate of the population migrating past the trap using methods described by Bjorkstedt (2005).

RESULTS AND DISCUSSION

Area of habitat remained relatively constant among the years surveyed, ranging from 23,296 – 26,773 m^2 (Table 2). Of this total, the area in pool habitats averaged 41% (range 35-49%) while the area in runs and riffles averaged 28% and 26% respectively. Other types of habitats made up less than 5% of the total, on average.

The number of adult salmon returning to Prairie Creek varied among years. Estimated escapement of coho salmon ranged from a low of 28 in 2010 to 680 in 2002 (Table 3). Escapement of coho salmon was low when sampling began in 1999 but increased in 2002 before declining in recent years. Escapement of Chinook salmon ranged from a low of 38 in 2008 to 710 in 2002 (Table 3). However, escapement of Chinook salmon has been relatively low since 2005. The estimated escapement of from 4 – 142 adult steelhead was been influenced by uncertainty in run timing during earlier years of surveys and precipitation during all years. From 1999 through 2004, spawning surveys were terminated in late February each year. Beginning in 2005, a weir was installed on Prairie Creek that revealed a migration of steelhead beginning in late February through mid-April. Thus, abundance of steelhead during 2005-2008 likely reflects a realistic run size for Prairie Creek. Low numbers observed in 2009 are accurate, but the result of an extended dry period when steelhead did not enter Prairie Creek. Numbers reported here for 2011 are incomplete at this writing. Anadromous coastal cutthroat trout escapement reported are primarily larger females and under represent total escapement.

Abundance of juvenile coho salmon estimated to occupy the study area in summer did not vary substantially among years (Table 4). The lowest abundance, 2,617 fish, was recorded during a dry year when adults could not access much of the habitat in the upper portion of the study area. Average abundance during both summer and fall sampling was 5,556 juvenile coho salmon.

Abundance of fish caught in DSMT has varied considerably among years (Table 5). Number of age 1+ coho salmon ranged from 110 in 2004 to 4,109 in 2001. Chinook salmon fry were exceptionally abundant during 1999-2004, but decreased after that. Catches of coastal cutthroat trout and steelhead appear to be less variable, in general, than catches of salmon (Table 5). Data are lacking from 2009 and 2010. In 2009, funding for this project was suspended during a period when state bond funds were frozen and we could not sample. In 2010, sampling was attempted during April through June, however frequent storms repeatedly damaged the sampling gear and made the data unreliable.

Survival of coho salmon during freshwater and marine life stages appear to be high (Table 6). Estimated survival in freshwater averaged 30.8%, but this averaged was heavily influenced by high estimated survival in 2002 and 2006 of 82.3% and 56.3% respectively. Removing these two estimates yielded an average freshwater survival rate of 23.1% among all other years and is probably realistic. Marine survival averaged 26.6% among all years, an unrealistically high estimate. Again, however, this estimate was biased by at least four years having very high estimated survival, 2002, 2005, 2006 and 2008. Removing these estimates yielded an average marine survival estimate of 11.9%, still high relative to values reported in the literature. We view the marine survival estimates as unresolved at this time and are continuing to explore methods for improving our analyses.

Literature Cited

Bjorkstedt, E. P. 2005. DARR 2.0: updated software for estimating abundance from stratified mark-recapture data. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-368, NOAA Fisheries, Santa Cruz, CA.

Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey and B. Collins. 1998. California salmonid stream habitat restoration manual, third edition. California Department of Fish and Game, Sacramento.

Hankin, D. G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Canadian Journal of Fisheries and Aquatic Sciences 41:1575-1591.

Hankin, D.G. and M. Mohr. 2001. Imporved two-phase survey designs for estimation of fish abundance in small streams. Unpublished manuscript.

Hankin, D. G. and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834-844.

Parken, C. K., R. E. Bailey, and J. R. Irvine. 2003. Incorporating uncertainty into area-under-the-curve and peak salmon escapement estimation. North American Journal of Fisheries Management 23: 78-90.

Poxon, B. 2011. Estimating observer efficiency for coho salmon and Chinook salmon in Prairie Creek, California. Master of Science Thesis, Humboldt State University, Arcata, CA. In prep.

Wright, K. A. 2011. Escapement, migration timing, and spatial distribution of adult Chinook and coho salmon in Prairie Creek, California. Master of Science Thesis, Humboldt State University, Arcata, CA.

Table 1. Estimated residence times (rt) of Chinook and coho salmon in Prairie Creek study area in 2006/2007.

	Chinook salmon			Coho salmon		
Sex	n	rt	SD	n	rt	SD
Female	3	15	2.3	15	18	9.8
Male	2	9	2.8	9	14	8.5
Total	5	12	3.8	24	17	9.3

Table 2. Area (m^2) of habitats in Prairie Creek during 1998-2010.

Date	Pool	Run	Riffle	Edgewater[1]	Complex	Other	Total
Oct-98	11877	6028	6249	236	0	0	25757
Jul-99	9672	5585	6034	110	2195	289	25185
Jul-00	8827	6868	6226	329	1703	74	25314
Jul-01	8813	7936	6316	260	0	0	24918
Jul-02	10433	7337	6918	183	0	0	26773
Jul-03	12927	7599	5878	171	0	0	26575
Jul-04	11289	6433	7218	0	0	0	24940
Jul-05	8561	8213	6522	0	0	0	23296
Jul-06	9313	8367	8526	0	0	246	26452
Jul-07	10718	8925	5420	0	0	423	25486
Jul-08	12952	6449	6703	0	0	302	26406
Aug-09	12296	6536	5372	0	869	0	25073
Aug-10	9326	8104	8385	310	0	0	26125

Table 3. Escapement of adult coho salmon to the Prairie Creek sub-basin during 1999-2011. Estimates are derived from AUC analysis of live fish observations. Year listed is the latter portion of the spawning season (e.g. 1999 = 1998/1999)

	Coho		Chinook		Steelhead		Cutthroat	
Year	n	95% CI	n	95% CI	n	95% CI	n	95% CI
1999	56	3.4	541	38.9	10	0.6	2	0.2
2000	84	6.7	353	19.9	4	2.2	22	1.3
2001	212	6.0	321	16.4	9	1.9	4	0.5
2002	680	19.4	710	34.1	9	1.6	1	0.4
2003	542	46.1	183	17.6	28	2.4	0	0.0
2004	268	12.4	654	48.6	24	6.3	21	1.3
2005	643	40.6	200	22.0	70	9.7	28	2.3
2006	349	27.6	121	13.0	142	9.8	22	3.8
2007	165	8.5	115	9.2	70	5.9	15	3.2
2008	466	44.5	38	4.1	136	9.0	27	2.8
2009	127	25.8	73	18.4	12	1.9	0	0.0
2010	28	4.1	46	7.5	4	0.0	3	0.6
2011	218	22.0	144	14.8	4	0.4	27	3.2

Table 4. Estimated abundance of juvenile coho salmon in the Prairie Creek sub-basin of Redwood Creek during 1998-2010.

		Pools		Runs		Riffles		Total	
Year	Month	Avg	95% CI	Avg	95% CI	Avg	95% CI	Avg	95% CI
1998	Oct	5080	75	1047	11	0	0	6127	67
1999	Aug	4256	63	1645	23	1229	240	7130	303
1999	Oct	5123	949	1703	27	537	95	7363	850
2000	Aug	2741	138	1733	17	20	0	4494	109
2000	Oct	2622	432	1443	21	22	0	4086	324
2001	Aug	1875	56	728	4	14	0	2617	40
2001	Oct	1588	83	805	8	0	0	2393	62
2002	Aug	4243	886	2919	17	1025	50	8187	657
2002	Oct	4500	2519	2764	32	465	63	7729	1826
2003	Aug	4481	435	2484	24	1699	801	8664	1126
2003	Oct	3709	81	2722	24	686	70	7117	144
2004	Aug	3134	260	1972	24	261	12	5367	231
2005	Aug	1460	93	1391	39	303	30	3154	122
2006	Aug	3870	84	2176	675	701	27	6747	578
2007	Aug	2950	77	1627	72	64	2	4641	107
2008	Aug	3276	217	1698	117	61	1	5035	242
2009	Aug	2465	80	1011	15	565	79	4041	148
2010	Aug	3102	112	1466	17	549	60	5117	153

Table 5. Catch of all fish species in downstream migrant traps in Prairie Creek, 1999 – 2008.

Species	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Coho salmon 1+	1,954	653	4,109	2,800	748	110	326	647	858	291
Coho salmon 0+	2,702	2,690	1,677	230,745	17,648	15,765	9,410	4,282	408	2,209
Chinook salmon	56,615	22,409	18,026	110,148	11,038	45,358	2,772	1,401	598	288
Steelhead trout	218	284	505	172	68	8	57	160	216	188
Cutthroat trout	462	394	1,316	477	36	49	233	479	458	299
Unidentified trout 0+	522	1,335	1,421	1,458	4,601	2,435	168	103	397	13
Unidentified trout 1+	828	453	2,061	46	76	7	1	0	2	0
Pacific lamprey	56	30	25	113	20	0	9	18	46	40
Western brook lamprey	159	1	219	9	51	1	80	58	58	13
Lamprey ammocete	152	18	189	246	79	79	0	0	0	0
Coastrange sculpin	95	24	154	71	80	0	18	28	13	12
Prickly sculpin	124	147	344	97	18	3	248	382	134	146
Threespine stickleback	41	13	103	78	46	6	62	117	60	66
Sacramento sucker	13	0	6	3	1	0	0	6	2	4

Table 6. Estimated rates of freshwater and marine survival for Prairie Creek coho salmon during 1999-2011.

	Estimated Abundance			**% Survival**	
Year	**Juvenile**	**Smolt**	**Adult**	**Freshwater**	**Marine**
1998	6127				
1999	7130	1,876	56	30.6	
2000	4494	1,182	84	16.6	4.5
2001	2617	689	212	15.3	17.9
2002	8187	2,154	680	82.3	98.7
2003	8664	2,280	542	27.8	25.2
2004	5367	1,412	268	16.3	11.8
2005	3154	830	643	15.5	45.5
2006	6747	1,775	349	56.3	42.0
2007	4641	1,221	165	18.1	9.3
2008	5035	1,694	466	36.5	38.2
2009	4041	1063	127	21.1	7.5
2010	5117	1346	28	33.3	2.6
2011			218		16.2
			Average	30.8	26.6