Spatial and temporal ecology of native and introduced fish larvae in Lower Putah Creek, California.

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TECHNICAL COMPLETION REPORT

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Key Words: Fish ecology, Natural history, Conservation biology, Streams and stream dynamics, Flow instream, Species identification and distribution - animals

Abstract

For two years we studied the distribution and abundance of native and introduced fish larvae in Putah Creek (Yolo County, CA), a low elevation regulated stream. We used light traps and conical drift nets to sample the fish larvae at two spatially separated sites from March through July 1997 and at four sites from February through August 1998. Native larvae occurred both earlier in the year and in higher abundance than those of introduced species. Both native larvae and overall numbers of larvae were more abundant at upstream sites in both years. Larval sampling appeared to be sensitive to the detection of rare species. Drift nets and light traps collected similar numbers of larvae, but each method tended to select for different taxa. There were significant trends in diel patterns of abundance, with more fish larvae being found during the hours of darkness. We suggest that differences between the sites were due to habitat changes resulting from an upstream dam that has created a refuge of diverse habitat and cool flowing water for native taxa.

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Title: Spawning and early life history ecology of native California fishes.

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Problems and Research Objectives:

Little work has been done on the ecology of fish larvae in streams and rivers (Floyd et al. 1984, Scott & Nielsen 1989, Harvey 1991a, 1991b, Turner et al. 1994, Copp 1997, Childs et al. 1998, Gadomski & Barfoot 1998, Robinson et al. 1998) especially on the competitive ecology of native and introduced fish larvae. Yet it is during this stage that many species disperse (Moyle & Cech 1996, Robinson et al. 1998), predation pressure may be the highest (Harvey 1991a, 1991b), future population structure may be determined (Gadomski & Barfoot 1998), and management decisions can have the projected effect (Conrow et. al 1990, Mueller et al. 1993).

The purpose of this study was to examine phenological and spatial aspects of the ecology of native and non-native fish larvae in a Central Valley, California stream in order to determine if differences in larval ecology can help account for differences in the distribution and abundance of juvenile and adult fish. The study included: (1) a description of the temporal occurrence of fish larvae (2) a comparison of species distribution and abundance at 2 sites in 1997 and 4 sites in 1998 (3) a comparison of light trap and drift net capture methodologies in terms of species specificity and abundance (4) an examination of diel patterns in drift.

Methodology:

Study area

We sampled fish larvae in lower Putah Creek (Yolo County, California) from March through July 1997 and February through August 1998. Putah Creek is a small stream with its headwaters high in the coast range of California. From the coast range, the creek flows approximately 129 km east before it is impounded by Monticello Dam, forming Berryessa Reservoir. The releases from Monticello Dam flow approximately 13 km to another dam, the Putah Diversion Dam (PDD) (Figure 1). The inter-dam reach is intensely managed through stocking as a cold water trout stream. Lower Putah Creek is fed by releases from PDD and flows an approximate 37 km across the alluvial plain of the western Central Valley before eventually emptying into the Sacramento River (Figure 1). The lower creek's hydrology is dominated by regulated flows during most months and most years. The exceptions occur in wet years during winter high flow events (peak flow = 392 m^3sec^{-1} in 1997). These occur when Berryessa Reservoir exceeds its capacity and the excess water is released downstream. Typically this can happen anytime during the months of December through April. Hydrologic patterns in Putah Creek are common for a Mediterranean climate, low flows in summer (0.05-0.85 m^3sec^{-1}) and high flows (5.66+ m^3sec^{-1}) during most winters. Water year 1998 recorded the second largest yearly flow (>700 million m^3) since Monticello Dam was closed in 1957. The forty year average annual flow is approximately 187 million m^3.

Sampling

Two sites were chosen along the lower creek in 1997, an upstream site (Dry Creek), located approximately 4 km downstream of PDD, and a downstream site (Pedric Road) approximately 19 km downstream of the Dry Creek site (Figure 1). In 1998 two additional sites were added to the sampling, Russell Ranch which is approximately 13 km downstream of the Dry Creek site, and Mace Boulevard which is approximately 13 km downstream of the Pedric Road site. (Figure 1). The sites were chosen to represent conditions typical of upstream and downstream areas in Putah Creek based on extensive sampling of the adult fauna during the 4 years previous (Marchetti 1999a). The sites vary in their adult fish communities, with the upstream sites dominated by native fishes and the downstream sites dominated by non-native species (Marchetti 1999a). All sites contain a combination of shallow (20-50 cm), low gradient gravel and cobble riffles and deep (1-2 m) silt bottomed pools. The four sites exhibited some difference in water quality parameters longitudinally and between years (Table 1).

In 1997 sample collection was on a weekly basis at the two sites from the first week in March through the last week in July (22 sample weeks). In 1998 sample collection began on 9 February only at the Pedric Road site but was not able to be resumed at any site until 23 February due to extreme high flows. The Dry Creek site was not sampled until the week of 9 March . For the remainder of 1998 sample collection was on a weekly basis from early March through the last week of August at the Dry Creek (25 sample weeks) and Pedric Road sites (27 sample weeks). Collection was on a staggered bi-weekly basis at the Russell Ranch (15 sample weeks) and Mace Blvd. sites (14 sample weeks) during the same time period. At each site two sampling techniques were used: square-mouthed conical drift nets (0.138 m^2 opening, 363μ Nitex cloth) and larval light traps. Light traps were constructed following Kissick (1993) with the following modifications: they had 5mm wide openings on each side, were equipped to float at the surface, and utilized waterproof flashlights (2 D cell type) as a light source. All samples collected were preserved in 5% formalin solution in the field and the drift samples were stained with rose bengal biological staining agent.

On each sample date, drift nets were anchored to the stream bed and rested on the stream bottom in near-shore flowing areas for 15 min. For each drift sample taken, total water column depth was recorded and a current velocity was measured at 60% of the total depth in front of the drift net. Catch per unit effort (CPUE)for the drift samples was estimated as the number of larvae collected per m^3 of water filtered. For each sample site and date in 1997 we collected four total drift samples; two collected approximately one hour before and two collected one hour after sunset. In 1998, three samples were collected before sunset and three after. The paired diel samples were collected from the same locations in the stream.

On each sample date in both years, three light traps were deployed and were anchored in non-flowing portions of the stream. The traps were set for sixty minutes, and illumination began 30 min after sunset. Flashlight batteries were changed after three hours of total use. CPUE for the light traps was defined as number of larvae collected per three hours of illumination per site (Peterson & VanderKooy 1995).

During the early spring of 1998 we conducted two 24 hour sample collections, one at the Pedric Road site on 11 & 12 April and one at the Dry Creek site on 18 &19 April. Paired drift samples were collected every hour during the entire 24 hour period and followed the above methodology.

At each sampling site on each sampling date we recorded surface water temperature (°C), ambient air temperature one hour before sunset (°C), pH, conductivity (μmhos), turbidity (NTU), moonphase (% full), weather conditions and flow (m^3).

Sample processing

In the laboratory, all fish larvae were sorted from the samples. Specimens were identified to the lowest taxonomic level by M. Marchetti, utilizing information in Wang[1]. All specimens were independently verified by Johnson Wang. Species identification was not possible for one native species in the Family

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[1] Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: a Guide to the Early Life Histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. technical report #9, Department of Water Resources, Sacramento. 1-43 pp.

Cyprinidae, for all of the five sunfish species in the genus *Lepomis* (Family Centrarchidae), the two species in the genus *Pomoxis* (Family Centrarchidae), and the two sculpin species in the genus *Cottus* (Family Cottidae) that are known to occur in the creek (Marchetti 1999a). The five species of sunfish were grouped into a *Lepomis* category, the two species of crappies were grouped into a *Pomoxis* category and both sculpins were grouped into a *Cottus* category for identification. For analysis, all centrarchid species were grouped together for two reasons, (1) species identification was often not possible within the *Lepomis* and *Pomoxis* genera, and (2) all centrarchid species in the creek are introduced and were assumed to respond to similar ecological factors.

Analysis

Kendall's rank correlation test (τ, α=0.05) was used to compare ranked abundance of taxa totals (Sokal & Rohlf 1995). Two sets of comparisons were made. The first set used taxonomic abundance at each site and compared between sites and years (Table 3). Dry Creek 1997 was compared with Pedric 1997. All the 1998 sites were compared against each other. The second set of comparisons used taxon specific light trap and drift net abundance and compared capture methods success within a site (Table 4). For these statistical comparisons, eight taxa were omitted due to low numbers (Table 2). Kendall's rank correlation was also used to examine temporal aspects of capture method success. Three taxa at four sites were compared for capture success by date (Table 5). All ranking procedures were performed using the BIOM-pc (Rohlf[2]) computer program . The overall number of native and non-native fish larvae were compared separately between sites in 1997 and 1998 using a two-way contingency table employing the G test with an overall significance level of α=0.05 (Sokal & Rohlf 1995). A diel comparison of drift examined the average # of fish larvae collected before and after dark at all sites for both years. Catch per unit effort (CPUE) was used in this comparison. Separate two-way ANOVAs (treatment and date, α=0.05) were used to compare day and night drift samples at each site using the BIOM-pc (Rohlf[2]) computer program.

One way analysis of variance (ANOVA) was used to compare the twenty four hours of larval drift capture on two dates and sites in 1998. The twenty four hour period was broken into four, six hour-long time periods, 7-12 AM, 1-6 PM, 7-12 PM, 1-6 AM. Each sample during the six hour period was the average of two simultaneous but independent drift samples that were standardized by CPUE. The analysis examined differences in total number of fish larvae, Sacramento sucker larvae, and sculpin larvae.

Results

In 1997 we collected a total of 6,042 fish larvae using larval light traps and drift nets, and in 1998 we collected 8,736. These fish represented 22 taxa, in 10 families and 17 species. In 1997, 97% of individuals sampled belonged to four taxonomic categories (Table 2): native sculpin, *Cottus spp.*, native Sacramento sucker, *Catostomus occidentalis*, non-native centrarchid species (*Lepomis* spp, *Pomoxis* spp, and largemouth bass *Micropterus salmoides*), and non-native bigscale logperch, *Percina macrolepida*. In 1998 these same four taxa accounted for 88% of the collections. The majority of the analysis was confined to these four major taxonomic groups.

In both years larvae and juveniles of native species overwhelmingly occurred earlier in the season (March through early June) than larvae and juveniles of non-native species which had peaks in abundance later in the season (June through August) (Figure 2). This pattern held across sites and across samples.

There were similar patterns in relative abundance for the four major taxa sampled (Figure 3), native taxa (Cottidae and Catostomidae) predominate earlier in the season and non-native taxa (Centrarchidae) dominate later in the season. One non-native taxa (bigscale logperch) did occur throughout the early season and tended to co-occur with native larvae (Figure 3).

[2] Rohlf, F.J. 1995. BIOM-pc program. Exeter Software. Setauket.

In 1997 more fish larvae per sample (176.0) were collected at the upstream site (Dry Creek) than at the downstream site (95.2 at Pedric Road). In 1998 there was a similar trend where the two more upstream sites collected more larvae per sample (Dry Creek - 147.9, Russell - 111.6) than the downstream sites (Pedric Road - 70.2, Mace - 105.7). In addition for both years, the vast majority of individuals at the Dry Creek site were native species, and this percentage decreased in a downstream direction (Table 2). In particular, prickly sculpin and Sacramento suckers dominated the fauna at the upstream sites while centrarchids became increasingly more dominant at the downstream sites (Table 2). The results of the G test indicated a significant difference between numbers of native and non-native larvae collected at both sites in 1997 ($G = 3624$, $p<0.0001$, $n=1$), and among all the sites in 1998 ($G = 2840$ $P<0.0001$, $n=3$). Kendall's rank correlation test indicates a significant correlation between overall rank of species abundances at Dry Creek and Pedric Rd. in 1997, and between Dry Creek and Russell, Russell and Pedric and Pedric and Mace Blvd. in 1998 (Table 3)

The temporal pattern of dominance by native versus non-native individuals within the larval fauna appears to be shifted between the upstream and the downstream sites. The native fish tend to occur later into the year and dominate the larval fauna for longer at the upstream sites (Figure 3). In 1997 Sacramento suckers have a later and longer temporal window of occurrence at the Dry Creek site, and in 1998 sculpin have a larger window of occurrence at the Dry Creek and Russell Ranch sites. At the two sites that were sampled in both years the native fish larvae dominate the fauna longer in 1998 than in 1997 (Figure 3).

A comparison of the two sampling methods, with data from all sites and dates combined, reveals that each method captured a similar total number of individuals (8066 in drift nets, 6652 in light traps). A comparisons between sites shows a different pattern. Three sites collected more fish larvae in the drift samples than in light trap samples (Dry Creek 1997 - 2 times more, Pedric Road 1998 - 3 times more, Mace Blvd. 1998 - 2.5 times more). Yet the Pedric Road 1997 site collected 3.5 times more fish larvae in light traps. The other two sites (Dry Creek 1998, and Russell Ranch 1998) collected approximately equal amounts of fish larvae in each technique. Kendall's coefficient was used to compare the rank abundance of species between methods and indicates a significant correlation between methods at all sites except Pedric Road 1997 (Table 4)

Kendall's coefficient was used to compare the overall numbers of larvae collected on each date between sample methods only at the Dry Creek and Pedric Road sites during both years. Other sites had too few captures or too few dates for statistical comparisons. Sacramento sucker were sufficiently abundant for comparison at all four sites and dates and indicated significant correlation between sample methods in every case (Table 5). Sculpin were sufficiently abundant for comparison at three of the four sites and also indicated significant correlation between sample methods in each case (Table 5). Centrarchid taxa were sufficiently abundant for comparison at only two sites and did not indicate statistical correlation between methods at either date (Table 5)

A comparison of paired drift samples collected during daylight versus night indicates a very strong tendency toward more drift during the night. Two way ANOVA results indicate significant treatment effects (day vs. night) and date effects for all six sites (Table 6). There were also significant interaction terms in all but the Dry Creek 1997 and Pedric Road 1997 sites (Table 6).

Analysis of the 24 hour drift samples provide fairly consistent results. One way ANOVAs were performed separately for all fish larvae, Sacramento sucker larvae and sculpin larvae collected at each site. All of these analyses indicated significant differences in mean number of larvae collected between the four time periods. Bonferroni adjustments for multiple comparisons among means indicated that more fish larvae were collected during the two time periods after sunset for all larvae and Sacramento sucker larvae. Multiple comparisons for sculpin larvae indicated different patterns. At the Dry Creek site, fewer sculpin were collected from 1 to 6 AM than any other time period. At the Pedric Road site, more sculpin were collected from 1 to 6 AM than any other time period. Low numbers of sculpin were collected at both sites.

Principal Findings, Conclusions and Recommendations

The results of this study indicate a temporal separation of native and introduced fish larvae in Putah Creek. This suggests the importance of early season environmental cues for the timing of native species spawning. Potential cues for native fish could include water temperature, photoperiod or changes in flow (Robinson et al. 1998, Moyle 2000) but are most likely a combination of all three. It has been demonstrated elsewhere in California that the natural hydrologic pattern in stream flow is an important cue not only for native species spawning (Moyle 2000) but also for the persistence of native species in the face of exotic invasions (Moyle & Williams 1990, Strange et al. 1992, Strange 1995). Additionally, the upstream areas of Putah Creek appear to provide better conditions for spawning and rearing of native species as indicated by the presence of native fish larvae at the upstream sites. This pattern has been noted elsewhere using Index of Biotic Integrity (IBI) scores (Moyle & Marchetti 1998), multivariate analysis (Marchetti 1999a) and was successfully defended in a recent lawsuit regarding the creek (Moyle et al. 1998). In the current situation, it appears more favorable conditions for native species reproduction exist in the upper portions of the lower creek.

A striking pattern with regard to spatial and temporal distribution of native larvae is the high number of native fish larvae early in the season. This is consistent with information on the spawning patterns of California native fish, which generally spawn early in the year (Moyle 2000, Wang[1]) typically in response to a changing hydrograph (Moyle 2000). As is indicated in Figure 2, in both years the peak of the native fish larvae began soon after stream flows had fallen below 2.8 $m^3\ sec^{-1}$. The pattern of spawning on a descending hydrograph has also been observed for native fishes in the Little Colorado river (Robinson et al. 1998). Our sampling began during the first week of March in 1997 and late February 1998, because we were not able to sample during the high flows. It is possible that we missed some early spawning, but the capture numbers during the first samples in both years were very low, suggesting we caught the first wave of emerging fish larvae. The majority of the introduced fishes in California are known to spawn later in the year, often in response to a temperature or photoperiod cue, although variation exists among taxa (Moyle 2000).

The large difference observed between sites (upstream sites having a higher total number of fish larvae and a higher relative abundance of native larvae) suggests the upstream sites afford better spawning habitat, both in general and for native fishes. The habitat at the upstream sites generally has more shade, more flow and more gravel riffles (Marchetti 1999a), three variables indicated by Canonical Correspondence Analysis (CCA) to be positively associated with abundance of native species in this system (Marchetti 1999a). The significant correlation of species' ranks between sites is interesting in light of the unequal distribution of native/non-native larvae. The correlation data suggests there is a downstream trend in terms of the overall pattern of species abundance. This implies that the observed difference in native versus non-native fish larvae between sites (demonstrated by the G test), is more a matter of absolute numbers of individuals than of the type or rank of taxa present. The sites exhibit similar overall faunal composition but the upstream sites have relatively more native individuals. This supports the idea that the upstream sites contain better spawning areas for native fish.

Two observations cloud this hypothesis. First, approximately 90% of the upstream native larvae were sculpin and Sacramento suckers, suggesting the upstream site is better habitat for those species. Secondly, only four sites were sampled, so generalizations regarding the entire stream are limited. Overall, even if these factors are taken into account, the difference in numbers of natives between upstream and downstream sites is still striking.

Although a gross comparison of the two methods indicates similar overall capture rates, the two methods do not correlate well at the downstream sites. The individual species comparisons suggest that species have different affinities for the capture methods. This is intuitive given the variation in individual species life history characteristics. For example, sculpin are known to drift as larvae (Moyle 2000) and are therefore more likely to be collected by drift nets (but see Floyd et al. 1984). Centrarchids on the other hand, are nest builders and their nests tend to be in shallow backwater areas (Moyle 2000). Therefore larval centrarchids are more likely to be collected with light traps, as has been observed in other studies (Scott & Nielsen 1989, Turner et al. 1994).

Results from the twenty four hour study and the diel comparison suggest that drift occurs more often after dark. This pattern is consistent with some studies (Brown & Armstrong 1985, Carter et al. 1986, Gadomski & Barfoot 1998) and in contrast to others (Robinson et al. 1998) and may depend on the specific taxa involved. Our results varied slightly between taxa, because there were separate patterns for sculpin drift at the two twenty-four-hour sites. In addition there were significant interaction terms in five out of the six two-way ANOVAs, suggesting that date and drift patterns were linked.

The downstream differences in the numbers of fish and the changes in taxon dominance through time might be predicted solely on the basis of longitudinal changes in gradient, channel morphology and temperature, as it has elsewhere in California streams (Moyle et al. 1982, Moyle 2000). Yet there is a difficulty with applying such a concept to the lower reaches of Putah Creek. The creek drops only 23.7 m over the 28 km between the Dry Creek site and the Mace Blvd. site and the channel morphology is relatively homogeneous between sites, suggesting site equivalence on a regional or geographic scale. The faunal changes we observed between sites are more likely attributable to the serial discontinuity concept put forth by Ward and Stanford (1983). This concept suggests an impoundment (such as Monticello Dam) will create irregularities, or a compression of the natural longitudinal gradient of physical and ecological parameters within a stream (Ward & Stanford 1979, 1983). The irregularities are predictable based on a number of factors including the placement of the dam in the watershed (Ward & Stanford 1995) and the method of water release from the dam (Ward & Stanford 1979). The cold water hypolimnial releases from Monticello Dam in part, effect the downstream longitudinal pattern of fish larvae observed in this study.

In addition to our sampling of fish larvae, we have also conducted six years of juvenile and adult sampling at the same stations on the creek (Marchetti 1999a). From this additional work, it appears that weekly larval sampling is more likely to pick up rare species than our monthly juvenile/adult sampling. For example, the larval sampling collected a significant percentage of common carp (3%), red shiners (1%) and channel catfish (1%) which are an order of magnitude less common in our adult sampling (0.5%, 0.04%, 0.3% respectively). It is intuitive to expect more larvae than juveniles of a rare species to be present in an area, given fishes' high fecundity rates. Larval sampling may therefore be an alternative method to determine an area's overall species diversity, because the presence of larvae indicate successful spawning (even if at low numbers), while the presence of a rare individual does not actually indicate a reproducing population in an area.

It would seem that earlier spawning and development of the native fishes could confer an ecological advantage over the non-native species in terms of food and habitat availability. This may be the case over the short term, when there are good water years. Flow variability is a natural feature of stream systems in California (Mount 1995, Moyle 2000), and as such the native fishes have adapted to the extreme fluctuations in both stream discharge and associated environmental parameters (Moyle 2000). The two sample years in this study occurred during periods of relatively high rainfall and associated high discharge from Monticello Dam. Water year 1998 was an extreme example of this as the total stream volume for the year fell outside two standard deviations of the 40 year average. During periods of drought, the native fishes do not seem to reproduce well (Marchetti unpublished data) and the lower sections of the creek become dominated by exotic species (Marchetti 1999a) which are known to reproduce under more lentic conditions. This temporal shift in numerical dominance by native or non-native species may be mediated by environmental fluctuations, (particularly annual flow volume) that effect recruitment success. This pattern has been demonstrated elsewhere in California with adult fauna (Strange et al. 1992, Strange 1995). Based on previous work in this system (Marchetti 1999a) during periods of relative drought, we would predict fewer total native fish larvae and a compression of the overall area where native fish larvae numerically dominate. This hypothesis awaits a series of drought years to be tested.

Summary:

The use of fish larvae to characterize the fauna of a region is encouraged. Sampling this life stage maybe a more sensitive indicator of rare species, and provide a window into the population dynamics of a stream fish community. It is also suggested that multiple sampling techniques be used to characterize the larval community, due to wide variation in the natural history of fish species and possible changes in phenology between sites.

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Table 1: Water quality parameters measured at each sample site and year during the periods sampled. Maximum flow was measured as releases from Putah Diversion Dam

	Dry Ck. 1997	Pedric Road 1997	Dry Ck. 1998	Russell 1998	Pedric Road 1998	Mace Blvd. 1998
Flow (m^3sec^{-1})						
Minimum	0.9	0.9	1.1	1.3	1.2	1.2
Maximum	10.7	10.7	229.9	229.9	229.9	229.9
Water Temp. Range (°C)	11.9-18.1	12.5-24.1	11.0-17.1	11.8-24.0	10.5-24.1	11-24.1
Conductivity Range (μS)	235-328	265-500	235-332	205-550	210-575	230-590
Turbidity Range (NTU)	2.5-19.4	5.0-30.2	3.8-30.8	3.7-134	6.6-370	11.7-290

Table 2. Scientific names of taxa captured, species codes, total number fish larvae sampled by site and method and native and non-native taxa totals.

	Dry Creek 1997		Pedric Road 1997		Dry Creek 1998		Russell 1998		Pedric Road 1998		Mace Blvd. 1998	
Taxon	drift	light	drift	light	drift	light	drift	light	drift	light	drift	light
Petromyzontidae												
Lampetra tridentata (plp)* †	0	0	1	0	0	0	0	0	0	0	0	0
Cyprinidae												
Crassius auratus (gf)	1	0	9	0	0	1	1	0	0	0	0	0
Cyprinus carpio (cp)	16	5	8	1	11	8	14	1	22	2	330	21
Lavinia exilicauda (hch)*†	1	0	1	3	0	0	0	1	1	2	1	0
Notemigonus crysoleucas (gs)†	0	0	5	0	1	1	0	0	0	0	0	0
Notropis lutrensis (rs)	0	0	2	24	0	1	0	1	15	50	18	80
Orthodon microlepidotus (bf)*	1	0	8	5	2	9	0	58	1	0	4	0
Ptychochelius grandis (sq)*	3	4	3	2	2	0	37	4	54	2	0	0
unidentified native cyprinid (spl)*	0	0	0	0	3	1	2	1	4	1	4	4
Pimephales promelas (fhm)†	0	0	0	0	0	0	0	0	1	0	0	0
Catostomidae												
Catostomus occidentalis (skr)*	728	789	226	244	516	425	308	651	823	363	225	96
Ictaluridae												
Ameiurus catus (wcf)	0	0	0	0	0	0	0	0	98	0	37	0
Ictalurus punctatus (ccf)	0	0	3	0	0	0	0	0	16	0	1	0
Poeciliidae												
Gambusia affinis (mqf)†	0	0	0	4	0	0	0	0	0	0	2	0
Atherinidae												
Menidia beryllina (iss) †	0	0	0	0	0	0	0	0	0	0	1	0
Gasteroteidae												
Gasterosteus aculeatus (stb)*†	1	5	0	3	0	3	0	0	1	1	0	0
Centrarchidae												
Pomoxis spp (pom)‡	1	15	2	40	10	2	0	0	1	0	0	0
Lepomis spp. (lep)‡	7	16	82	1294	2	11	171	37	127	27	389	189
Micropterus salmoides (lmb)‡	6	5	1	4	1	21	16	26	7	2	0	0
Micropterus dolomieui (smb) ‡†	0	1	0	0	0	0	0	0	0	0	0	0
Percidae												
Percina macrolepida (bslp)	54	13	87	12	69	8	49	9	102	1	35	4
Cottidae												
Cottus spp. (scp)*	1788	487	6	14	1130	1461	194	96	119	37	28	11
native total	2522	1285	245	277	1653	1899	541	811	1003	406	262	111
non-native total	85	55	199	1379	94	53	251	74	389	82	813	294

* Denotes native species, ‡ Taxa grouped into Centrarchid (cent) taxon, † taxa omitted from rank abundance comparisons due to low numbers

Table 3: Kendall Tau-B Coefficient comparisons of total taxa abundance between sites. *significant at α<0.05, **significant at α<0.01

	Dry Creek 1997	Dry Creek 1998	Russell 1998	Pedric Rd. 1998	Mace Blvd. 1998
Pedric Rd. 1997	0.520**				
Dry Creek 1998		1.000			
Russell 1998		0.686**	1.000		
Pedric Rd. 1998		0.291	0.443*	1.000	
Mace Blvd. 1998		0.208	0.341	0.541**	1.000

Table 4: Kendall Tau -B Coefficient comparisons of taxon specific capture method success within a site. *significant at α<0.05, **significant at α<0.01

	n	Kendall's Tau - B
Dry Creek 1997	13	0.615**
Pedric Rd. 1997	17	0.210
Dry Creek 1998	15	0.458*
Russell 1998	12	0.586**
Pedric Rd. 1998	16	0.455*
Mace Blvd. 1998	13	0.635**

Table 5: Kendall Tau -B Coefficient for individual taxa comparisons of capture method success by date. Sample size is in parentheses. *significant at α<0.05, **significant at α<0.01

	Cottidae	Catostomidae	Centrarchidae
Dry Creek 1997	0.536** (15)	0.653** (18)	
Pedric Rd. 1997		0.524* (11)	0.324 (11)
Dry Creek 1998	0.656** (20)	0.478** (18)	
Pedric Rd. 1998	0.510** (15)	0.689** (19)	0.589 (8)

Table 6: Results of two-way ANOVA for day/night comparisons of fish larvae abundance in drift samples. * P < 0.05, ** P < 0.001

		treatment		dates		treatment*dates	
	N	Mean-Square	F-ratio	Mean-Square	F-ratio	Mean-Square	F-ratio
Dry Creek 1997	84	16232.4	27.69**	3791.9	6.47**	993.9	1.70
Pedric Rd. 1997	84	2788.8	14.24**	508.9	2.60**	146.9	0.75
Dry Creek 1998	132	1749.5	5.17**	14167.1	41.84**	984.7	2.91**
Russell 1998	66	5046.1	19.24**	3084.1	11.76**	2422.8	9.24**
Pedric Rd. 1998	161	27000.7	41.58**	2000.1	3.08**	1616.9	2.49**
Mace Blvd. 1998	78	59359.6	93.07**	19790.7	31.03**	15539.1	24.37**

Figure Legends

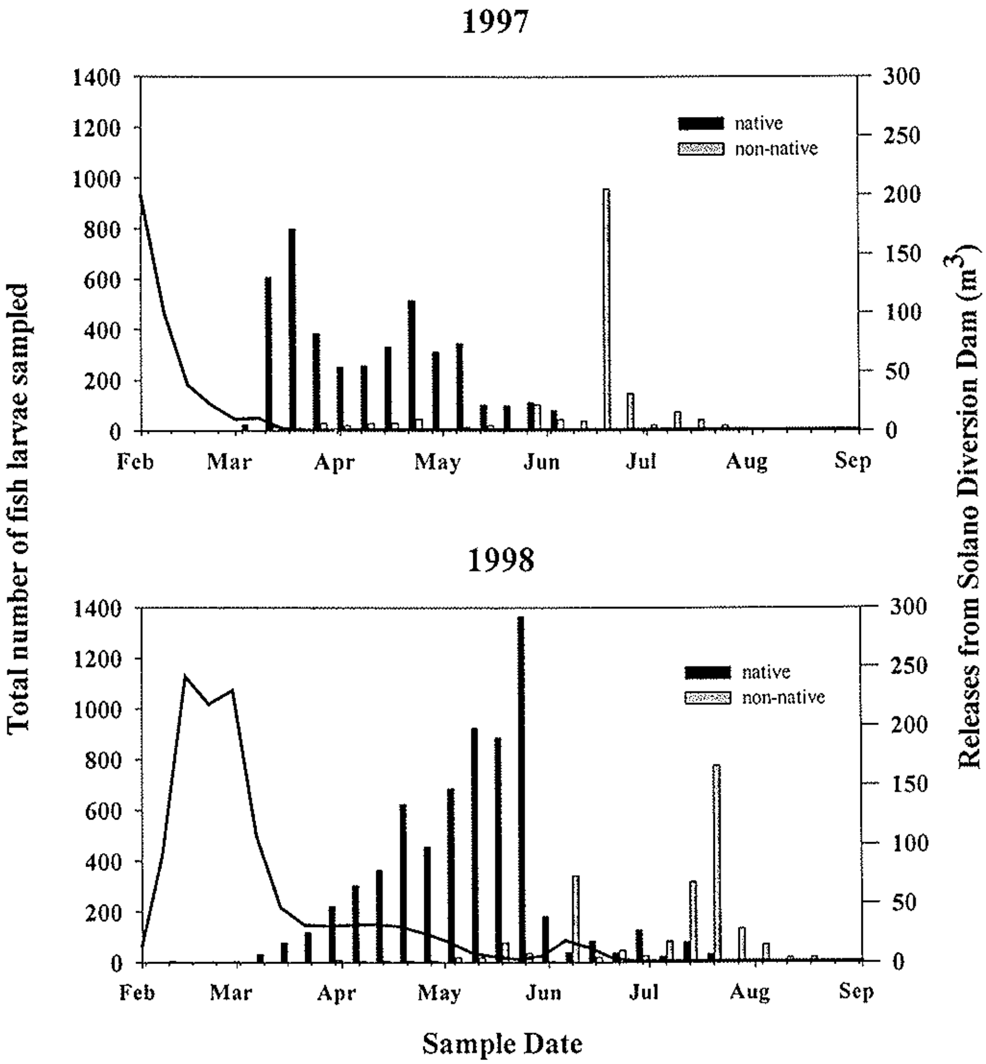
Figure 1. Map of Lower Putah Creek, Yolo County, California, and study sites. D is Dry Creek site, R is Russell Ranch site, P is Pedric Road site and M is Mace Blvd. site..

Figure 2. Native and non native fish larvae in Lower Putah Creek, February through July 1997(2 sites combined) and February through August 1998 (4 sites combined), with daily average releases from Putah Diversion Dam on second y axis.

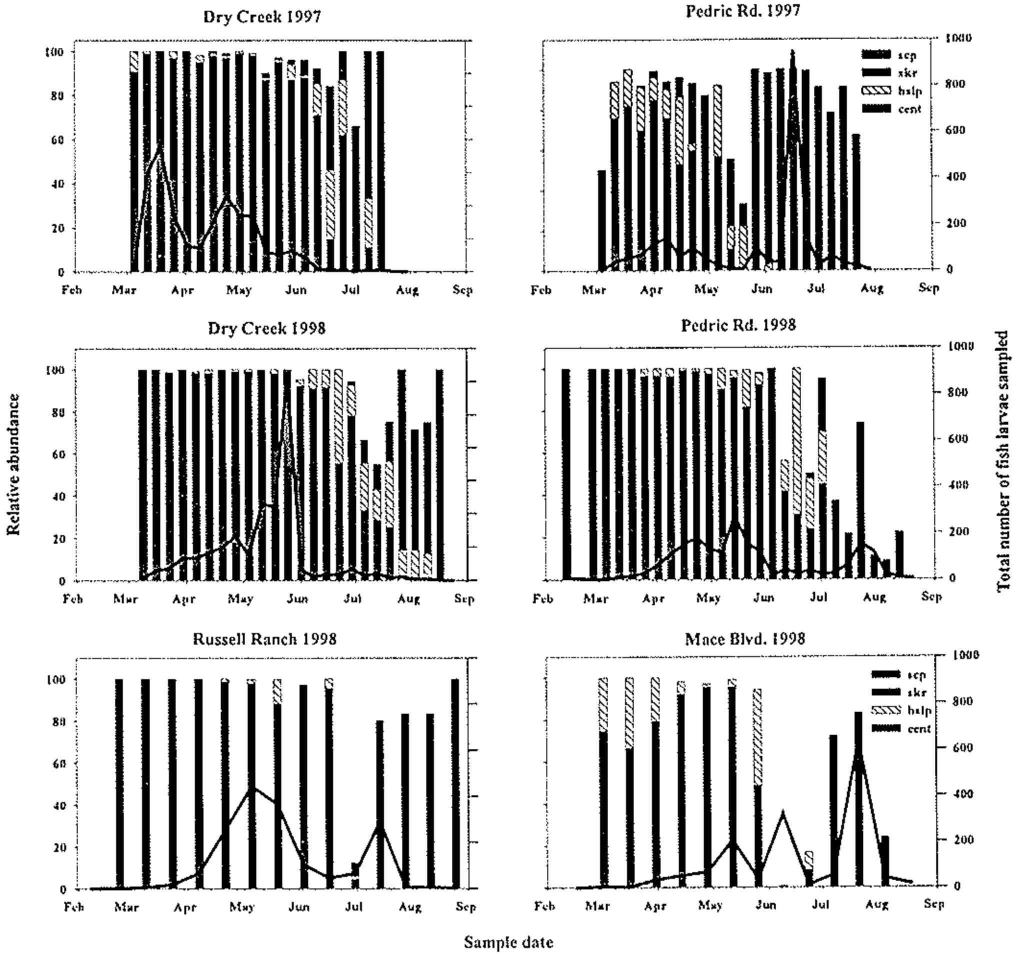
Figure 3. Relative and absolute abundance of major taxa collected at two sites in 1997 and four sites in 1998. Relative abundance does not always equal 100% due to the presence of rare species. psp = sculpin spp., skr = Sacramento sucker, bslp = bigscale logperch, cent. = Centrarchidae spp.

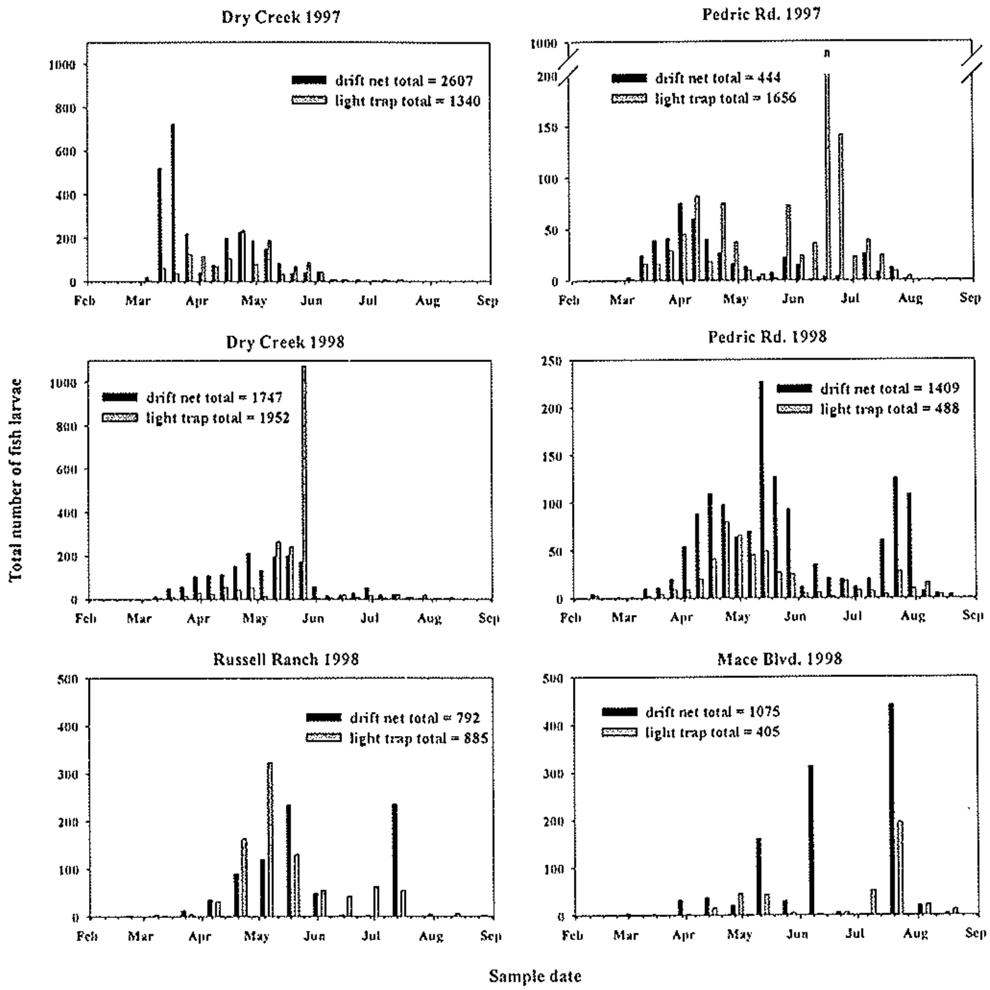
Figure 4. Total number of larval fish collected using drift nets and light traps at two sites in 1997 and four sites in 1998

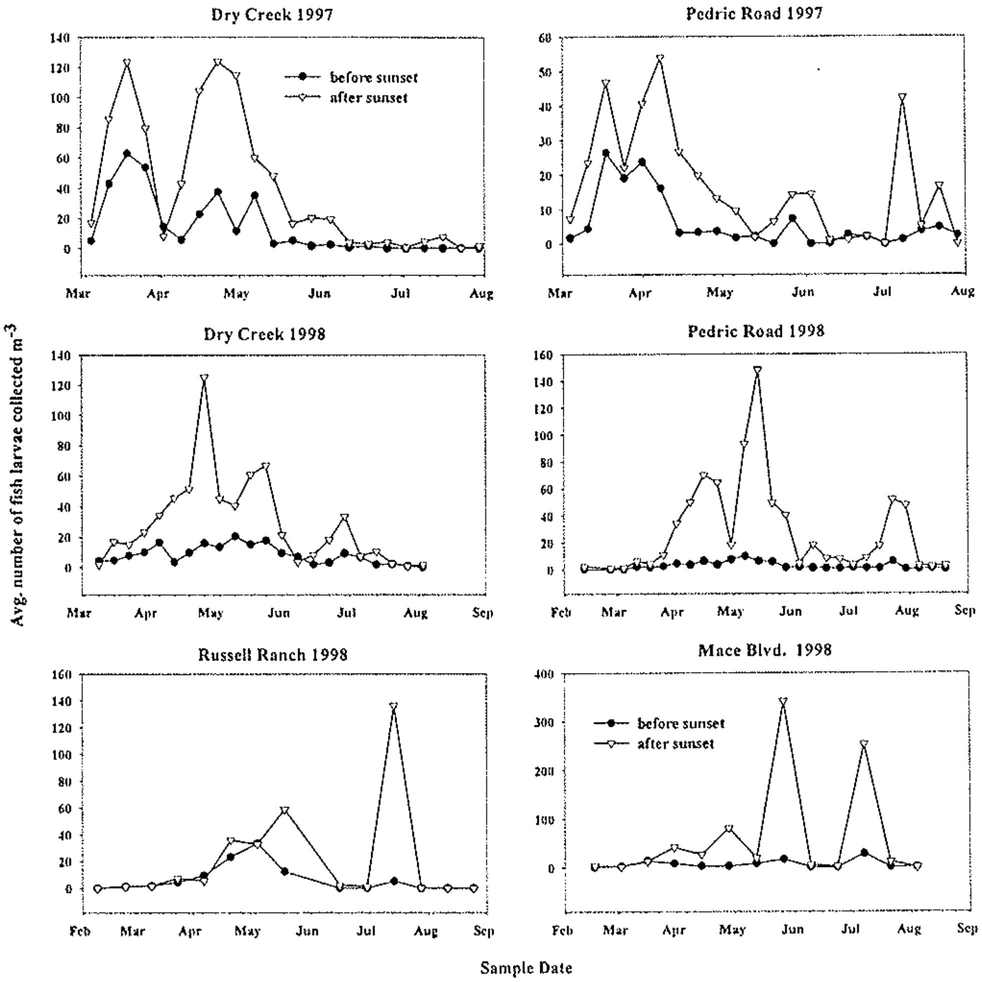
Figure 5. Average numbers of larval fish per m^3 from drift samples at two sites in 1997 and four sites in 1998 comparing before and after sunset collections,



1997
1400
1200
1000
800
600
400
200
0
300
250
200
150
100
50
0
native
non-native
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
1998
1400
1200
1000
800
600
400
200
0
300
250
200
150
100
50
0
native
non-native
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Total number of fish larvae sampled
Releases from Solano Diversion Dam (m3)
Sample Date


Dry Creek 1997
Pedric Rd. 1997
Dry Creek 1998
Pedric Rd. 1998
Russell Ranch 1998
Mace Blvd. 1998
scp
skr
hslp
cent
Relative abundance
Total number of fish larvae sampled
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Sample date


Dry Creek 1997
drift net total = 2607
light trap total = 1340
Pedric Rd. 1997
drift net total = 444
light trap total = 1656
Dry Creek 1998
drift net total = 1747
light trap total = 1952
Pedric Rd. 1998
drift net total = 1409
light trap total = 488
Russell Ranch 1998
drift net total = 792
light trap total = 885
Mace Blvd. 1998
drift net total = 1075
light trap total = 405
Total number of fish larvae
Feb Mar Apr May Jun Jul Aug Sep
Sample date


Dry Creek 1997
before sunset
after sunset
Pedric Road 1997
Dry Creek 1998
Pedric Road 1998
Russell Ranch 1998
Mace Blvd. 1998
before sunset
after sunset
Avg. number of fish larvae collected m-3
Sample Date
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep