Use of a restored Central California floodplain by larvae of native and alien fishes

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Abstract. We sampled larval fish in 1999 and 2001 on a restored floodplain along the lower Cosumnes River, California, from the onset of flooding to when the sites dried up or when larval fish became rare. We collected over 13,000 fish, of which prickly sculpin *Cottus asper* made up the majority (73%). Eleven species made up 99% of the catch. Three native fishes (prickly sculpin, Sacramento sucker *Catostomus occidentalis,* and Sacramento splittail *Pogonichthys macrolepidotus*) and two alien species (common carp *Cyprinus carpio* and bigscale logperch *Percina macrolepida*) were associated with higher inundation and associated cool temperatures of early Spring. In contrast, six other alien taxa , sunfish *Lepomis* spp., largemouth bass *Micropterus salmoides,* crappie *Pomoxis* spp. , golden shiner *Notemigonus crysoleucas*, and inland silverside *Menidia beryllina* were associated with less inundation and warmer water temperatures. One native species, Sacramento blackfish *Orthodon microlepidotus*, was also associated with these conditions. Species did not show strong associations with habitat because of different spawning times of adults and expansion and contraction of flood waters. Most species could be found at all sites throughout the flooded areas, although river and floodplain spawning fishes usually dominated sites closest to levee breaches. Highest species richness was consistently found in two sloughs with permanent water, because they both received drainage water from the floodplain and had a complement of resident species. Splittail, an obligate floodplain spawner, was found primarily in association with submerged annual plants. Our results suggest that a natural hydrological cycle in the Spring is important for providing flooding and cool temperatures required by many native larval fishes. Alien fishes are favored if low flows and higher temperatures prevail. Restoration of populations of native fishes that use floodplains for rearing should emphasize early (February-April) flooding followed by rapid draining to prevent alien fishes from becoming abundant.

Floodplains are important spawning and nursery habitats for many fishes (Welcomme 1979, Bayley 1995, Sparks 1995). Seasonal spawning and rearing habitat is made available when terrestrial vegetation becomes inundated by flood waters. Floodplains are important nursery habitats because they provide abundant small invertebrates for food (Holland and Huston 1985), sanctuary from unfavorable temperatures and high velocity river currents (Holland 1986), and cover from predators (Paller 1987). Many of the habitats available to fishes change seasonally in relation to the ebb and flow of flood waters, resulting in successional shifts in the use of floodplains by fishes (Winemiller 1989).

In California, the importance of floodplain habitats to fishes has not been appreciated until recently, although native fishes are adapted to seasonal inundation of valley flood lands, a major event in pre-water development times (Sommer et al. 2001). Rain and snowmelt occur mainly in winter and spring and native riverine fishes spawn during periods of high flow from February through early May (Marchetti and Moyle 2000, Moyle 2002). Historically, the high flows provided both access to upstream spawning areas and created extensive flooded habitat for rearing. Today dams and diversions have altered the natural flow regimes in most California rivers, with most high flows captured in reservoirs (Moyle 2002). Floodplains have become separated from rivers through channelization and levee construction and heavily developed for agricultural and urban uses (Mount 1995, Rasmussen 1996). The combination of altered flows and reduced habitats has been a major factor in the decline of the native fish fauna of California (Moyle 2002). An additional problem has been the invasion of many alien fishes that are favored by the altered habitats (Moyle 2002). This high degree of habitat loss has greatly enhanced the significance of remnant floodplain habitat (Sommer et al. 2001), such as that found along the lower Cosumnes River in central California. The Cosumnes River is the largest stream flowing into California's Central Valley without a major dam on its main stem (Florsheim and Mount 2002). Because the Cosumnes River still maintains its natural hydrograph during winter and spring, a major floodplain restoration effort along the lower river has been undertaken by The Nature Conservancy (TNC) and various state and federal agencies (Florsheim and Mount 2002). Levees were breached in five places to allow seasonal flooding of a mosaic of habitat types including rice paddies, oak woodland, willow and cottonwood riparian forest, grasslands, marshlands, and sloughs.

We initiated a study in February 1999 to study use of the restored floodplain habitat by larval native and alien fishes. The goals of our study were to (1) compare fish use of different habitats within the floodplain, (2) assess temporal trends in abundance of native and alien species, and (3) characterize the environment in relation to use by larval fish. Special attention was paid to the use of floodplain habitat by native fishes including Sacramento splittail *Pogonichthys macrolepidotus* for spawning and rearing because it is listed as a federal threatened species (Moyle 2002) and is a floodplain-dependent species (Sommer et al. 1997, 2001, 2002).

Study Site

The Cosumnes River Preserve (CRP) is located in south Sacramento County bordering the Cosumnes River. It is a large (5,261 hectares) mosaic of floodplain and surrounding uplands (Florsheim and Mount 2002). The preserve has some of the best remaining examples of Central Valley freshwater wetlands, cottonwood-willow riparian corridors, and valley oak riparian forests. The preserve also contains managed farmlands and diked waterfowl ponds, together with annual grasslands interspersed with vernal pools. The CRP is located just upstream (0.5 km) of the confluence of the Cosumnes River and the Mokelumne River (Figure 1). The preserve encompasses three major tidally influenced freshwater sloughs, Middle Slough, Tihuechemne Slough, and Wood Duck Slough. During high flows a large portion of the overland flow exits through Middle Slough into the North Delta (upper San Francisco Estuary). Wood Duck Slough penetrates the middle of the floodplain area and also acts as a conveyor of overland flow during periods of high inundation. Tiechumne Slough sits in between Wood Duck Slough and Middle Slough. It is very similar to Wood Duck Slough in that it bisects the floodplain and conveys overland flow during high flow events. It was not used as a sampling site because access to it was very difficult during high flooding. The extent of flooding is highly variable from year to (Figure 2). In 1999 the river was connected to the floodplain for 135 days and in 2001 for 88 days (Wendy Trowbridge, University of California, Davis unpublished data). Five sampling sites were chosen on the basis of representativeness of habitats and accessibility during flood events (Figure 1): (1) Middle Slough; (2) Wood Duck Slough; (3 and 4) two flood plain sites near levee breaches; and (5) the Cosumnes River adjacent to the floodplain. Another site, only sampled in 1999, was in a ditch that ran perpendicular between the floodplain sites and acted as a catch basin when floodplain waters receded.

Methods

Field methods. Sampling was conducted in 1999 and 2001 and began with the onset of flooding and terminated when the site dried up or larval fish became rare in samples. In 1999 samples were collected on a weekly basis with Middle Slough and the river site collection beginning on February 9 and ending the end of July (24 weeks). Wood Duck Slough sampling started on February 23 and extended through July (22 weeks). The floodplain site opposite the upper breaches was sampled from February 23 through May 11 (11 weeks). The ditch site was started on March 16 and extended through June 22 (14 weeks). The floodplain site opposite the lower breaches was begun on March 9 and extended through May 25 (12 weeks). In 2001 all sites were started on February 20 except the lower breach floodplain site, which was started on March 1. All sampling was terminated on July 5 (20-21 weeks). At each site light traps were used following the design of Kissick (1993) with the following modifications (Marchetti and Moyle 2000): the openings leading into the traps had 5-mm wide slots on each side, the traps were equipped with extra foam to allow them to float, and the light source used was a waterproof flashlight (2 cell, D size). For each sample date in both years, a single light trap was placed out in each site at least one hour after sunset. Traps were placed out in succession so that each trap could be picked up after 60 minutes of illumination. At each site surface water temperature, pH (1999 only), and conductivity (µS) were measured using a Hanna HI991300 portable meter. Water clarity was measured during daylight hours prior to sampling to the nearest cm using a 10 cm secchi disk. The presence or absence of velocity was determined using a small dip net; any ballooning represented the presence of current. River discharge data were obtained from the USGS gage at Michigan Bar, approximately 58 km upstream. Depth was measured to the nearest centimeter. Percentages of different substrates (silt, mud, clay, sand, gravel, and cobble) and of bottom covered with different types of vegetation (annual plants, trees, woody debris, aquatic macrophytes, emergent macrophytes, and filamentous algae) were estimated in a 1 meter circle surrounding the light trap. Samples were preserved in a 5% solution of buffered formalin.

Larval fish identification. Samples were sorted and larvae identified using Wang (1986). Identifications of voucher specimens were verified by Johnson Wang (National Environmental Services Inc.) to assure that identifications (especially of cyprinids) were correct. Larval sunfish (*Lepomis*) and crappie (*Pomoxis*) could not be identified to species, although based on juvenile and adult studies the sunfish are bluegill and redear sunfish and both species of crappie were captured during the study (P. Crain unpublished data). For convenience these two taxa groups are refered to as species for the remainder of this paper. All other larvae were identified to species except for two pro-larvae smelt that were caught in 2001. The smelt were assumed to be wakasagi *Hypomesus nipponensis* because juveniles were caught and identified later in another sampling program.

Statistical analysis. Light trap catches of larval fish were converted into catch per unit effort (CPUE, fish per unit hour of illumnination). Any species that did not make up at least 0.005% of the total catch over the two years was dropped from further analysis. CPUE data and environmental data that were not expressed as percentages were ln(x + 1) transformed before analysis. Environmental data taken as percentages were square root transformed. All environmental data were standardized to a mean of 0 and a standard deviation of 1. Analyses included principal components analysis (PCA), detrended correspondence analysis (DCA), and canonical correspondence analysis (CCA) (Canoco 4.0, ter Braak 1986). Patterns in CPUE for sites and years were explored using PCA. Monthly succession of larval species was explored graphically for each year. A DCA analysis was also performed on these data. DCA was used because an initial PCA showed a pronounced “arch effect” indicating a unimodal response gradient. CCA was used to describe the relationships between species abundances and environmental variables.

Results

Summary of catch

A total of 7,709 larval fish was collected in 1999 and 5,808 in 2001 (Table 1). The combined abundance of four species—threadfin shad *Dorosoma petenense*, American shad *Alosa sapidissima*, western mosquitofish *Gambusia affinis* and wakasagi—was less than 0.007% of the total catch for the two years and were eliminated from further analysis, leaving eleven species. The other eleven species made up over 99% of the total catch (Table1). Prickly sculpin *Cottus asper* was by far the most abundant species, accounting for 73% of the total larvae. Other common taxa were the sunfish *Lepomis macrochirus* and *Lepomis microlophus* (6%), common carp *Cyprinus carpio* (4%), Sacramento sucker *Catostomus occidentalis* (4%), bigscale logperch *Percina macrolepida* (3%), crappie *Pomoxis annularis* and *Pomoxis nigromaculatus* (3%), and inland silverside *Menidia beryllina* (3%). All other species (Sacramento blackfish *Orthodon microlepidotus*, Sacramento splittail *Pogonichthys macrolepidotus*, largemouth bass *Micropterus salmoides*, and golden shiner *Notemigonus crysoleucas*) were each around 1% of the catch (Table1).

Comparisons among Sites

The highest diversity of fishes was found in Middle Slough where all eleven species were present (Figure 3). Three and two of the four most abundant species were natives in 1999 and 2001, respectively. The two floodplain sites (Floodplain 1, Floodplain 2) and the ditch intersecting those two sites all had 8 species (4 native) in 1999, while in 2001 Floodplain 1 had 6 species (2 native) and Floodplain 2 had 10 (4 native). Wood Duck Slough contained 10 species (4 native) in 1999 and 9 species (2 native) in 2001. The river site had 8 species (2 native) present in 1999 and 9 (2 native) in 2001. Catches in all sites were dominated by prickly sculpin in both 1999 and 2001, except the 1999 river site, which was dominated by sunfish (Figure 3).

The PCA of larvae CPUE for site and year suggested differences related to both factors. The first three components combined explained 80% of the variance (Table 2). The first component had heavy positive loadings on prickly sculpin and Sacramento sucker and a heavy negative loading on bigscale logperch. The second component had heavy positive loadings on sunfish and inland silverside and a heavy negative loading on common carp. The third component had significant positive loading by crappie, with negative loadings on common carp and Sacramento blackfish. From the biplot of species and site scores (Figure 4) it is apparent that the sites were very different between the two years; only Wood Duck Slough was similar in species composition between years. There were three groups of fish within which the species had positive correlations with each other: (1) common carp and splittail, (2) blackfish, golden shiner, and crappie, (3) sunfish, Sacramento sucker and inland silverside (Figure 4).

Comparisons among months

There was a clear temporal pattern in larval fish catch by month (Figure 5). In February, the only fish larvae present were prickly sculpin. Bigscale logperch appeared in March with a few carp, splittail and golden shiners (Figure 5). In April, all species were present, with splittail showing their strongest presence in 1999. In May some early spawners (sculpin and logperch) were less abundant. Splittail abundance was higher in May of 2001 than in 1999 (Figure 5). In late May, blackfish, sunfish, crappie, golden shiner, largemouth bass, and inland silverside became increasingly common in the catches (Figure 5). Sunfish and silversides dominated June catches in both years, although numbers were higher in 2001. In July, sunfish and crappie were the most abundant taxa in 1999, while inland silverside were dominant in 2001 (Figure 5).

The DCA analysis of species abundance by month and year clearly shows this pattern of temporal change (Figure 6). The first two axes of the DCA explained 58% of the variance in the species abundance data (Table 3). The first axes segment length of 3.94 standard deviations shows that species found in February and early March were not present in June and July (Figure 6). The graphical relative abundance data bears this out (Figure 5), although common carp and golden shiner appeared earlier in 2001.

Environmental Variables

The use of the forward selection mode in the CCA analysis ($P < 0.05$) resulted in the retention of 6 variables in the 1999 model and 5 in the 2001 model (Table 4). In 1999, flow, temperature, sand and clay substrate, and terrestrial and emergent vegetation were selected (Figure 7). In 2001 flow, temperature, mud substrate, macrophytes, and filamentous algae were selected (Figure 7). River flow and temperature explained the largest amount of variation among species in both years, although the other environmental variables were also important. Because the first and second axes cumulatively explained the most species variance (28% and 24%, respectively) the third and fourth axes were not interpreted (Table 4). Monte Carlo tests showed that the first axis (1999, F=15.9, p=.005, 2001, F=13.1, p=.005) and the full model (1999, F=7.0, p=.005, 2001, F=5.5, p=.005) were statistically significant.

Although river flow is an indirect measure of inundation of the floodplain it was directly related to flows at the slough and river sites. Temperatures were lower on the floodplain when there was connectivity to the cool waters of the river (Table 5). Conversely, when the river was disconnected from the floodplain there was a dramatic warming effect (Table 6). The timing and magnitude of flow was very different for the two years, changing the number of days that the river was connected to the floodplain (Figure 2). Because of the dramatic difference in river flow between the years, the average temperature in 2001 of 19.7ºC was significantly higher than in 1999 (17.9ºC, t-test, $t = 2.66$, d.f. = 71, $P<0.001$). The types of vegetation were also related to the magnitude of inundation. When flows were high in 1999 the water covered a large amount of terrestrial and emergent vegetation. In 2001, the water came up and receded very quickly into low areas, most of which were ponds or wetlands, with beds of aquatic macrophytes.

Species Composition

The CCA species scores when plotted in relation to environmental gradients (Figure 7), showed patterns that reflect the different conditions on the floodplain in a wet (1999) and dry (2001) year. In 1999, with more extensive flooding in space and time, two species (prickly sculpin and bigscale logperch) were associated with flooded terrestrial vegetation and two species (Sacramento sucker and common carp) were associated with higher flows. Splittail larvae also showed an association with higher flows but were more closely associated with emergent vegetation. Late-season spawners (inland silverside, crappie, and sunfish) show an association with warmer temperatures and the clay substrates of the permanent floodplain ponds, while species with fairly broad spawning times (golden shiner, Sacramento blackfish, and largemouth bass) showed less defined patterns. In 2001, sculpin, sucker, logperch, carp, Sacramento blackfish, golden shiner, and splittail were most abundant when flows were highest but, presumably because of the limited extent of inundation, did not show strong associations with vegetation types (Figure 7). Silversides, sunfish, largemouth bass, and crappie were associated with higher temperatures present in the disconnected ponds and, to a lesser extent, the macrophyte beds that developed in the ponds.

Discussion

It is clear that each species had a fairly predictable response to flows and temperatures on the floodplain, as indicated by comparisons among sites, changes in abundance through time, and characteristics of the habitats in which the fish appeared. Although the monthly larval fish data shows clear patterns related to flooding regime, on a finer scale larval distribution and abundance on the Cosumnes floodplain is highly variable. Part of the variability results from the spawning sites of the different species. There were three basic types of spawners (Moyle 2002): (1) river spawners whose larvae washed into the floodplain (Sacramento sucker, prickly sculpin), (2) floodplain spawners (Sacramento splittail and common carp), and (3) resident pond or slough fishes that opportunistically spawned in the floodplain areas close to their adult habitats (Sacramento blackfish, golden shiner, sunfishes, crappies). Thus the appearance on the floodplain of each species depended on factors such as connectivity between river and flooplain and temperatures required for spawning.

Comparisons among sites

There were few strong or consistent relationships among species and sites because of the continous expansion and contraction of floodwaters. Most species could be found at all sites at one time or another (Figure 3), although sites closest to levee breaches were most likely to be dominated by larvae (mostly from native species) from river spawning fishes and by larvae of obligate floodplain spawners such as splittail. Highest diversity of species was consistently found in the two sloughs, because they received drainage water from the entire floodplain and also had their own complement of resident species. Some species (e.g., inland silverside, and golden shiner) were found primarily in low lying floodplain ponds and in Middle Slough when these waters were warm and there was little influence from river flow.

Temporal Changes

The clear temporal separation of different groups of species suggests that early season to late season environmental cues were important to the timing larval emergence (Figure 6). Some of the potential cues include flow, temperature, and photoperiod (Robinson et al. 1998, Marchetti and Moyle 2000, Moyle 2002). Flow and temperature together explained the most variation in the abundance of species. Although the pattern is not as clear as in other nearby systems (Marchetti and Moyle 2000, Meng and Matern 2001), in general native larvae appeared early in the season (February-April) and aliens appeared later (April-July) (Figure 8). The fact that 1999 and 2001 were very different in terms of hydrological events (Figure 2) is seen in the timing of emergence of native and alien larval fish. Carp and splittail, for example, appeared a month earlier in 2001 than they did in 1999.

Habitat characteristics

Temperature and flow clearly had the biggest impact on larval fish abundance and resulted in seasonal changes in the distribution and abundance of species. However, catches in light traps were also positively influenced by the presence of dense growths of annual terrestrial vegetation or aquatic macrophytes. Presumably the vegetation was a combination of refuge from predators, shelter from high flows, and source of small invertebrates as food (Holland and Huston 1985, Holland 1986, and Paller 1987). Flooded terrestrial vegetation also served as spawning substrate for floodplain spawning fishes such as splittail and common carp (Moyle 2002). Although not quantified, our observations during this study suggest that dense stands of dead annual plants that occur in open, unforested areas are especially favorable to native species, including splittail.

Native Species

A key reason for this study was to determine how native species use floodplain habitats for rearing in order to develop management strategies to favor them. The four most abundant native fishes were prickly sculpin, Sacramento sucker, Sacramento splittail, and Sacramento blackfish.

Prickly sculpin were the most abundant larvae in every site from February through April. Adults or juveniles were rarely found on the floodplain, so the larvae must have washed in from upstream. The greater abundance of larvae in 1999, when the floodplain was connected more often than in 2001, also suggests this. Just above the levee breaches that carried water into the Cosumnes floodplain the river channel is heavily rip-rapped with boulders. We sampled this area and found densities of adult prickly sculpin to be very high (5-10 fish m^2, unpublished data). Prickly sculpin spawn underneath rocks and have an extended spawning season, producing large numbers of pelagic larvae (Moyle 2002). Thus, they can send a continuous stream of larvae onto the floodplain as long as there is connection between the river and the floodplain. However, the importance of floodplain as a rearing habitat for prickly sculpins is not known; it is possible that it is a 'sink' for the larvae because we collected relatively few juveniles during an associated weekly beach seine study (P. Crain, unpublished data) and have no evidence of strong outward movement of young fish in fyke net catches set in outflow channels (P. Crain, unpublished data).

Sacramento sucker were most abundant in the Middle Slough and river sites, but some were also found on floodplain sites. The larvae presumably originated from the large numbers of suckers that moved up into the river to spawn from the nearby estuary, beginning in January. In a study of North Delta fishes, just downstream of the floodplain, sucker numbers were dramatically reduced in winter sampling and large numbers of suckers were observed in the tidal areas of the lower Cosumnes River in December (P. Crain, unpublished data). While juvenile suckers were collected later in the season, they were most abundant in the river itself and not on the floodplain. Therefore the overall importance of the floodplain to sucker populations is not known but is not likely to be high.

Sacramento splittail, a federally threatened species, used the floodplain in both years, but was most abundant in 1999 (Table 1). Splittail spawned on flooded vegetation even in 2001, when only a portion of the floodplain was flooded for a limited amount of time (P. Crain, unpublished data). Based on the initial appearance of larvae, spawning mostly took place in the last week of March or first week in April. This is about the same time that temperatures on the floodplain reached 17-20°C (Table 6). The larvae grew quickly and the small juveniles usually moved off the floodplain in the last week of April or first week in May, when short pulses of cold water, from rain or snow melt, reconnected the floodplain to the river for brief periods (unpublished data).

Sacramento blackfish are different from most native fish species in that they spawn late in warmer water. Blackfish larvae first appeared in our samples in late April, although the majority of juveniles were caught in our beach seine study in May (P. Crain, unpublished data). This is also about the time the river disconnected from the floodplain entirely, so the fish persisted only in permanent water that also contained abundant alien species.

Conclusions

Use of the Cosumnes River floodplain by native and alien fishes was related to inflowing flood waters and the lower temperatures that accompanied it. This study suggests that floodplains were historically important for rearing of native fishes, such as splittail, although their importance to river-spawning species, such as Sacramento sucker and prickly sculpin, and native species resident in sloughs, such as blackfish is poorly understood. Today floodplains seem to be important for native fishes mainly early in the season (February-April) (Figure 8) because warmer temperatures and lower flows later in the season favor alien species, especially those that are permanent residents in ponds, ditches, and sloughs on the floodplain. By summer, the only fishes appearing as larvae are alien fishes, especially inland silversides and centrarchids. However, some alien species, especially common carp, have spawning habits very similar to native species and also benefit from early season flooding.

Another important observation is that larval fishes in the main floodplain were secondarily associated with flooded annual vegetation in 1999. This suggests that unforested fields of annual vegetation may be useful for larval rearing because of the abundance of food and cover. Larval fish use of forested habitats, however, has not yet been adequately studied. Presumably the historic floodplains of the Central Valley were a mosaic of forested and open habitats, so would have provided plenty of rearing habitat regardless. Overall, our observations suggest that management of recreated floodplains, such as the Cosumnes River, should involve strong emphasis on (1) flooding in February-April, with rapid draining thereafter, (2) reduction in permanent habitats that support resident alien fishes, and (3) maintenance of habitat mosaics that keep large expanses of annual vegetation available for flooding.

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Figure Captions

Figure 1 Cosumnes River floodplain study site, showing locations of principal sampling areas.

Figure 2. Hydrograph for the Cosumnes River (1996-2002), showing flows at which the floodplain becomes connected to the river. Bottom: Numbeer of days floodplain was connected to the river (pale bars, 1995-2002) and number of days of major floods that actively changed floodplain topograpy (dark bars).

Figure 3. CPUE of larval fishesfor 1999 and 2001. Species codes are as follows: PSC prickly sculpin, SKR Sacramento sucker, SBF Sacramento blackfish, SST Sacramento splittail, SSP sunfish, LMB largemouth bass, CSP crappie, CRP common carp, GSH golden shiner, BSLP bigscale logperch, ISS inland silverside.

Figure 4. Principal component analysis biplot of larval fish CPUE defined by site and year. Species codes are the same as Figure 3. Native species are in bold type.

Figure 5. Detrended correspondence ordination plot of larval fish CPUE by month. Species codes are the same as Figure 3. Native species are in bold type.

Figure 6. Bar graph of species CPUE by month for 1999 and 2001. Species codes are the same as Figure 3.

Figure 7. Canonical correspondence ordination diagram showing larval fishes relationships to environmental gradients. Species codes are the same as in Figure 3. Native species are in bold type.

Figure 8. Percent native and alien species larvae by month, with 1999 and 2001 combined.

Table 1.__Average CPUE (larvae/illumination hour) and annual percent composition of larval fish species caught in 1999 and 2001. Native and alien species are denoted by (N) and (A). Percentages of all species were rounded to the nearest whole number. Number of species indicates the number of fish species caught in that year. Months are those in which spawning took place (2 =Feb., 3 = Mar. etc.); Bold equals month of highest CPUE.

Variable	1999	2001	Total	
Total Light Trap Hours	116	104	220	
Average CPUE[a]	66	56	62	
Number of species	12	14	14	
Species	N (%)	N (%)	N (%)	Months
Prickly sculpin				
Cottus asper (N)	54 (84)	35 (62)	45 (73)	2, **3**, 4, 5
Sacramento sucker				
Catostomus occidentalis (N)	2.3 (3)	2.4 (4)	2.3 (4)	**4**, 5
Sacramento blackfish				
Orthodon microlepidotus (N)	1.0 (2)	0.5 (1)	0.8 (1)	**4**, **5** , 6
Sacramento splittail				
Pogonichthys macrolepidotus (N)	0.6 (1)	0.3 (1)	0.5 (1)	3, **4**, **5**
Sunfish[b] (A)	1.0 (1)	6.4 (12)	3.5 (6)	5, **6**, 7
Largemouth bass				
Micropterus salmoides (A)	0.2 (<1)	0.7 (1)	0.4 (1)	4, **5,** 6, 7
Crappies[c] (A)	1.4 (2)	1.7 (3)	1.5 (3)	3, **4**, **5**, **6**, **7**
Common carp				
Cyprinus carpio (A)	3.2 (5)	1.7 (3)	2.5 (4)	3**,4, 5,** 6
Golden shiner				
Notemigonus crysoleucas (A)	1.1 (2)	0.4 (1)	0.7 (1)	3**, 4,** 5, 6
Bigscale logperch				
Percina macrolepida (A)	1 (2)	3.2 (6)	2.1 (3)	**3**, 4, 5
Inland silversides				
Menidia beryllina (A)	0.4 (1)	3 (5)	1.6 (3)	4**, 5,**6, 7

[a]Rare species not included in this analysis: threadfin shad *Dorosoma petenense*, American shad *Alossa sapidissima*, western mosquitofish *Gambusia affinis*, and wakasagi *Hypomesus nipponensis*. [b]Sunfish include: bluegill *Lepomis macrochirus*, and redear sunfish *Lepomis*

microlophus. [c]Crappies include: white crappie *Pomoxis annularis*, and black crappie *Pomoxis nigromaculatus*

Table 2. PCA component loadings for fish species data summarized by site and year. Native species are in bold type. An asterisk indicates a heavy loading with the component.

	Component Loadings		
Species or correlation	1	2	3
Prickly sculpin	0.94*	-0.31	-0.09
Common carp	-0.18	-0.55*	-0.74*
Sacramento splittail	-0.17	-0.37	-0.19
Sacramento blackfish	0.23	-0.46	-0.49*
Sacramento sucker	0.48*	0.35	-0.36
Sunfish	0.46	0.84*	-0.12
Largemouth bass	0.01	0.05	-0.23
Crappies	0.43	-0.39	0.75*
Golden shiner	0.33	-0.36	0.47
Bigscale logperch	-0.52*	-0.06	-0.22
Inland silverside	0.24	0.82*	-0.09
Eigenvalue and explained variance			
Eigenvalue	3.70	2.80	1.40
Culmulative percent of variance explained	37.20	65.20	79.00

Table 3. Results of detrended correspondence analysis run on data defined by CPUE (catch per unit effort) of a species by month and year. Shown are the eigenvalues, length of gradient, and the percentage of variance explained by the species data by each axes.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.668	0.103	0.013	0.003	1.227
Lengths of gradient:	3.94	1.55	0.95	0.91	
Percent variance	51.38	57.73	58.08	57.83	
Sum of all unconstrained eigenvalues					1.227

Table 4. Results of canonical correspondence analysis run on environmental variables and larval fish abundance data (CPUE) collected on the Cosumnes River floodplain in 1999 and 2001. Shown is the CCA summary table for the first three ordination axis, canonical regression coefficients, and inter-set correlations for the standardized environmental variables with the first two ordination axes.

1999				Canonical coefficients		Inter-set correlations	
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 1	Axis 2
Eigenvalues	0.558	0.353	0.091				
Species-environment	0.880	0.787	0.542				
Cumulative percentage variance							
Species data	16.9	27.6	30.4				
Species -environment relation	48.2	78.6	86.5				
Flow				-0.608	-0.612	-0.777	-0.255
Temperature				0.370	-0.865	0.613	-0.417
Sand substrate				0.075	-0.255	0.033	-0.353
Clay substrate				0.235	0.291	0.440	0.259
Terrestrial vegetation				-0.206	0.230	-0.356	0.201
Emergent vegetation				-0.022	-0.197	-0.082	-0.300

2001				Canonical coefficients		Inter-set correlations	
	Axis 1	Axis 2	Axis 3	Axis 1	Axis 2	Axis 1	Axis 2
Eigenvalues	0.592	0.217	0.125				
Species-environment	0.915	0.713	0.584				
Cumulative percentage variance							
Species data	17.7	24.2	27.9				
Species -environment relation	57.0	77.9	90.0				
Flow				-0.844	-0.481	-0.886	-0.155
Temperature				0.215	-0.424	0.609	-0.167
Mud substrate				-0.008	-0.219	-0.045	-0.320
Macrophytes				0.180	-0.911	0.156	-0.592
Filamentous algae				-0.064	0.284	-0.124	-0.146

Table 5. Physical characteristics of Cosumnes River floodplain sites sampled for larval fish in 1999 and 2001. Mean river flow (m3sec-1), temperature (degrees Celsius), conductivity (uS), secchi (cm), depth (cm), and range of values in parentheses for all sites in both years.

	1999 Sites					
Characteristic	Floodplain 1	Ditch	Floodplain 2	Wood Duck S.	River	Middle S.
River Flow	35 (22-60)	24 (5-45)	31 (21-49)	29 (31-60)	46 (.31-374)	44 (.31-374)
Temperature	17 (13-26)	16 (11-20)	20 (10-29)	19 (12-29)	16 (9-26)	16 (9-26)
Conductivity	115 (2-247)	112 (61-191)	105 (66-234)	161 (67-741)	104 (38-248)	125 (77-256)
Secchi	51 (25-85)	77 (22-120)	49 (23-78)	34 (10-48)	54 (15-87)	47 (20-70)
Depth	51 (39-62)	66 (46-84)	50 (40-63)	56 (44-75)	55 (45-72)	61 (45-110)

	2001 Sites					
Characteristic	Floodplain 1	Ditch	Floodplain 2	Wood Duck S.	River	Middle S.
River Flow	9 (1-23)	No Data	12 (7-18)	10 (1-26)	10 (1-26)	9 (1-26)
Temperature	22 (11-30)		21 (16-31)	20 (11-28)	20 (10-28)	20 (11-29)
Conductivity	150 (102-253)		126 (106-155)	171 (67-487)	100 (56-258)	177 (104-273)
Secchi	37 (10-71)		31 (9-47)	34 (1-72)	49 (5-81)	41 (12-90)
Depth	53 (42-63)		54 (42-72)	56 (40-103)	54 (38-80)	51 (36-84)

Table 6. Mean temperatures with range (degrees Celsius), by site and month.

1999	Feb	Mar	Apr	May	Jun	Jul
Floodplain 1	15 (10 - 17)	20 (16 - 23)	18 (15 - 21)	22 (19 - 26)	No Data	No Data
Ditch	No Data	13 (11 - 14)	15 (11 - 18)	17 (16 - 18)	19 (17 - 20)	No Data
Floodplain 2	No Data	15 (10 - 17)	20 (16 - 23)	24 (19 - 30)	No Data	No Data
Wood Duck Slough	12 (12 - 12)	14 (13 - 15)	17 (13 - 21)	21 (17 - 26)	25 (21 - 29)	25 (23 - 28)
River	10 (9 - 11)	11 (10 - 12)	14 (11 - 17)	18 (15 - 21)	24 (22 - 25)	22 (19 - 25)
Middle Slough	10 (9 - 12)	12 (10 - 14)	15 (12 - 18)	19 (16 - 22)	24 (22 - 26)	22 (21 - 23)

2001	Feb	Mar	Apr	May	Jun	Jul
Floodplain 1	11 (11 - 11)	17 (14 - 21)	18 (16 - 25)	26 (20 - 30)	26 (24 - 28)	26 (26 - 26)
Floodplain 2	No Data	17 (13 - 22)	19 (16 - 24)	26 (22 - 31)	No Data	No Data
Wood Duck Slough	11 (11 - 11)	17 (12 - 19)	17 (14 - 22)	23 (19 - 26)	25 (23 - 28)	27 (27 - 27)
River	10 (10 - 10)	16 (12 - 19)	16 (14 - 19)	22 (18 - 24)	26 (24 - 28)	27 (27 - 27)
Middle Slough	11 (11 - 11)	15 (12 - 20)	16 (15 - 16)	20 (17 - 23)	26 (25 - 29)	28 (28 - 28)

Figure 1

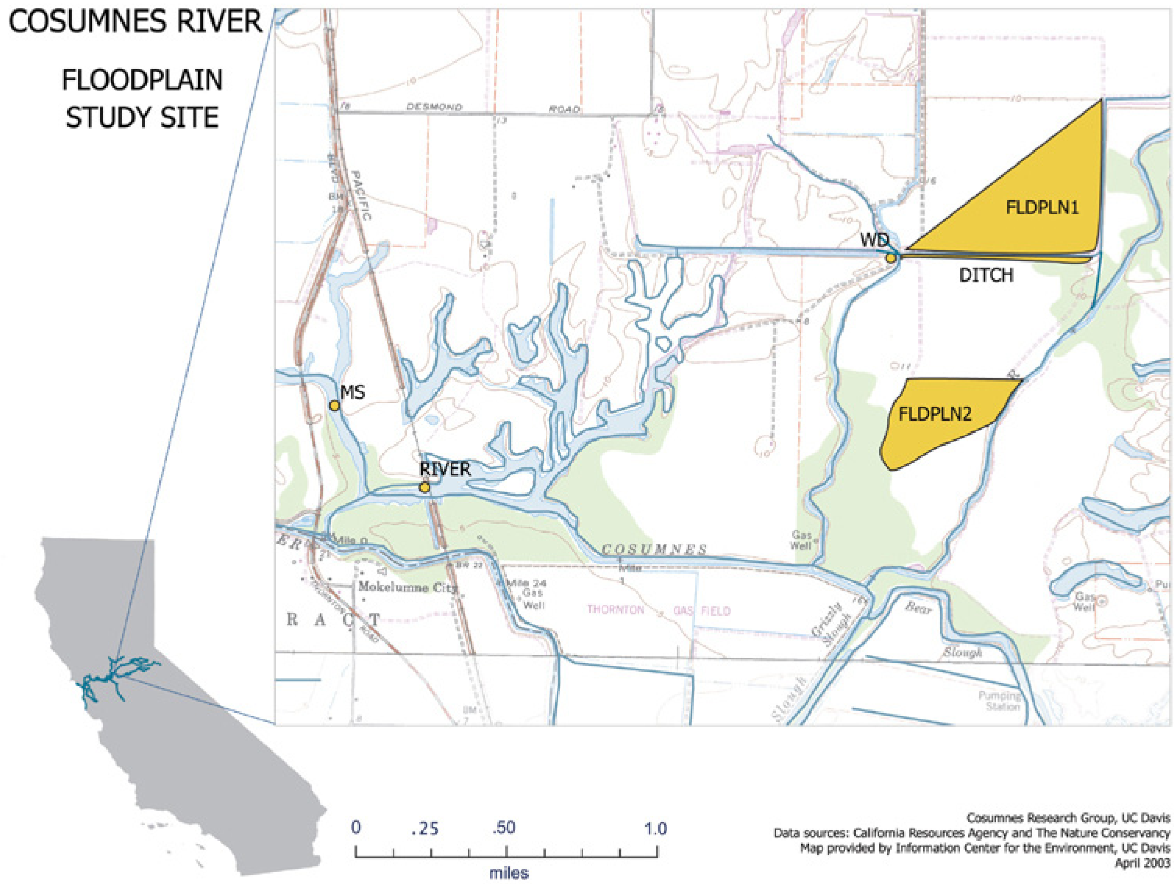
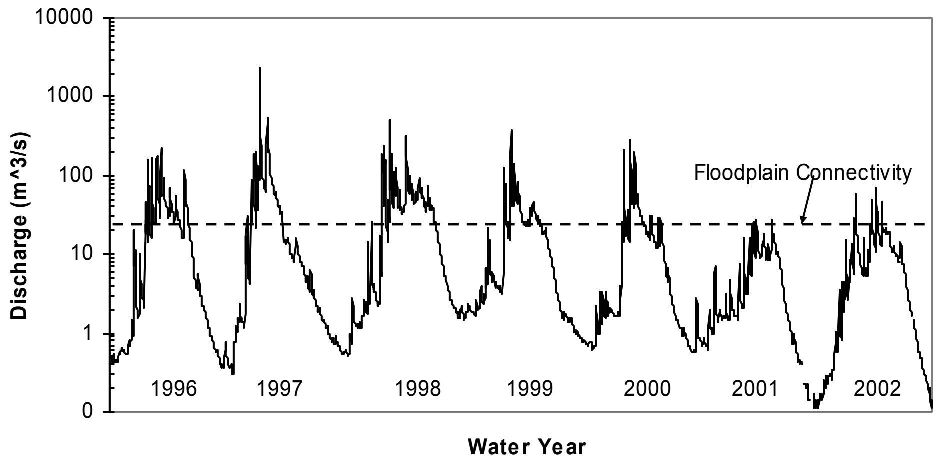

COSUMNES RIVER
FLOODPLAIN STUDY SITE
FLDPLN1
WD
DITCH
MS
FLDPLN2
RIVER
COSUMNES
Mokelumne City
THORNTON GAS FIELD
DESMOND ROAD
PACIFIC
Bear
Slough
Pumping Station
0
.25
.50
1.0
miles
Cosumnes Research Group, UC Davis
Data sources: California Resources Agency and The Nature Conservancy
Map provided by Information Center for the Environment, UC Davis
April 2003

Figure 2


10000
1000
100
10
1
0
Discharge (m^3/s)
Floodplain Connectivity
1996
1997
1998
1999
2000
2001
2002
Water Year

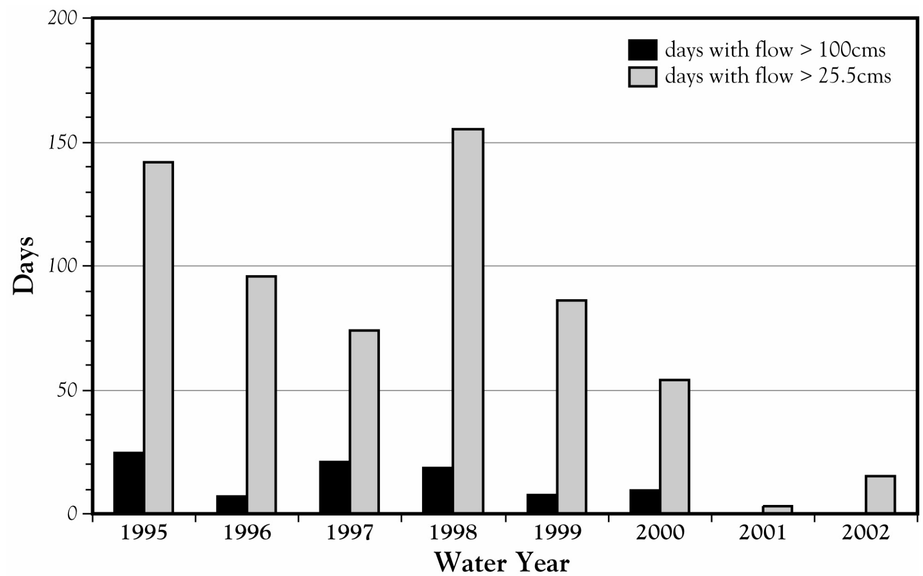

200
150
100
50
0
Days
days with flow > 100cms
days with flow > 25.5cms
1995
1996
1997
1998
1999
2000
2001
2002
Water Year

Figure 3

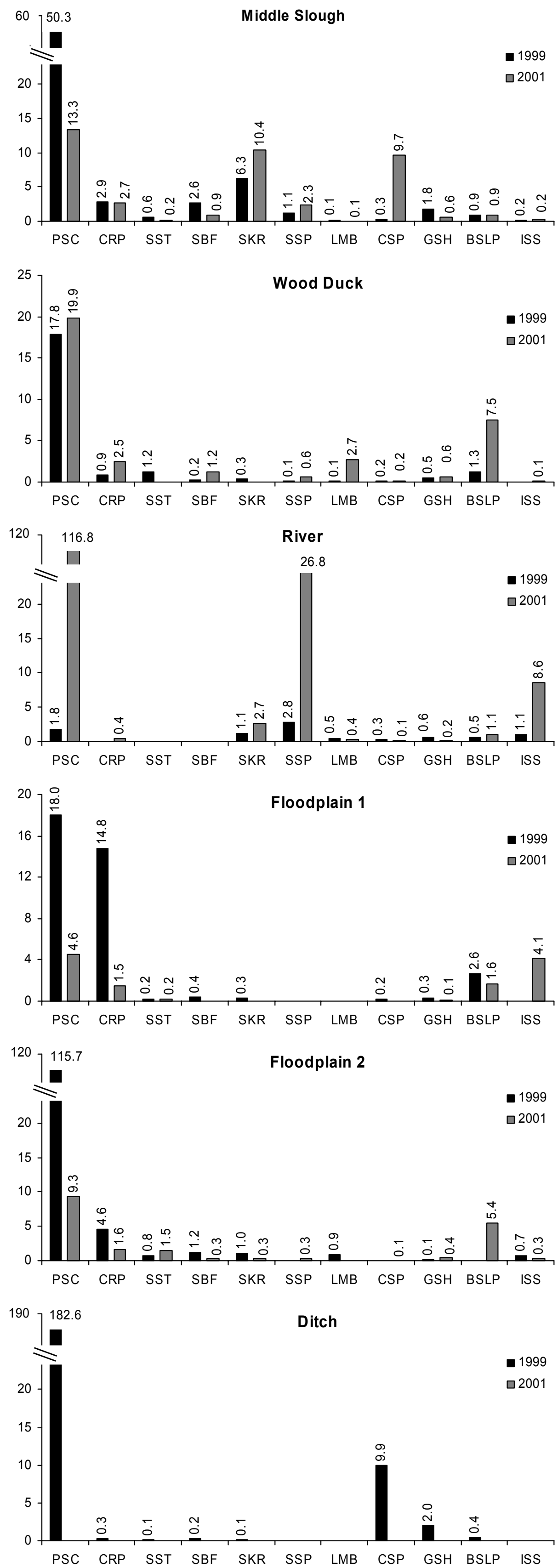

Middle Slough
Wood Duck
River
Floodplain 1
Floodplain 2
Ditch
1999
2001
PSC
CRP
SST
SBF
SKR
SSP
LMB
CSP
GSH
BSLP
ISS

Figure 4

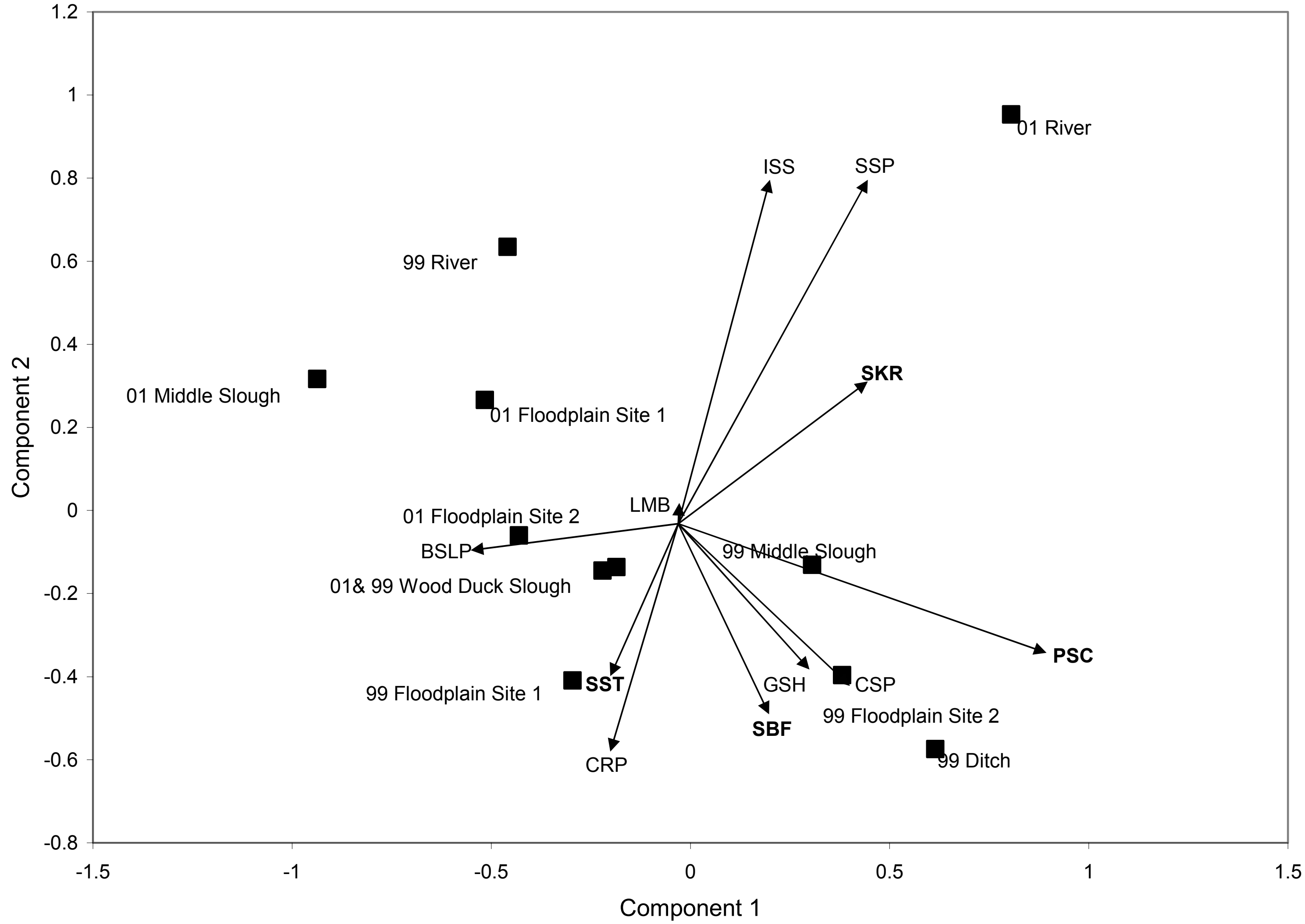

1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Component 2
-1.5
-1
-0.5
0
0.5
1
1.5
Component 1
01 River
ISS
SSP
99 River
SKR
01 Middle Slough
01 Floodplain Site 1
LMB
01 Floodplain Site 2
BSLP
99 Middle Slough
01& 99 Wood Duck Slough
PSC
99 Floodplain Site 1
SST
GSH
CSP
99 Floodplain Site 2
SBF
CRP
99 Ditch

Figure 5

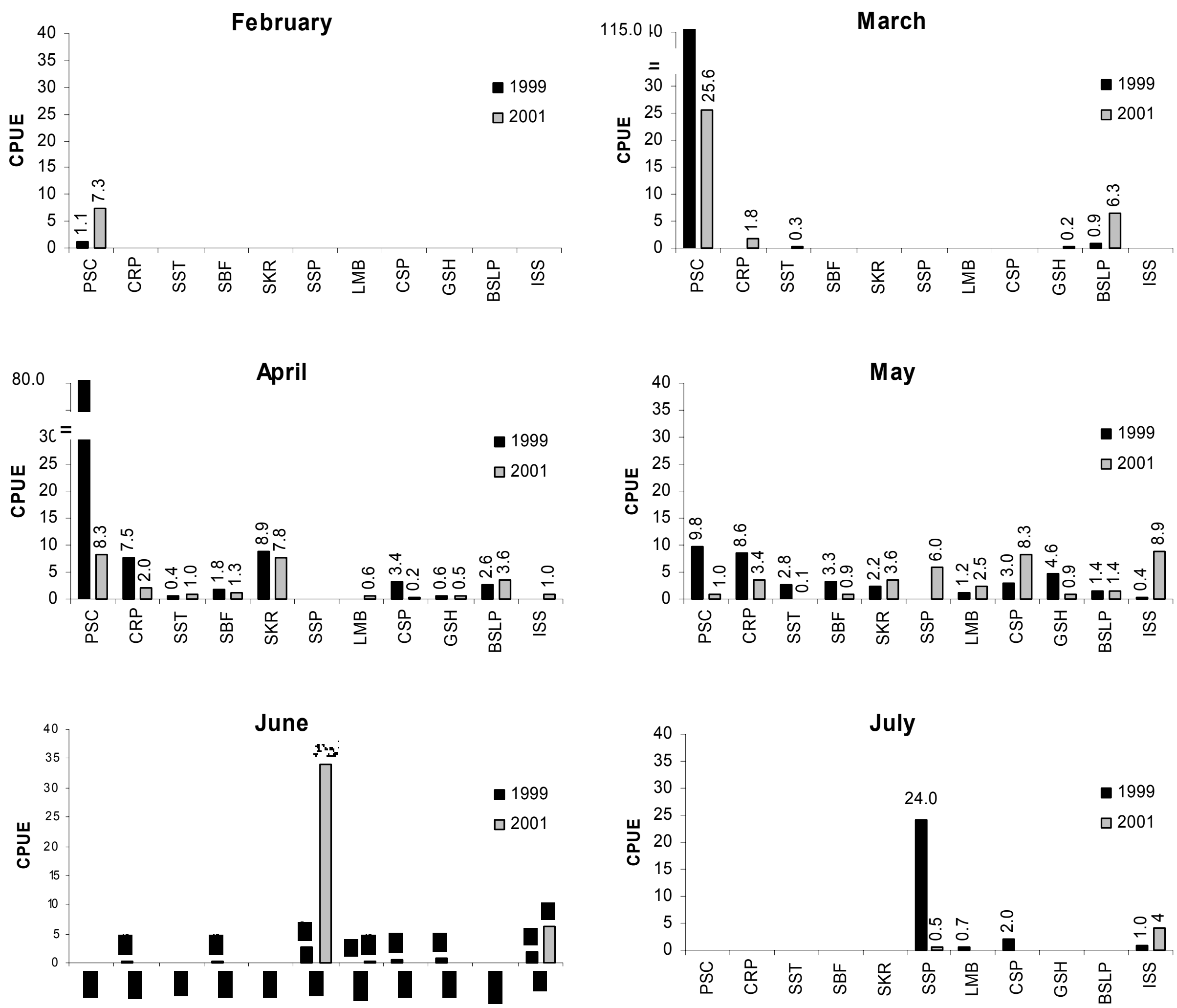

February
March
April
May
June
July
CPUE
1999
2001
PSC CRP SST SBF SKR SSP LMB CSP GSH BSLP ISS
1.1 7.3
115.0 25.6 1.8 0.3 0.2 0.9 6.3
80.0 8.3 7.5 2.0 0.4 1.0 1.8 1.3 8.9 7.8 0.6 3.4 0.2 0.6 0.5 2.6 3.6 1.0
9.8 1.0 8.6 3.4 2.8 0.1 3.3 0.9 2.2 3.6 6.0 1.2 2.5 3.0 8.3 4.6 0.9 1.4 1.4 0.4 8.9
24.0 0.5 0.7 2.0 1.0 4

Figure 6

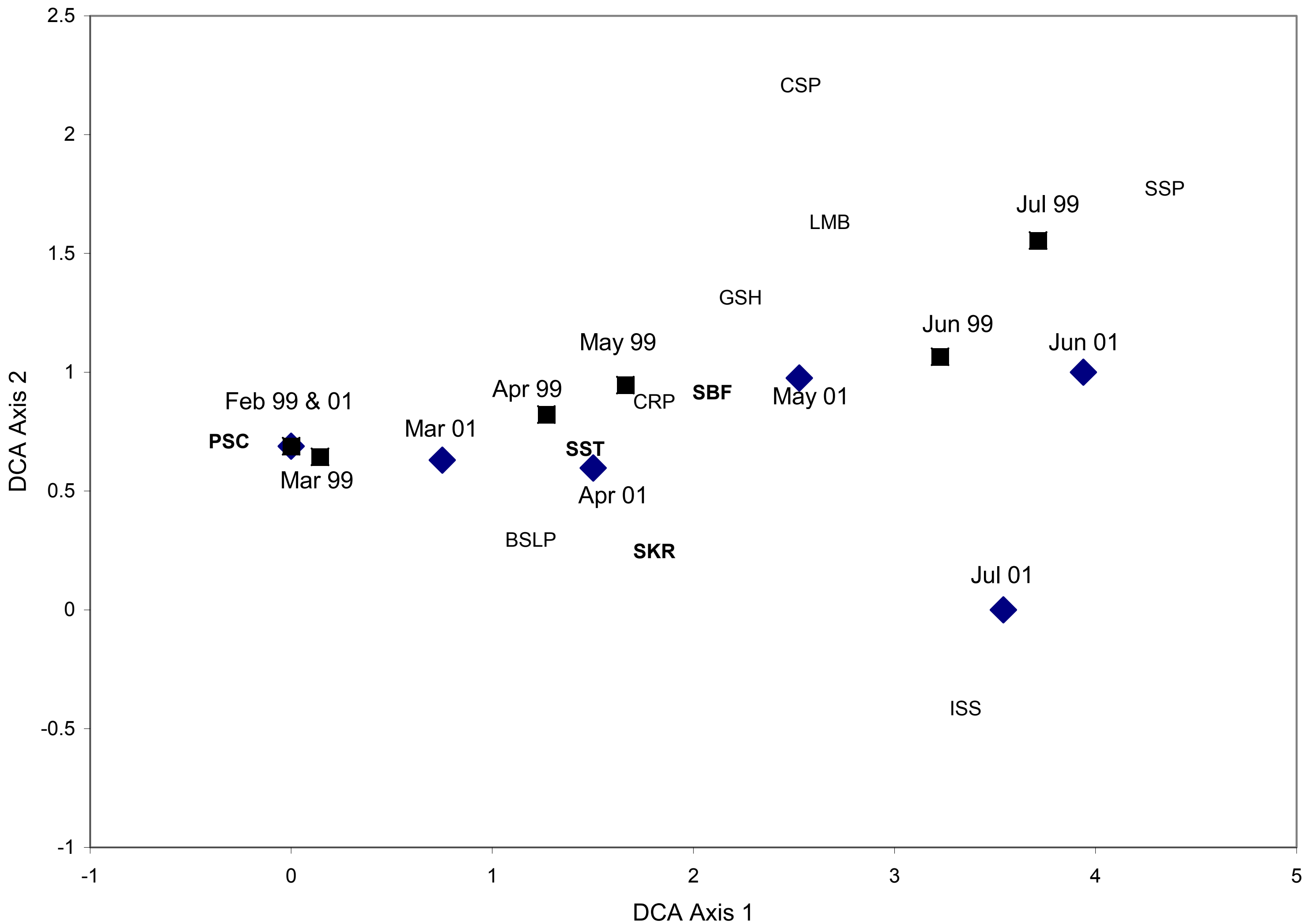
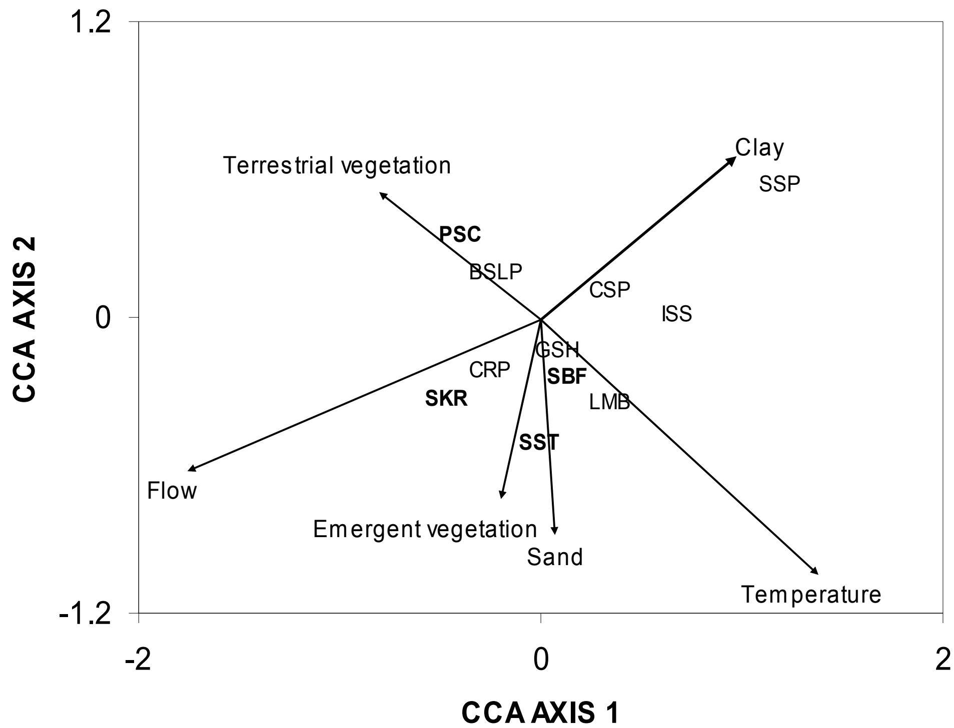

2.5
2
1.5
1
0.5
0
-0.5
-1
-1
0
1
2
3
4
5
DCA Axis 2
DCA Axis 1
CSP
SSP
Jul 99
LMB
GSH
Jun 99
Jun 01
May 99
Apr 99
SBF
May 01
CRP
Feb 99 & 01
Mar 01
PSC
SST
Mar 99
Apr 01
BSLP
SKR
Jul 01
ISS

Figure 7


1.2
0
-1.2
-2
0
2
CCA AXIS 2
CCA AXIS 1
Clay
SSP
Terrestrial vegetation
PSC
BSLP
CSP
ISS
GSH
CRP
SBF
SKR
LMB
SST
Flow
Emergent vegetation
Sand
Temperature

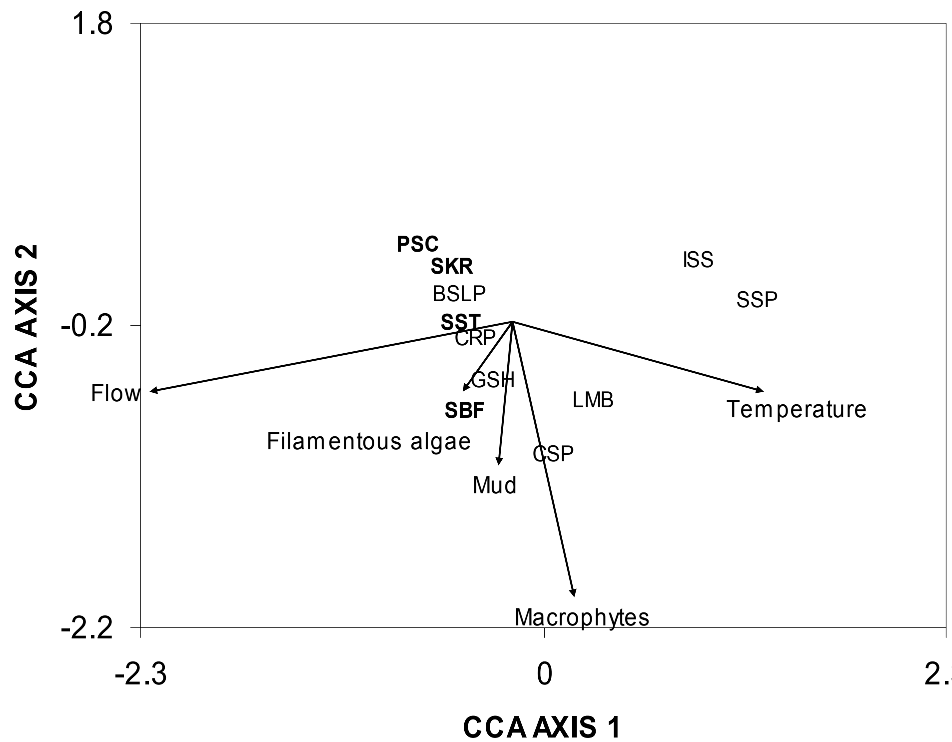
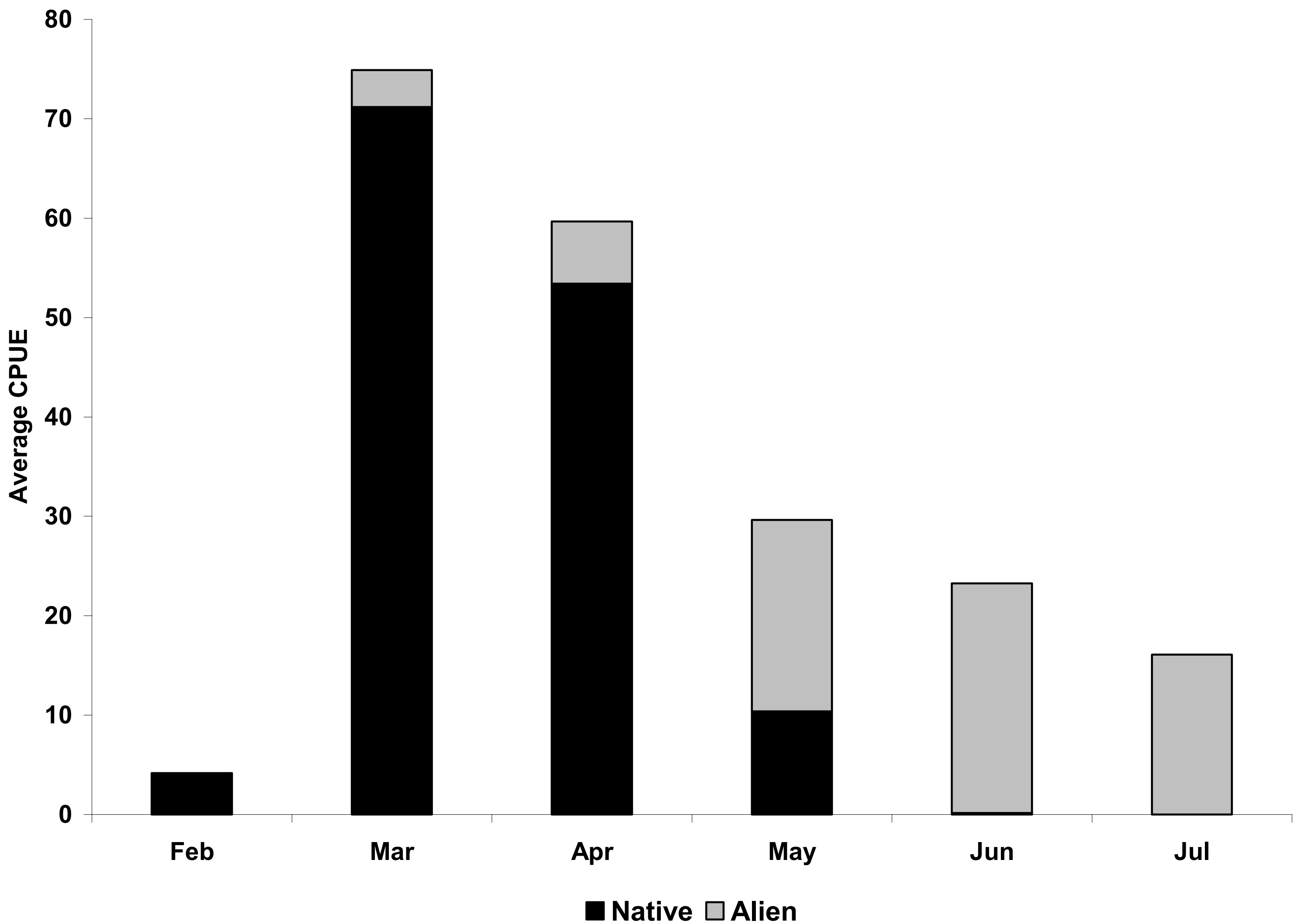

1.8
-0.2
-2.2
-2.3
0
2.3
CCA AXIS 2
CCA AXIS 1
PSC
SKR
BSLP
SST
CRP
ISS
SSP
Flow
GSH
SBF
LMB
Temperature
Filamentous algae
CSP
Mud
Macrophytes

Figure 8


80
70
60
50
40
30
20
10
0
Average CPUE
Feb
Mar
Apr
May
Jun
Jul
Native
Alien