# Survey of fish and their diets surrounding the McCormack-Williamson Tract (2000-2001) 

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#### Abstract

We surveyed eleven sites around the McCormack-Williamson Tract on a quarterly basis during 2001 and 2002. The purpose of the study was to develop baseline fisheries data so that informed restoration strategies could be developed. Using boat electrofishing we captured 5,362 fish, bluegill, redear sunfish, and largemouth bass made up 70\% of the total fish caught. Sacramento sucker were the only native fish caught in significant numbers ( $4 \%$ of the total), while all other native fish accounted for less than $1 \%$ of the total catch. Redeye bass a species not recorded in the North Delta previously was found in low numbers in this survey. Site similarities and differences measured with Principal Components Analysis on CPUE/Site grouped sites into three basic groupings explaining 84\% of the variance in CPUE. Species abundance in relation to environmental variables was analyzed using Canonical Correspondence Analysis. The model chosen used four variables that explained $25 \%$ of species abundance using the first and second axis. Analysis of the seasonality of abundances using Friedman's ANOVA resulted in four species having significant seasonality to their abundances. Two of the species were migratory salmonids, and two were shad species. Diets of the more abundant fishes were analyzed showing a predominately benthic driven food web with some epibenthic and phytal components. Restoration strategies for MWT should focus on migratory natives like splittail and juvenile Chinook salmon. This could best be done by using strategies aimed at creating seasonal floodplain habitat.


## Introduction

The Sacramento-San Joaquin Delta is one of the most highly modified ecosystems in the world. It is estimated that over 95\% of the original fresh-water wetlands in this system have been leveed causing them to lose their connection to tidal and floodwater inundation (Brown 2003, Simenstad 2000). One of the primary goals of the CALFED Ecosystem Restoration Program is the restoration of "ecosystem health" to the Delta. To accomplish this CALFED has proposed to breach levees surrounding some Delta islands, thus allowing tidal and floodwater inundation to be restored. It was thought that the creation of shallow water habitat would enhance native fish populations through the creation of food resources, spawning, rearing, and predator refugia habitat. However, the responses of alien fishes and their interactions with natives in this new habitat are not well known. Few published Delta fish studies have discussed the relationship between freshwater wetlands and fish populations Brown (2003) reviews what is known about this relationship and presents models of key processes.

We studied the fish fauna in the different habitat types around the McCormack Williamson Tract quarterly in 2001 and 2002. The goals of the project were (1) to establish baseline knowledge of fish species and their associations with habitat and water conditions and (2) look at diets of prominent fishes to examine dominant food items and food web structure. This baseline study emphasizes documentation of life histories of species of concern and the role that the new habitat will have on invasive, non-native fishes. This in turn should allow us to develop strategies to enhance native fish rearing and survival.

## Study Area

The McCormack Williamson Tract (herewith referred to as MWT) is a 648ha levied island that is located in the north east corner of the Sacramento-San Joaquin Delta in Central California ~2.2km downstream of the confluence of the Cosumnes and Mokelumne Rivers (Figure 1). It
historically supported tidal freshwater marsh and floodplain habitats, but has been completely leveed and drained so that it could be farmed. In its current state the interior topography ranges from -. 9m to 1.5 m ASL in elevation, so that if the levees are removed it would become a mosaic of subtidal, intertidal, and supratidal habitats. The waters that surround the MWT are all tidally influenced and include channeled riverine habitat, open sloughs, and backwater sloughs. Sites surrounding the MWT were chosen to be representative of these different habitats and the number within each habitat was representative of the habitat's size. Two sites were chosen in Lost Slough, which is a backwater slough on the north side of MWT. Lost Slough is somewhat reminiscent of the Delta in its natural state, with an intricate weave of channels, islands, and backwaters on its north side. In stark contrast to the north side, the south side consists of a leveed mud bank along MWT. Large amounts of woody debris have accumulated on both sides from the extensive willow-cottonwood riparian forests on the north side of the slough. Another prominent feature is the extensive submerged aquatic vegetation (SAV), which during the summer envelops the whole slough except for the deepest portion of the channel. The principal SAV is the invasive Brazilian waterweed (Egeria densa) that has been linked to the dominance of alien fishes in the system (Freyer 2002, Simenstad et al. 2000). Four sites were chosen in Snodgrass Slough, which borders the West Side of MWT. Snodgrass Slough is similar to Lost Slough, but has wider channels and more tidal current velocity moving through it. The channels within Snodgrass are deeper and thus the SAV is more confined to its edges as is the woody debris. The levy forming the MWT side of the slough is riprapped and trees and bushes protrude into the slough from the levy edge. The sites furthest south (Snodgrass $3 \& 4$ ) are levied on both sides and are basically large channels with some woody debris, SAV, and tules in the littoral zone. Dead Horse Cut is very similar to the lower sites in Snodgrass Slough except the channel is much narrower where it enters the North Fork of the Mokelumne River, which creates very
high tidal current velocities. Railroad Slough is located in the Delta Meadows State Park adjacent to the MWT and is very similar to the Lost Slough sites in vegetation and woody debris.


The Delta Current Ecosystem

Figure 1. Map of the Sacramento-San Joaquin Delta (Delta) showing position of McCormack Williamson Tract. Map modified from Bay Institute (TBI).


Figure 2. Eleven labeled sites surrounding the McCormack Williamson Tract

The main difference was a large expanse of reeds on one side of the site and higher tidal current influence. The three sites on the Mokelumne River on the south side of MWT are typical of many river channels in the Delta and Sacramento and San Joaquin River systems. Much of the channel edges were rip-rapped, or had mud banks along the edges of the three sites. The slope of the banks was generally quite steep, allowing for little or no littoral habitat along the edges. There was some inundation of tree branches, patches of woody debris, and small patches of SAV where small mud shelves allowed its growth. Tidal currents were generally higher than in the sloughs because of the constriction of water flow into smaller channels and, because the channels were generally deeper.

## Methods

## Field Methods in Electrofishng

Eleven sites were sampled on a quarterly basis, starting in January of 2000 through January of 2002 (Figure 2). Initially boat electrofishing and otter trawling were both used to sample sites around the MWT. Otter trawling was dropped from the study after two quarters because of the low diversity, abundance in catches, and the substantial amount of trawling gear that was lost
due to large amounts of woody debris in the main channels. Electrofishing surveys were conducted with a 4.7 m GSIII aluminum johnboat with a 15-hp Yamaha 4-stroke outboard. The boat was modified with a bow railing, two forward 1.83 m Smith-Root mini-booms supporting SAA-6 anode arrays, and a spring mounted cathode array bar mounted under the bow. A SmithRoot 5.0 GPP shore unit mounted to offset the weight of the bow powered the arrays. In each site one complete pass was made over littoral and channel habitats. As fish were caught they were transferred to a holding tank where they were held until the whole site had been covered. At the end of each site the number of shocking seconds was recorded so that a fish/sec-min CPUE could be calculated. Fish were identified to species and the standard length was recorded. A few fish were preserved in 5\% buffered formalin for later diet analysis. Water quality measurements made within each site included: (1) water clarity, (2) temperature, (3) and conductivity. We measured water clarity with a DRT-15 CE turbidimeter, while temperature and conductivity were measured with a Hanna HI 991300 multimeter. Habitat measurements included: (1) length, (2) mean width from 3 shots with a Bushnell Yardage Pro 600, (3) average depth from 15 equally spaced measurements with a Depthmate portable sounder, (4) maximum depth from the max depth recorded from the average depth measurements, (5) tide height measured at New Hope gauging station, (6) percent of water visually occupied by SAV, woody debris, bushes-trees, or open channel (7) whether the tide was moving in, out, or was slack.

## Diet Methods

Fish were collected during 2002 from Lost Slough and Snodgrass Slough for diet analysis. Species collected for diet analysis included black crappie, bluegill, redear sunfish, largemouth bass, warmouth, yellowfin goby, inland silverside, golden shiner and rainbow trout. Fish were killed with a blow to the head and then preserved in $10 \%$ buffered formalin until they were dissected. Prior to dissection each fish was washed off with water, patted dry with a fresh paper
towel, weighed to the nearest tenth of a gram, and measured to standard length. Fish were dissected using a scalpel and/or scissors. The stomachs were removed from centrarchid species and the foregut was removed from other species with a cut at the first bend of the gut. A visual estimation of the fullness of the stomachs and fore guts was recorded categorically with ' 0 ' meaning empty, ' 1 ' meaning $1 \%$ to $25 \%$ full, ' 2 ' meaning $26 \%$ to $75 \%$ full, ' 3 ' meaning $76 \%$ to $99 \%$ full, and ' 4 ' meaning completely full. Each stomach and fore gut was weighed before the contents were removed and the content of each was then weighed separately. Stomachs, fore guts and contents were weighed to the nearest tenth of a gram.

Organisms removed from each stomach and fore gut were mixed with water identified, measured, counted and estimated for percent volume of total gut content under a Baush and Lomb 40X dissection scope. Organisms were identified to the level of family for amphipods, order for copepods, family or genus for cladocerans, order for insects (except for families Chironomidae and Corixidae), and to furthest level possible or useful for other groups. A miscellaneous category (gorp) was created to include algae, woody debris, and animal material too digested to be identified. Insects, amphipods, copepods, shrimp and similar organisms were measured from base of head to end of body (not including a tail if present). Snails, clams, ostracods and similar organisms were measured at longest carapace length. Cladocerans were measured by total length. Fish were measured by standard length or by total length of fragment if not whole. Annelids were measured by total length of whole body or fragment. No more than 10 of any group of organisms were measured, but all whole organisms were counted. Many organisms were in parts and could not be measured or counted. These were estimated visually by placing the whole organisms and fragments into piles according to taxonomic group, then estimating what percentage of the entire gut contents it equaled. Notes were made if parasitic worms were found in the body cavity or hearts of the fish. To estimate the ages of the fish,
approximately eight scales were taken off each fish from underneath the pectoral fins. These scales were then projected on a Micron XL-10 microfiche screen in order to view and count the rings and determine the number of winters each fish had lived through.

## Statistical analysis

Fish catch data were summarized as number of fish caught per electrofishing minute (CPUE). We analyzed data with principal components analysis (PCA), and canonical correspondence analysis (CCA) using the Canoco 4.0 software program (ter Braak and Smilauer 1998). Patterns of species abundance between sites for both years were examined using PCA. CCA was used to examine the relationship between species abundance and environmental variables. All CPUE data used with Canoco were $\ln (x+1)$ transformed within the program. Species that were not of special concern, or that comprised less than or equal to $1 \%$ of the total catches were excluded from the analysis. Environmental variables described as percentages were Arc sin/ square root transformed. All other environmental data was $\ln (x+1)$ transformed. Friedman ANOVA analysis was used for multiple comparisons of abundance data grouped by season over the two years.

## Diet Calculations

In order to see if size of food items eaten changed with the size of the fish, an average value for prey length was calculated for each fish. Organisms measured from stomach contents were placed into size classes and up to 150 of each taxa were included and an average size for each class was calculated. Ten classes were created and were (1) Amphipoda and Isopoda, (2) Cladocera, (3) Copepoda, (4) Chironomidae larvae, (5) Hemiptera and Coleoptera, (6) Odonata, Mysidacea, Megaloptera and misc. worms, (7) mites and Ostracoda, (8) snails and clams, (9) fish, Palaemonidae, and crayfish, (10) other insects. Next the percentages of each of these classes in individual stomachs were calculated and then a weighted average was used to create a food
length value for each fish. This prey length value was plotted against the standard length of each fish and a trend line was added.

Related to the issue of prey length vs. fish standard length is foraging method. Fish can filter plankton in the water column and at the surface, they can pick off benthic invertebrates from the substrate or they can eat large free-swimming nekton. Percent plankton eaten vs. nekton and benthic invertebrates was used to determine if size of the fish was related to foraging method. Correlations between percent plankton in the diets and standard length were calculated for the species BCR, BGS, LMB, and RES.

## Results

## Catch summary

A total of 5,362 fish were caught representing 31 species, 8 native, and 23 alien to California. All native fishes were found in very low abundance except for the Sacramento sucker Catostomus occidentalis, which made up 4 percent of the total catch. Alien fishes dominated the catch, but were themselves dominated by 3 sunfishes. Ranked 1, 2 and 3 were bluegill (Lepomis machrochirus) redear sunfish (Lepomis microlophus), and largemouth bass (Micropterus salmoides) which together made up 70 percent of the total catch. Two shad species, threadfin shad (Dorsoma petenense) and American shad (Alosa sapidissima) together made up 8 percent of the total catch. Inland silversides Menidia beryllina represented 4 percent of the catch and golden shiners Notemigonus crysoleucas another 2 percent. All of the remaining species (Pacific lamprey Lampetra tridentata, hitch Lavinia exilicauda, Sacramento blackfish Orthodon microlepidotus, Sacramento pikeminnow Ptychocheilus grandis, common carp Cyprinus carpio, black bullhead Ameiurus melas, white catfish Ameiurus catus, channel catfish Ictalurus punctatus, wakasagi Hypomesus nipponensis, Chinook salmon Oncorhynchus tshawytscha, rainbow trout Oncorhynchus mykiss, Western mosquitofish Gambusia affinis, prickly sculpin

Cottus asper, striped bass Morone saxitilis, green sunfish Lepomis cyanellus, warmouth Lepomis gulosus, white crappie Pomoxis annularis, black crappie Pomoxis nigromaculatus, spotted bass Micropterus punctulatus, redeye bass Microptuerus coosae, bigscale logperch Percina macrolepida, tule perch Hysterocarpus traski, yellowfin goby Acanthogobius flavimanus each made up 1 percent or less of the total catches (Table 1).

| Species | Code | N | $\%$ | Rank |
| :--- | :--- | ---: | ---: | ---: |
| Pacific lamprey Lampetra tridentata | PLR | 47 | $<1$ | 14 |
| Threadfin shad Dorosoma pretenense | TFS | 306 | 6 | 4 |
| American shad Alosa sapidissima | AMS | 88 | 2 | 8 |
| Hitch Lavinia exilicauda | HCH | 3 | $<1$ | 26 |
| Sacramento blackfish Orthodon microlepidotus | SBF | 2 | $<1$ | 27 |
| Sacramento pikeminnow Ptychocheilus grandis | SPM | 17 | $<1$ | 20 |
| Golden shiner Notemigonus crysoleucas | GSH | 122 | 2 | 7 |
| Common carp Cyprinus carpio | CRP | 52 | 1 | 13 |
| Sacramento sucker Catostomus occidentalis | SKR | 202 | 4 | 5 |
| Black bullhead Ameiurus melas | BBH | 13 | $<1$ | 24 |
| White catfish Ameiurus catus | WCF | 15 | $<1$ | 23 |
| Channel catfish Ictalurus punctatus | CCF | 19 | $<1$ | 19 |
| Wakasagi Hypomesus nipponensis | WAG | 1 | $<1$ | 30 |
| Chinook salmon Oncorhynchus tshawytscha | CHN | 59 | 1 | 12 |
| Rainbow trout Oncorhynchus mykiss | RBT | 22 | $<1$ | 18 |
| Inland silverside Menidia beryllina | ISS | 195 | 4 | 6 |
| Western mosquitofish Gambusia affinis | MSQ | $* * *$ | $* * *$ | $* * *$ |
| Prickly sculpin Cottus asper | PSC | 26 | $<1$ | 17 |
| Striped bass Morone saxatilis | STB | 79 | 1 | 9 |
| Bluegill Lepomis macrochirus | BGS | 1608 | 30 | 1 |
| Redear Lepomis microlophus | RES | 1476 | 28 | 2 |
| Green sunfish Lepomis cyanellus | GSF | 2 | $<1$ | 27 |
| Warmouth Lepomis gulosus | WRM | 30 | $<1$ | 16 |
| White crappie Pomoxis annularis | WCR | 2 | $<1$ | 27 |
| Black crappie Pomoxis nigromaculatus | BCR | 77 | 1 | 10 |
| Largemouth bass Micropterus salmoides | LMB | 669 | 12 | 3 |
| Spotted bass Micropterus punctulatus | SPB | 76 | 1 | 11 |
| Redeye bass Micropterus coosae | REB | 17 | $<1$ | 20 |
| Bigscale logperch Percina macrolepida | BLP | 10 | $<1$ | 25 |
| Tule perch Hysterocarpus traski | TUP | 17 | $<1$ | 20 |
| Yellowfin goby Acanthogobius flavimanus | YFG | 42 | $<1$ | 15 |

Table 1. List of species caught with, species code, number, percentage of total, and rank. Bolding represents a fish species that are Native to California, *** equals present but ignored because inadequately sampled.

## Comparison among sites

The highest diversity in fishes was found in Dead Horse Cut where 24 species (6 native) were present (Table 1). The Mokelumne River Site 1 and Snodgrass Site 3 each had 23 species (6 native). Snodgrass Slough Site 4 had 22 species (7 native) and Snodgrass Slough Site 1 and Railroad Slough each had 21, with 6 and 5 native species respectively. Snodgrass Slough Site 2 had 18 species (4 native), with Mokelumne River Site 3 and Lost Slough Site 2 having 17 species each. More natives were found in Mokelumne River Site 3 (6 natives), while Lost Slough Site 2 had only 2 . The lowest diversity was found in Lost Slough Site 1 which had only 16 species, 2 of which were natives. The PCA of fish CPUE for sites lumped for both years suggested differences in species CPUE at different sites. The first three components accounted for $86 \%$ of the variance explained by the PCA (Table 2). Inspection of the biplot of site and species scores (Figure 3) indicated that there were gradients in species CPUE around MWT that accounted for high correlation between sites. There were heavy positive loadings (above .7) on the first component by Lost Slough Site 1, Lost Slough Site 2, Railroad Slough., and a heavy negative loading on Snodgrass Slough Site 2. There were heavy positive loadings on the second component by Dead Horse Cut and heavy negative loadings by Mokelumne River Sites 1, 2, 3 and Snodgrass Slough Site 1. There was a heavy positive loading on component 3 by Snodgrass Slough Site 4.

|  | Component loadings |  |  |  |
| :--- | :---: | ---: | ---: | :---: |
| Site or correlation | 1 | 2 | 3 |  |
|  |  |  |  |  |
| Dead Horse Cut | -0.4718 | $0.8158^{*}$ | -0.3121 |  |
| Lost Slough 1 | $0.9193^{*}$ | -0.0575 | -0.2624 |  |
| Lost Slough 2 | $0.8963^{*}$ | 0.0434 | 0.0192 |  |
| Mokelumne River 1 | -0.2058 | -0.6678 | -0.3073 |  |
| Mokelumne River 2 | -0.6493 | -0.6573 | 0.3123 |  |
| Mokelumne River 3 | -0.5743 | $-0.7063^{*}$ | 0.0575 |  |
| Railroad Slough | $0.9643^{*}$ | 0.1589 | 0.0036 |  |
| Snodgrass Slough 1 | -0.3009 | $-0.7435^{\star}$ | -0.2521 |  |
| Snodgrass Slough 2 | -0.6595 | -0.1065 | -0.0057 |  |
| Snodgrass Slough 3 | 0.4820 | 0.2157 | -0.2048 |  |
| Snodgrass Slough 4 | -0.0574 | 0.6368 | $0.7558^{\star}$ |  |
|  |  |  |  |  |
|  |  |  |  |  |

Table 2. PCA component loadings for site abundance data summarized by site over two years. An asterisk indicates a heavy loading with the component.


Figure 3. Principal component analysis biplot of CPUE defined by site over the two years. Species codes are the same as Table 1.

## Comparisons among seasons

Seasonal abundances for both years were examined graphically and differences in CPUE were apparent between seasons for some species. To sort out the significance of the seasons for species Friedman's ANOVA analysis was performed based on ranks of CPUE. Three migratory and one pelagic species had significantly higher CPUE seasonally. Two shad species, threadfin and American had higher CPUE in the fall and summer. Chinook salmon and rainbow trout, both migratory salmonids, had their highest CPUE in the spring and fall. All other species showed no difference between seasons in CPUE at a significant level; striped bass was the exception, with non-significant results (Table 3).

| Species | p -value | Winter | Spring | Summer | Fall |
| :---: | :---: | :---: | :---: | :---: | :---: |
| TFS | $*$ | L | L | L | H |
| AMS | $* *$ | L | L | H | L |
| GSH | $*$ |  |  |  |  |
| SKR | $* *$ |  |  |  |  |
| CHN | $* *$ | L | H | L | L |
| RBT | $*$ | L | L | L | H |
| ISS | $*$ |  |  |  |  |
| STB | NS | --- | --- | --- | --- |
| BGS | $* * *$ |  |  |  |  |
| RES | $* * *$ |  |  |  |  |
| LMB | $* * *$ |  |  |  |  |

Table 3. Seasonal distribution of the eight most abundant species plus Chinook salmon, rainbow trout, and striped bass in all sites around the McCormack Williamson Tract. Cells labeled "H" indicate a season that had significantly higher CPUE than seasons labeled "L" over the two years of the study, unlabeled cells had no significant differences between seasons (Friedman ANOVA multiple comparisons ( ${ }^{*}, \mathrm{p}<0.05 ;{ }^{* *}, \mathrm{p}<01 ;{ }^{* * *}, \mathrm{p}<0.001$ ).

## Environmental variables and species composition

The forward selection mode in CCA resulted in retention of 4 variables in the model. Submerged aquatic vegetation (SAV), temperature, conductivity, and maximum depth were selected as the variables that explained the most variation in species abundance. The first two axes together explained the greatest portion of the variance ( $11 \%$ and $16 \%$ respectively), while the third and fourth axes were not interpreted (Table 4). Monte Carlo tests resulted in the first axis $(\mathrm{F}=7.6, \mathrm{P}=$ $.005)$ and the full model $(\mathrm{F}=3.7, \mathrm{P}=.005)$ were statistically significant. SAV was present at all sites, but was most abundant in backwater slough sites (Table 3). Mean temperatures did not vary much between sites, although the range over the sampling period was considerable (Table 3). Conductivity was generally higher in backwater slough areas, although none of the measurements could be considered extremely high or low (Table 3). Maximum depth ranged widely, with channel type habitat having the highest depths among the sites (Table 3).

| Site | SAV | Wood | Tules | Riprap | Chan | Tree | Tide | Temp | Cond | NTU | Avg | Max <br> depth |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| depth |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |  |  |
| DHC | $(2-20)$ | $(3-10)$ | $(0-0)$ | $(0-15)$ | $(40-85)$ | $(0-5)$ | $(1.1-1.9)$ | $(6-23)$ | $(57-301)$ | $(7-21)$ | $(1.6-2.1)$ | $(1.1-3.4)$ |
|  | 14 | 6 | 0 | 8 | 70 | 1 | 1.3 | 16 | 179 | 13 | 1.7 | 2.8 |
| LS1 | $(10-85)$ | $(5-30)$ | $(0-0)$ | $(0-0)$ | $(10-60)$ | $(0-5)$ | $(1.3-1.9)$ | $(8-27)$ | $(111-423)$ | $(5-21)$ | $(1.1-1.5)$ | $(1.7-3.4)$ |
|  | 61 | 11 | 0 | 0 | 29 | 2 | 1.6 | 17 | 227 | 10 | 1.4 | 2.5 |
| LS2 | $(0-50)$ | $(5-15)$ | $(0-10)$ | $(0-0)$ | $(30-70)$ | $(0-5)$ | $(1.0-1.8)$ | $(7-26)$ | $(103-305)$ | $(7-22)$ | $(1.4-1.9)$ | $(2.7-3.3)$ |
|  | 29 | 10 | 3 | 0 | 56 | 3 | 1.6 | 17 | 187 | 14 | 1.6 | 3.2 |
| MOK1 | $(0-5)$ | $(3-10)$ | $(0-0)$ | $(0-15)$ | $(70-90)$ | $(0-5)$ | $(1.2-1.7)$ | $(5-23)$ | $(46-292)$ | $(10-18)$ | $(3.0-3.5)$ | $(4.4-4.9)$ |
|  | 3 | 8 | 0 | 8 | 78 | 4 | 1.4 | 16 | 158 | 13 | 3.3 | 4.6 |
| MOK2 | $(0-0)$ | $(5-15)$ | $(0-0)$ | $(10-25)$ | $(60-85)$ | $(0-10)$ | $(1.2-1.6)$ | $(5-23)$ | $(49-171)$ | $(6-21)$ | $(2.4-3.2)$ | $(3.5-4.0)$ |
|  | 0 | 9 | 0 | 13 | 74 | 3 | 1.4 | 16 | 121 | 13 | 2.7 | 3.7 |
| MOK3 | $(0-5)$ | $(2-10)$ | $(0-0)$ | $(0-10)$ | $(80-90)$ | $(0-5)$ | $(1.0-1.6)$ | $(5-23)$ | $(48-183)$ | $(9-21)$ | $(2.0-4.7)$ | $(3.0-5.2)$ |
|  | 2 | 5 | 0 | 3 | 85 | 3 | 1.3 | 16 | 116 | 14 | 3.3 | 4.5 |
| RRS | $(20-60)$ | $(5-30)$ | $(0-10)$ | $(0-0)$ | $(35-70)$ | $(0-5)$ | $(1.1-1.7)$ | $(5-27)$ | $(91-392)$ | $(7-20)$ | $(1.3-2.7)$ | $(2.2-3.8)$ |
|  | 36 | 20 | 5 | 0 | 54 | 3 | 1.5 | 16 | 238 | 14 | 1.9 | 3 |
| SNG1 | $(0-20)$ | $(5-10)$ | $(0-0)$ | $(0-10)$ | $(70-83)$ | $(0-5)$ | $(1.0-1.6)$ | $(7-25)$ | $(96-318)$ | $(7-22)$ | $(2.6-5.4)$ | $(3.6-7.6)$ |
|  | 7 | $\mathbf{6}$ | 0 | 8 | 78 | 2 | 1.4 | 16 | 196 | 17 | 3.2 | 5.1 |
| SNG2 | $(5-20)$ | $(5-20)$ | $(0-0)$ | $(0-8)$ | $(35-80)$ | $(5-10)$ | $(1.2-1.6)$ | $(7-24)$ | $(157-334)$ | $(7-22)$ | $(1.7-2.6)$ | $(2.7-3.9)$ |
|  | 10 | 10 | 0 | 1 | 64 | 6 | 1.4 | 16 | 231 | 17 | 1.9 | 3.4 |
| SNG3 | $(5-40)$ | $(0-5)$ | $(0-5)$ | $(0-25)$ | $(50-80)$ | $(0-10)$ | $(1.3-1.8)$ | $(8-23)$ | $(85-303)$ | $(7-20)$ | $(0.8-1.9)$ | $(1.1-3.9)$ |
|  | 15 | 3 | 1 | 12 | 57 | 3 | 1.5 | 16 | 193 | 14 | 1.5 | 2.7 |
| SNG4 | $(10-60)$ | $(2-5)$ | $(0-5)$ | $(5-10)$ | $(40-80)$ | $(0-5)$ | $(1.2-1.7)$ | $(6-25)$ | $(87-303)$ | $(7-20)$ | $(0.8-3.2)$ | $(1.8-5.6)$ |
|  | 25 | 4 | 2 | 7 | 65 | 1 | 1.4 | 17 | 212 | 15 | 2.6 | 4.6 |

Table 4. Minimum and maximums, with means of environmental variables in bold for each site studied. DHC = Dead Horse Cut, LS1 = Lost Slough Site 1, LS2 = Lost Slough Site 2, MOK! = Mokelumne River Site 1, MOK2 = Mokelumne River Site 3, RRS = Railroad Slough, SNG1 = Snodgrass Slough Site 1, SNG2 = Snodgrass Slough Site 2, SNG3 $=$ Snodgrass Slough Site 3, SNG4 $=$ Snodgrass Slough Site 4.

Species scores when plotted against environmental gradients (Figure 4) reflected the different conditions among the sites around MWT. Centrarchid species (bluegill, redear, and largemouth bass) and golden shiner were associated with SAV, high conductivity, lower temperatures, and, to a lesser extent, shallower water depth. The other groupings of fish (Chinook salmon, threadfin shad, inland silverside, striped bass, and sucker) were associated with lower amounts of SAV, conductivity, higher water temperature and water depth. Two other species did not seem to group into the previous two groups. American shad were associated with low SAV, low conductivity, very high temperature, and intermediate water depths. Rainbow trout were associated with high SAV, high conductivity, cold water temperature, and deep-water depth.

|  |  |  | Canonical coefficients |  | Interset correlations |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | Axis 1 | Axis 2 | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Eigenvalues | 0.118 | 0.057 |  |  |  |  |
| Species-environment | 0.685 | 0.650 |  |  |  |  |
| Cumulative percentage variance |  |  |  |  |  |  |
| Species data | 10.90 | 16.20 |  |  |  |  |
| Species-environment relation | 58.20 | 86.30 |  |  |  |  |
| Submerged aquatic vegetation |  |  | -0.571 | -0.168 | -0.480 | -0.225 |
| Temperature |  |  | 0.516 | -0.288 | 0.419 | -0.386 |
| Conductivity |  |  | -0.312 | 0.205 | -0.502 | 0.176 |
| Maximum depth |  |  | 0.214 | 0.793 | 0.180 | 0.586 |

Table 5. Results of canonical correspondence analysis run on environmental variables and fish abundance data (CPUE) collected from sites around the McCormack Williamson Tract in 2001 and 2002. Shown is the CCA summary table for the first two ordination axis, canonical regression coefficients, and interset correlations for the standardized environmental variables with the first two ordination axis.


Figure 4. Canonical correspondence ordination diagram showing fish abundance relationships with environmental gradients.

## Diet Results

Fullness: Of the four sample dates (July 2002, November 2002, February 2003, and May 2003), November 2002 had the lowest levels of fullness in the stomachs, followed by July 2002, then February 2003, with May 2003 having the fullest stomachs (Figure 1.). November 2002 had the highest numbers of empty stomachs and no level 3 (full) stomachs. July 2002 and February 2003 were very similar with nearly $80 \%$ level 1 stomachs and very few of the other levels but February 2003 was slightly higher having more level 3 and less level 1 than July 2002. May 2003 was the only date where level 3 stomachs dominated level 2 stomachs.


Figure 5. Stomach and foregut levels of fullness with all diet analysis species and individuals included.

Diet Components: - Average percentages of taxa in the diets of each species are presented in full in Table 2 for all fish species and are graphed for the centrarchid species in Figure 2. If gorp (algae and unidentifiable digested material) is ignored, Diptera becomes the major food item for BGS, LMB and RES (16-22\%) by volume. Gorp was plentiful in both RES and BGS (29 and 20\%) but largely absent in BCR and absent in LMB. BCR ate mainly amphipods (27\%) while other centrarchids ate them in lesser percentages (8-15\%). Fish were the second largest food item for both BCR and LMB, but were absent entirely from the diets of BGS and RES. Hemiptera were marginally important to BC and LMB (15\% and 9\%) but were very rare in BGS and RES (<1\%). Cladocera were marginally important to both BGS and LMB (13 and 12\%) but were slightly less important to BCR and RES (8 and 4\%).

|  | $\mathrm{n}=9$ | n=85 | $\mathrm{n}=43$ | $\mathrm{n}=78$ | $\mathrm{n}=2$ | $\mathrm{n}=2$ | $\mathrm{n}=6$ | $\mathrm{n}=2$ | $\mathrm{n}=2$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | BC | BG | LMB | RES | RT | WM | YFG | ISS | GS |
| Gammaridae | 27.67 | 13.46 | 7.91 | 8.74 | 0.00 | 2.50 | 25.83 | 0.00 | 0.00 |
| Corophium | 0.00 | 1.60 | 0.00 | 0.64 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Isopods | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Bosmina | 0.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ceriodaphnia | 0.00 | 0.41 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Daphnia | 5.11 | 11.05 | 10.23 | 2.13 | 2.50 | 0.00 | 19.17 | 55.00 | 0.00 |
| Diaphanosoma | 0.44 | 1.31 | 1.74 | 1.46 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chydoridae | 1.78 | 0.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Calanoid | 10.67 | 1.74 | 0.23 | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Cyclopoid | 1.78 | 6.21 | 0.72 | 0.54 | 0.00 | 0.00 | 0.00 | 45.00 | 0.00 |
| Copepoda Can't ID | 2.22 | 2.25 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Chironomidae larva | 5.00 | 12.42 | 5.95 | 14.19 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Diptera Pupa | 1.11 | 1.41 | 9.58 | 0.73 | 10.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ceratopogonidae | 0.33 | 0.82 | 0.00 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Muscidae | 0.00 | 0.14 | 0.00 | 2.36 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other Diptera larvae | 0.22 | 0.69 | 0.00 | 0.29 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Diptera adults | 0.00 | 6.67 | 0.58 | 0.85 | 5.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ephemerata | 0.00 | 0.00 | 0.00 | 1.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Plecoptera | 0.00 | 0.00 | 2.33 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tricoptera | 0.89 | 1.86 | 0.00 | 1.46 | 5.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Coleoptera | 0.00 | 0.45 | 0.00 | 0.29 | 17.50 | 0.00 | 0.00 | 0.00 | 0.00 |
| Corixidae | 14.00 | 0.02 | 6.33 | 0.08 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other Hemiptera | 0.78 | 0.00 | 3.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Anisoptera | 4.44 | 2.12 | 7.21 | 0.51 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Zygoptera | 1.11 | 2.72 | 4.07 | 4.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Other Aquatic Can't IL | 0.00 | 0.29 | 0.23 | 1.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Terrestrial | 0.00 | 0.12 | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Oligochaeta | 0.00 | 0.00 | 0.00 | 1.09 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Worms | 0.00 | 0.06 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Spiders | 0.00 | 0.00 | 0.70 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Hydracarina | 0.00 | 0.99 | 0.70 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mysidacea | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Caridea | 0.00 | 0.00 | 2.30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Clams | 0.00 | 0.00 | 0.00 | 6.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Snails | 0.00 | 3.99 | 0.00 | 7.82 | 0.00 | 0.00 | 18.33 | 0.00 | 0.00 |
| Ostracods | 0.00 | 1.04 | 0.00 | 1.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Fish | 22.11 | 0.00 | 15.12 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Eggs | 0.00 | 0.00 | 0.00 | 0.24 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Crayfish | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 47.50 | 0.00 | 0.00 | 0.00 |
| Gorp | 0.00 | 20.19 | 0.02 | 29.49 | 10.00 | 0.00 | 20.00 | 0.00 | 100.00 |

Table 6. Summary of diet components and their average percentages within each species.


Figure 6. Average percentage of major groups in the diets of Centrarchids.

Scale Age:- Scale age (determined by numbers of winters a fish has experienced) corresponded very well to the standard length of the fish species BCR, BGS, LMB, and RES ( $r^{2}>.6$ for all species Figure 3) However, there was too much overlap of standard lengths within ages to make lengths a good predictor of age. For example a 110 mm RES could be anywhere from 1 to 4 years old. Because of this overlap we decided to compare differences in diet within species according to length of the fish and not age.


Figure 7. Scale age of the Centrarchids (in numbers of winters survived determined by annulus in the scales) plotted against the standard length of each fish by species.

Prey length vs. Fish Standard Length: - Average prey length values plotted against standard length values of the four centrarchid species are shown in Figure 4. The class averages are shown in table .BGS and RES show almost no relationship between prey length and fish length. All the prey length values for these fish were below 10 mm and few were above 6 mm . The larger organisms were mainly Odonata for the BGS and RES. It should be noted that none of the young of the year BGS or RES ( $<60 \mathrm{~mm}$ ) had large prey length values. BCR and LMB showed stronger positive trends but LMB still had much variation. Larger prey length values around 25 were fish and Palaemonidae. LMB are capable of eating this large prey even at young of the year sizes.
black crappie $\quad R^{2}=0.84$
bluegill $\quad R^{2}=0.01$

largemouth bass

$$
\mathrm{R}^{2}=0.51
$$



Fish S. Length mm


Fish S . Length mm


Fish S . Length mm

Figure 8. Standard length of each Centrarchid fish plotted against an average food item length value determined by the weighted average of the different length classes of the food items eaten by each fish.

Foraging method: - Of the four centrarchid species only BCR showed a strong correlation between \% zooplankton in the stomach and standard length of the fish (-0.814) Figure 5. LMB, and BG showed moderate correlation (-0.396, -0.345 ) with no LMB over the size of 71 mm (max size was 166 mm ) eating plankton. Plankton became less important in the diets of BGS as the fish became larger, but they were still present. RES continued to feed on plankton in approximately equal amounts as they became larger (correlation $=0.044$ ).


Figure 9. The standard length of Centrarchid fish, by species, plotted against the percentage of each diet that was planktonic (Cladocera and Copepoda). Correlation values were BC -0.814 , BG -0.345 , LMB -0.396 , and RES 0.044 .

## Discussion

Alien fish dominated the fish fauna surrounding the MWT, with natives being rare, except for the Sacramento sucker. This was not unexpected as it follows other studies done in the Delta where alien fishes, especially centrarchids dominated the fish catches (Brown, Freyer, Freyer, Siemens and, unpublished studies Except Fred's have been). For the first time redeye bass were identified in the region, but this was not surprising; (Moyle et. al. 2003) found redeye bass to be common in the fish catches in the Cosumnes River just above the MWT. East Bay Municipal Utility District has also found redeye bass below Woodbridge Dam in the Mokelumne River (J.

Merz, per. comun.). Redeye bass could have been in the Delta system for some time because they are easily misidentified as smallmouth or spotted bass. Native fishes especially minnows were found to be extremely rare (Table 1). Many factors have been involved in the decline of native species (Moyle 2002). The greatly altered hydrodynamics and high amount of channelization has been implicated (Nichols et al. 1986). The capture of winter and spring pulse flows is another postulated reason. This is not completely true of the North Delta Area as the Cosumnes River has no major dams on its mainstem and has a hydrograph typical of a natural stream during the winter and spring (Figure 10).


Figure 10. Hydrograph of the Cosumnes River (1995-2002).

However, what may be equally important is the lack of connectivity during the dry months. The Cosumnes River was once a perennial stream, having ground water flow sustaining its flow during the summer months. Because of the massive pumping of it's aquifer for agriculture, it now dries up during the summer months. This can happen as early as June in really dry years.

Literally thousands of native minnows and suckers are lost to this drying effect. Another reason for decline is presumably the virtually continuous levees around Delta islands; the assumption is that the high bank slope of levees leaves little room for shallow water (interidal) habitat. However, a substantial amount of the habitat in the backwater sloughs surrounding MWT contained this intertidal habitat. Although this habitat is more similar to what was contained in the "original Delta" important differences exist. For one, SAV dominates these habitats to such an extent that it in some places it forms a wall along the edges of the channel. This type of barrier may exclude native fishes from being able to utilize these areas successfully. Most of the large native minnows and suckers caught in this study were found in the center of the channels.

Interactions by native fishes with aliens may be another limiting factor. The littoral areas we sampled contained the highest densities of centrarchid fishes that we encountered around MWT. Interspecific competition between blugill and native Sacramento perch was found to cause the perch to gain less weight and to shift their habitat use (Marchetti 1999). Predation by aliens on native fishes (especially native larvae) could be a significant limiting factor in this system (Turner and Kelley 1966, Bennett and Moyle 1996).

## Site Comparisons

Sites surrounding MWT from figure 2 fell into three basic categories. High amounts of SAV, higher conductivity, and high residence time of water could typify backwater slough habitats. The fishes associated with these areas were predominately centrarchid species, mainly blugill, redear sunfish, and largemouth bass. There were other alien species, but they were in very low abundance compared with the sunfishes. Few natives were associated with these areas; the ones that were found were seasonal migratory fishes that seemed to be lost. Another grouping the river channel sites were typified by leveed banks, lower conductivity, less SAV, and higher
depth. These sites typically had higher abundances of sunfishes, but they were still low when compared with slough sites. These sites contained the highest numbers of spotted and redeye bass that were highly associated with the riprap banks of the levees. There were few natives, but abundances of pikeminnows were the highest in these areas. Migratory natives (Chinook salmon) and aliens (American shad) were also found in some abundance in the spring and summer months. Noticeably absent from the two years of this study were splittail a native minnow that spawns on floodplain habitat in the Cosumnes River (Crain et al. 2004) and then migrates to the San Francisco Estuary. This is probably a result of poor recruitment off the floodplain (Figure11), caused by a lack of connection between floodplain and river in dry years. Finally the channel slough sites grouped intermediately with the two previous types and a loose grouping with Dead Horse Cut being significant on the third component of the PCA. These sites were very much intermediate in their associations with environmental variables, having some SAV, medium conductivity, and intermediate channel depth. There was a high abundance of sunfishes, but also other alien species and all migratory fishes including natives.

## Comparisons among seasons

There were four species of fish that had significant seasonal differences in abundance. Juvenile Chinook salmon were more abundant in the spring when they are migrating through the area to the estuary. They were most abundant in the Dead Horse Cut site in this study, which could mean that they are very vulnerable to the tidal sucking action that occurs at this site because of the narrow channel that connects it with the North Fork of the Mokelumne River. Rainbow trout were most abundant in the fall season. Most of the fish that we caught were of hatchery origin and seemed to be sloshing back and forth between sites with the tides. Most of these fish are presumed to be steelhead smolts from the Mokelumne River Hatchery, although when the

.Figure 11. Splitail catches by FWS at Wimpy’s marina from 1999 through 2003.

Delta Cross Channel is open they could come from the Sacramento River. American shad were most abundant in our catches during the summer months. American shad runs exist on both the Cosumnes and Mokelumne Rivers. In the Cosumnes the pelagic larvae float from upstream (as far as Hwy 99) into the lower portion of the river in late spring. The fish rear in the upper tidal portion of the Cosumnes until they migrate towards the Estuary sometime in late summer. Finally, threadfin shad were found to be most abundant during the fall. We are not sure if this is true, or a product of our sampling technique. Threadfin shad spawn in the upper portion of the Cosumnes tidal region. We have also found adult shad in this area and are unclear as to whether there is a migration out of the area. All the other fish species had no significant seasonal abundance pattern, which would indicate that they are resident species.

## Environmental variables and species composition

It is clear that fish distribution and abundance is strongly influenced by physical attributes around MWT---specifically, SAV, water temperature, conductivity, and water depth. As found in the BREACH study (Simenstead et al) largemouth bass, blugill, and redear sunfish were found to have a very strong association to beds of aquatic vegetation. Alien aquatic vegetation has been found to support different epiphytic and epibenthic invertebrate communities than that of native plants (Toft et al. 2003). In the same study invertebrates that were associated with alien plants common were less abundant in the diets of fish adjacent to the vegetation. It is clear that SAV is having an effect on the habitat structure and associated biological communities around MWT. Exactly what that effect is remains unclear, although the dominance of alien fishes and rarity of natives is clearly evident.

## Diets and Food Web Structure

Thirty-one prey items were found in the diets of 9 species of fish. The orientation of each prey item in the water column is given in table 7. Diet composition data was collected from all 9 species, although only 4 were analyzed because of inadequate sample sizes of the other species. Largemouth bass as small juveniles were eating primarily planktonic prey, specifically cladocerans. As juveniles they fed heavily on benthic prey, mostly chironomids and amphipods (Figure 6). As their gape increased they increasingly included larger prey items, primarily fish. (Figure 6).

Largemouth bass (>300 mm) not included in the diet study were examined in the field by placing fingers down the throat of the fish to feel what was in the gut. Primarily, the bass were eating crayfish and to a lesser extent fish (P. Crain pers. obs.) Black Crappie were very similar to largemouth bass eating planktonic prey (cladocerans) at small sizes, then switching to benthic prey (chironomids and amphipods) then switching to larger prey items (fish) at a larger size, around 90 mm . Bluegill sunfish were very omnivorous in their feeding habits, feeding opportunistically on invertebrates in SAV habitats. Bluegill used benthic, epibenthic, phytal, planktonic, and nuestonic/surface invertebrates in their diets. Redear sunfish diets were similar to bluegill, but contained less plankton and were more benthic orientated in food preferences. Prey items were ranked using a modified Index of Relative Importance (IRI; Pinkas et al. 1971; Simenstad et al. 1991): IRI = \% frequency of occurrence $x$ [\% numerical occurrence $+\%$ gravimetric composition]. The IRI for the four species shows a highly benthic derived food web, with only largemouth bass having a larger nuestonic component, presumably because of the preference to eat fish when there size overcomes gape limitation.

| Prey Taxa | Benthic | Epibenthic | Phytal |
| :--- | :--- | :--- | :--- |
|  |  | Planktonic |  |


| Oligochaetes | $\checkmark$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Gastropods | $\sqrt{ }$ |  |  |  |  |
| Bivalves | $\sqrt{ }$ |  |  |  |  |
| Araneae |  |  |  |  | $\sqrt{ }$ |
| Acarina |  |  | $\sqrt{ }$ |  |  |
| Cladocerans |  |  |  |  |  |
| Ceriodaphnia sp. |  |  |  |  |  |
| Daphnia sp. |  |  |  |  |  |
| Diaphanosoma |  |  |  |  |  |
| Chydoridae |  |  |  |  |  |
| Ostracods |  | $\sqrt{ }$ | $\checkmark$ |  |  |
| Copepoda |  |  |  | $\checkmark$ |  |
| Calanoid |  |  |  |  |  |
| Cyclopoid |  |  |  |  |  |
| Unidentified |  |  |  |  |  |
| Isopods |  | $\sqrt{ }$ | $\checkmark$ |  |  |
| Amphipods |  |  |  |  |  |
| Gammarid amphipods |  |  |  |  |  |
| Corophium spinicorne | $\checkmark$ |  |  |  |  |
| Unknown | $\sqrt{ }$ | $\sqrt{ }$ |  |  |  |
| Caridea | $\checkmark$ |  |  |  | $\sqrt{ }$ |
| Insects |  |  |  |  |  |
| Ephemeroptera | $\sqrt{ }$ |  |  |  | $\checkmark$ |
| Zygoptera |  |  | $\checkmark$ |  | $\sqrt{ }$ |
| Anisoptera | $\checkmark$ |  |  |  |  |
| Plecoptera |  |  |  |  | $\checkmark$ |
| Hemiptera |  |  |  |  |  |
| Corixidae |  | $\sqrt{ }$ |  |  | $\checkmark$ |
| Other |  |  |  |  | $\sqrt{ }$ |
| Tricoptera | $\sqrt{ }$ |  |  |  |  |
| Coleoptera |  |  |  |  | $\sqrt{ }$ |
| Diptera |  |  |  |  |  |
| Adults |  |  |  |  | $\checkmark$ |
| Larvae | $\sqrt{ }$ |  |  |  |  |
| Muscidae |  |  |  |  | $\sqrt{ }$ |
| Chironomidae-larvae | $\sqrt{ }$ |  |  |  |  |
| Ceratopogonidae | $\sqrt{ }$ |  |  |  |  |
| Fish | $\sqrt{ }$ |  |  | $\sqrt{ }$ | $\sqrt{ }$ |

Table 7. Categories of prey taxa from 9 species of common fishes found around MWT.

This is not to say that zooplankton and other food sources are not important. If the fish diets were broken down into size classes, YOY (young of the year) fishes would be eating predominately zooplankton and other small invertebrates. The IRI presented is more of a reflection of intermediate and adult fish diets, thus there is a lack of resolution on the diets of YOY. Also, data from pelagic species like silversides, juvenile salmon, and juvenile shad are not presented, although other studies in the Delta have found them to primarily feed on planktonic invertebrates (Simenstad et al. 2000).

IRI of Prey Items


Figure 12. Index of Relative Importance for black crappie (BCR), bluegill (BGS), Largemouth bass (LMB), and redear sunfish (RES) showing major position of food items in the water column.

## Conclusions

The fish fauna in the sloughs and channels around the MWT is dominated by alien centrachid fishes, especially bluegill, redear, and largemouth bass. Native fishes except for Sacramento
suckers are rare and may be transients in the system. Seasonal usage of channels by Chinook salmon, splittail, and American shad can be substantial as they migrate out of lower Cosumnes and Mokelumne Rivers down to the San Francisco Estuary. The sloughs and edges of the channels are dominated by water weeds, with the Brazilian water weed Egeria densa being prominent. Some of the backwater sloughs with high water residence times become so choked that they become virtually impassable to boat traffic during late summer months. These invasive water weeds probably have changed the food web to some extent as found by Toft et al. 2003 in their study of water hyacinth and pennywort. Unfortunately the design of the invertebrate study by (Grosholz and Gallo) did not sufficiently study the benthos to substantiate the benthic, epibenthic, and phytal components of the invertebrates. The food web for the fish seems to be benthic and phytal in nature, although predatory fishes like largemouth bass and crappies switch to eating fish at larger sizes. Two new invasive species the redeye bass Micropterus coosae and Siberian prawn Exopalemon modestus were found to be in the system, although in low numbers.

## Management Recommendations

Because of the large number of sunfish and other large alien predators in the waters surrounding the MWT it is hard to imagine what could be done to enhance native fish populations. Any permanent or intertidal habitat will be quickly invaded and dominated by these types of fish. We would therefore not recommend creating any new subtidal, or intertidal habitat in restoration activities, at least as a means to benefit native fishes. The creation of temporary floodplain habitats that would become inundated during high flows would be the most beneficial for the bulk of native fish, such as Chinook salmon and splittail.

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