2008 Laguna de Santa Rosa Aquatic Community Survey

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Abstract

The Laguna de Santa Rosa, the Russian River's largest tributary, is the focus of projects that seek to improve its ecological health. However, no studies of the Laguna de Santa Rosa's aquatic community have been performed since 1988. As a result, we surveyed water quality, phytoplankton, invertebrates, fishes, and fish gut contents in 2008 to (1) assess changes in the Laguna de Santa Rosa's fish community since 1988, (2) provide baseline data for restoration efforts, and (3) relate fish community composition to abiotic and biotic parameters. Our water-quality and phytoplankton data in 2008 showed that the Laguna de Santa Rosa is a very eutrophic system. Concomitantly, the fish community was dominated by species that can handle very low oxygen levels and do not spawn in riffles. Fish gut contents showed that smaller fish were heavily dependent on zooplankton, while larger fish focused more on macroinvertebrates. These results are consistent with those obtained in 1988 and suggest that the conditions structuring the fish community have remained relatively stable.

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Introduction

Setting

The Laguna de Santa Rosa, located in northern California, is the largest tributary of the Russian River. The watershed of the Laguna de Santa Rosa is bracketed in the east by the Sonoma and Mayacamas mountains, in the west by the Goldridge Hills, and in the south by a low-lying, gentle rise that separates it from the Petaluma River. The mainstem flows roughly northwest for about 37 kilometers before emptying into the Russian River. The climate is Mediterranean, with cool, wet winters and dry, hot summers. Likewise, flows are highest in winter and early spring and reach their lowest point in early autumn.

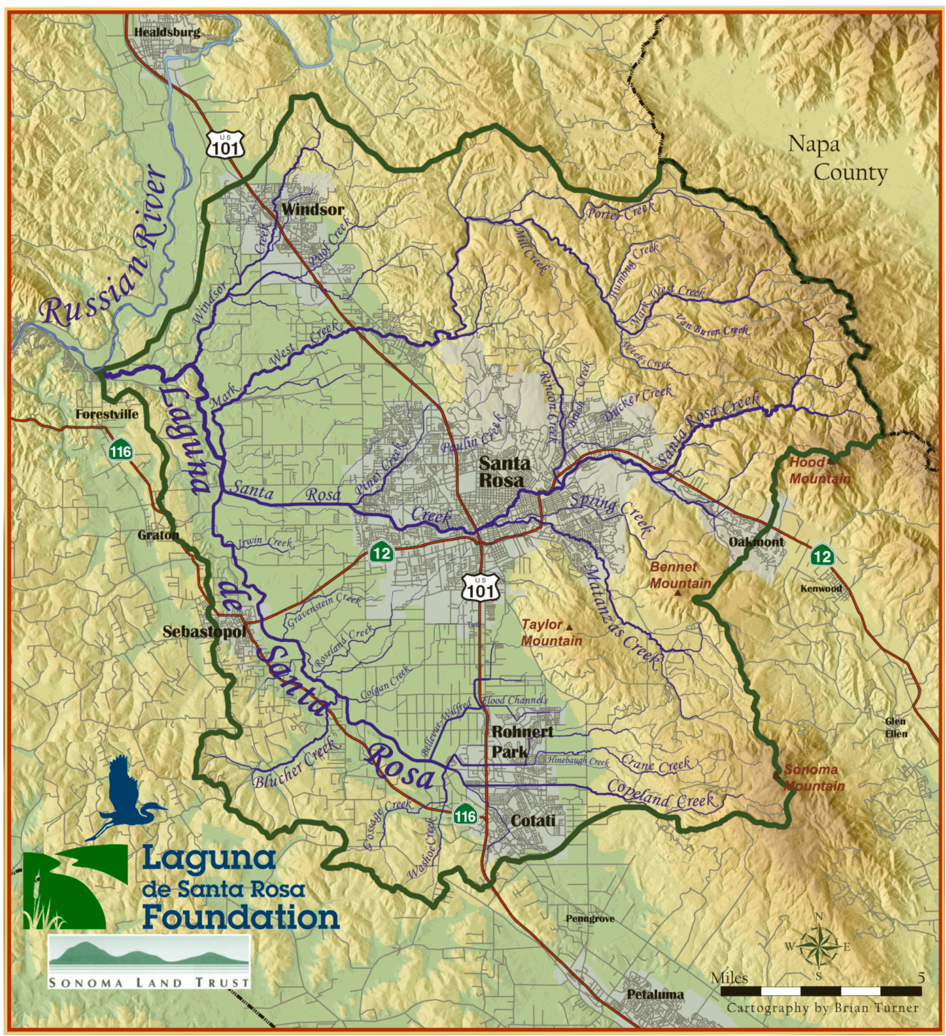

Figure 1. Map of Laguna de Santa Rosa Watershed

Much of the Laguna de Santa Rosa is flanked by agricultural and urban landscapes. Most of the major urban centers of Sonoma County, including the county's largest city, Santa Rosa, lie within its watershed (Figure 1). Agricultural landscapes such as vineyards, dairies, pasturelands and small private ranches are interspersed by riparian zones and oak savannah grasslands, all of which form green belts between urban centers. During seasonal rains, the increased surface flow from the Laguna de Santa Rosa's mainstem and tributaries causes localized flooding and creates temporary wetlands on agricultural fields and grasslands.

There are three perennial, open-water areas that are substantially wider than the rest of the mainstem channel in the Laguna de Santa Rosa: the first resides upstream of the Laguna de Santa Rosa-Roseland Creek confluence; the second is adjacent to Laguna Park in Sebastapol; and the third is immediately south of the Occidental Road bridge (the "Occidental Road Reach"). Major tributaries, from south to north, include Copeland, Blucher, Colgan, Roseland, Santa Rosa, and Mark West creeks. Many parts of these tributaries have been channelized and funneled through culverts. Similarly, much of the Laguna de Santa Rosa has also been channelized for flood control, especially between the Occidental Road Bridge and just south of River Road.

The gradient of the Laguna de Santa Rosa is extremely low for much of its length, resulting in very slow flows (Honton and Sears 2006). As a result, the Laguna de Santa Rosa often appears more as a slough or pond rather than a stream. The low gradient also provides little stream power to entrain larger particles of sediment; consequently, the substrate is frequently very fine grained. These fine-grained sediments, when disturbed by stream or wind currents, give the Laguna de Santa Rosa's water its characteristically brown color. The sediments and slow stream velocities also provide favorable habitat for a variety of macrophyte (i.e., aquatic plant) species (e.g., pennywort *Hydrocotyle* sp., water primrose *Ludwigia* spp., parrotfeather *Myriophyllum aquaticum*), the majority of which remain rooted during high flow events. These macrophytes often form very dense stands that can impede the flow of floodwaters.

The surrounding developed landscape and the geomorphology of the watershed substantially influences the water quality of the Laguna de Santa Rosa. High inputs of nutrients from agricultural and urban areas fuel significant growths of algae and macrophytes. Additionally, slow stream velocities allow the accumulation of organic matter and minimize the diffusion of atmospheric oxygen into the water. Consequently, oxygen concentrations in the Laguna de Santa Rosa are often very low (Smith et al. 1989).

In 1988, Smith et al. (1989) performed the only known study of the Laguna de Santa Rosa's biotic community, the primary goal of which was to evaluate the effects of tertiary-treated water discharged from Sonoma County Water Agency's Delta Pond facility. Their study revealed that the zooplankton (i.e., the community of animals at the mercy of water currents) was dominated by species commonly found in ponds (e.g., chydorid and moinid cladoceran zooplankters), which is not surprising given the Laguna de Santa Rosa's pond-like character (Honton and Sears 2006). The benthic (i.e., bottom-dwelling) invertebrate community, which was sampled around the Laguna de Santa Rosa-Santa Rosa Creek confluence and downstream near Trenton Road, was comprised of species common in slow-flowing or still waters with fine sediments [e.g., triangular-gilled mayflies (Leptohyphidae), midges (Chironomidae)]. The fish community was surveyed with gillnets and seines, which revealed an assemblage that mostly consisted of species with high tolerances for poor water quality (e.g., common carp *Cyprinus carpio*, Sacramento blackfish *Orthodon microlepidotus*). In sum, the biotic community of the Laguna de Santa Rosa was typical for a warm, eutrophic (i.e., very fertile), slow-flowing waterway found in temperate zones.

Current Activities

The Laguna de Santa Rosa is the focus of several management activities. The stream is currently designated an impaired waterway according to Clean Water Act, Section 303(d) for temperature, sediment, low dissolved oxygen, nitrogen, phosphorous, and mercury. A determination of acceptable thresholds, or Total Maximum Daily Load (TMDL) values, for these constituents is in progress and the results are due in 2011. Efforts to remove an invasive water primrose that threatens the Laguna de Santa Rosa's ecology and flood-control functions are underway. Additionally, riparian and oak forests along the middle reaches of the mainstem are in the process of being restored. However, the paucity of baseline data on the aquatic ecosystem of the Laguna de Santa Rosa limits the evaluation and effectiveness of restoration projects.

To enhance the restoration of the Laguna de Santa Rosa, it is important to understand the immediate and long-term shifts in biological communities that co-occur with changes in physical habitat properties (e.g. water quality, channel shape). Fish and aquatic-invertebrate communities are useful indicators of both physical and biological factors since their composition is a result of (1) stream-flow parameters (e.g., velocity and depth), (2) available egg-laying habitat, (3) available rearing habitat, (4) availability of food sources at different life-history stages (5) water-quality parameters (particularly temperature, dissolved oxygen, and turbidity), and (6) biotic interactions (e.g., competition and predation). Because fish and aquatic invertebrates are relatively long lived, they integrate the chemical, physical, and biological histories of the waters they inhabit.

The Draft Laguna de Santa Rosa TMDL 2008 Monitoring Plan (NCRWQCB 2008) identifies the need to choose nonsalmonid warm-water fish species or aquatic invertebrates as appropriate indicators of environmental conditions throughout the Laguna de Santa Rosa. Additionally, a list of suggested general hydrologic, geomorphic, water quality, and ecosystem health indicators recommended by the Laguna conceptual model development project includes warm-water fish. Thus, we conducted a small-scale aquatic community survey on August 16 – 17, 2008 at two of seven locations previously sampled in 1988 along the Laguna de Santa Rosa. The goals of this study were to

- evaluate changes in the composition of the fish community within the last 20 years
- link fish and aquatic-invertebrate community composition to environmental parameters
- provide baseline data for measuring management activities (e.g., the TMDL process)

To address these goals, our specific objectives were to

- assess water-quality conditions
- assess the lateral and longitudinal distribution and abundance of fishes and invertebrates in the Laguna de Santa Rosa
- use fish abundance, aquatic invertebrate abundance, phytoplankton (i.e., suspended algae) density, and fish gut contents to construct simplified Laguna aquatic trophic model
- provide current biotic and abiotic data.

Materials and Methods

We chose three sites for this study, with two in the Occidental Road Reach and one at the confluence of the Laguna de Santa Rosa and Santa Rosa Creek. We had originally chosen to survey a fourth site; however, this site had dried by the sampling date (Figure 2). One of the sites in the Occidental Road Reach was near its inlet [the Occidental Road Pool South site (ORPS)], while the other [Occidental Road Pool North (ORPN)] was closer to the Occidental Road Bridge (Figure 2). The third site was immediately downstream of the Santa Rosa Creek-Laguna de Santa Rosa confluence (SRLC; Figure 2). These sites were chosen for their ease of access, for their history of previous sampling efforts, and for their representation of diverse Laguna habitats.

Water Quality Survey

The Community Clean Water Institute (CCWI, www.ccwi.org/) conducted water quality sampling at all three sampling sites immediately prior to biotic surveys. As in 1988, parameters measured included dissolved oxygen (milligrams per liter, mg/L), pH, water temperature (degrees Celsius,°C) along a depth gradient, specific conductivity (microSiemens, µS), turbidity (nephelometric turbidity units, NTU), nitrate (NO_3), and phosphate (PO_4; Table 1). Samples were collected by direct insertion of a sampling probe or collection of surface water by a container on a pole or by a bucket attached to a rope. Field analyses were performed on the samples collected on site. For samples returning to CCWI, the sampling containers for nutrient testing were sterilized Whirl Pak bags. Samples were placed in a cooler with ice or blue ice for transport to CCWI and were then kept refrigerated until analysis.

Additionally, the fish-survey crew measured temperature (°C) and specific conductivity (µS) once during each gillnet set (discussed below) with a Yellow Springs Instruments (YSI) 63 multimeter; dissolved oxygen concentrations (mg/L) were also measured with the same meter at 0.3-meter (m) depth intervals at each gillnet set after being calibrated to air and adjusted for altitude. Water transparency (centimeters, cm) was determined with a Secchi disk measuring 20 cm in diameter. Water temperature, specific conductance, and dissolved oxygen values from the fish crew only are reported herein since they were not different from those obtained by CCWI.

Figure 2. Map (north is up) showing the sampling sites for the 2008 surveys along the Laguna de Santa Rosa.

Table 1. Water quality sampling methods used by CCWI. Method names refer to the protocol source and kit identification (e.g., Hach NI-14 refers to the Hach kit number NI-14). RS = resolution (size of the smallest observed interval), NA = not applicable.

Analysis	Method Name	Method Description	RS	Reporting Limit	Units
Field	EPA170.1B	Temperature by Bulb	0.3	NA	°C
Field	EPA170.1T	Temperature by Thermocouple	0.1	NA	°C
Field	EPA150.1	pH	0.1	NA	pH Units
Field	EPA120.1	Specific Conductance	--	10	µS
Field	EPA180.1	Hach 2100P Turbidimeter	--	0.01	NTU
Field	ICM-DO	Dissolved Oxygen (polarographic)	0.1	NA	mg/L

Analysis	Method Name	Method Description	RS	Reporting Limit	Units
Lab	EPA300.0M	NO_3-nitrogen (ion chromatography)	--	.02	mg/L
Lab	EPA300.0M	PO_4-phosphorus (ion chromatography)	--	.03	mg/L

CCWI Field Testing

Temperature
CCWI used an alcohol-filled bulb thermometer and a thermocouple in the dissolved oxygen meter. The range of the bulb thermometer was from -5 to 50 °C in 0.5 divisions. The thermocouple was a digital output to the tenths of a °C.

pH
CCWI used a pH Tester model 10 from Eutech instruments. The method was electrometric with temperature compensation and a two-point calibration (pH 7 and pH 10). Results were recorded as displayed to the tenths place.

Specific Conductance
CCWI used the EC Tester from Eutech. The EC Tester Low operates in the 0 to 2000 µS range with a resolution of 10 µS. The EC Tester High operates in the 0 to 19900 µS range with a resolution of 100 µS. The method is direct conductivity measurement with temperature compensation and a single-point calibration. Results were recorded as displayed. The probe was checked for accuracy and calibrated as needed before deployment.

Turbidity
CCWI used a Hach Model 2100P Portable Turbidimeter catalog number 46500-88 with a range of 0-1000 NTU. Instrument calibration was performed with a Hach StablCal Calibration set catalog number 26594-05 as per manufacturer's instructions on a quarterly or as-needed basis. Secondary Gelex Standards were used between calibrations to check accuracy to within 5 percent and accompanied the meter to the field for use as an accuracy check should meter malfunction be suspected. The meter was set to autorange and signal average. Data were recorded as displayed in digital format. No rounding rules were applied.

Dissolved Oxygen
CCWI used a Polaragraphic Electrode method with an ICM Model 31050 Oxygen Meter. The instrument was calibrated to moist air at the lab or in the field prior to use per day. Reported values are as observed on the meter without compensations for altitude, barometric pressure, or salinity.

CCWI Lab Testing

NO_3-Nitrogen
NO_3 was assayed via ion chromatography. The procedure consisted of a Dionex Model 4000i

with Anion Seperator 14S column running a carbonate/bicarbonate eluent (0.005 molar sodium carbonate/0.0007 molar sodium bicarbonate). A six-point calibration curve was prepared following each eluent prep. The calibration was verified by performance on an externally prepared reference solution that also served as the continuing calibration verification. This method measured nitrite (NO_2) separately from NO_3. The results are NO_3-nitrogen with a reporting limit of 0.02 mg/L.

PO_4-Phosphorus

PO_4 was assayed with a Hach Total Phosphate Test Kit Model PO-24 catalog number 2250-01 using the Low Range procedure. The observed value from the disk was divided by 50 to obtain the mg/L PO_4 and then divided again by 3 to represent the mg/L PO_4-phosphorus.

Phytoplankton Survey

Phytoplankton was surveyed via assessment of chlorophyll a. It is the most widely used measure of phytoplankton biomass because of the following advantages: (1) the measurement is relatively simple and direct, (2) it integrates cell types and ages, (3) it accounts to some extent for cell viability, and (4) it can be quantitatively coupled to important optical characteristics of water.

Two samples collected from within 0.5 meters of the surface within each reach were pooled, visually evaluated for color, and sent by CCWI to an accredited laboratory for analysis within three days of collection. Results were reported as milligrams per cubic meter (mg/m^3).

Invertebrate Community Survey

Although aquatic invertebrates were collected, inconsistencies in the field and lab methods precluded the ability to draw any meaningful results from the data. Consequently, no further discussion of the aquatic-invertebrate data is provided in this report.

Fish Community Survey

A gillnet (15 m x 2 m, with mesh dimensions of 5 cm^2 and 2 cm^2) was set at the three sites at approximately the same time of day in order to minimize the effect of diel shifts in fish densities. The gillnets were set in open water and straddled the thalweg (i.e., the deepest point in the cross section of a channel). The gillnet was pulled every 90 minutes in order to minimize losses to crayfish and to minimize fish mortality. Gillnets were set two times per site for a total of six sets.

Inshore fish densities were assessed by seining (seine length = 6 m, mesh width = 6 mm) three times at the Occidental Road Reach sites and twice at the SRLC site. All sites were seined at approximately the same time of day as for gillnets to reduce the effect of diel shifts in fish densities.

With the exception of some small minnows from the family Cyprinidae, small sunfishes *Lepomis* spp., and sculpins *Cottus* spp., fishes were identified to species following Moyle (2002) and Wang (1986) and counted; standard lengths were measured and recorded. If more than 30 fish of one species was captured, only the first 30 were measured. When possible, sex and parasite presence were also noted. A random sample of each common fish species and life-history stage was killed and preserved on site in buffered 10-percent formalin for later gut-content analyses; small fishes were preserved whole, while guts from larger fishes were dissected and preserved on site. Catches for each method were graphed and compared to catches from the 1988 study (Smith et al. 1989). Catch-per-unit-effort values, with minutes and number of seine hauls as the effort divisors for gillnets and seines, respectively, were calculated; the results were then graphed and visually compared.

Depths (m) at each gillnet set and at each seine haul were determined by averaging the depths measured at each end of the net.

Fish Gut Content Analyses

The esophagus and stomach of sunfishes, and the tract from the esophagus to the apex of the second turn in minnows and western mosquitofish *Gambusia affinis*, were evaluated for gut contents. All contents of all sunfishes, mosquitofish, juvenile minnows, and small minnow species were identified and counted; contents of large minnows were diluted and subsampled, with final counts multiplied by the dilution factor (e.g., if 10 chironomid larvae were counted from a 1 mL subsample taken from a 10 mL sample, then the final count for chironomid larvae would be 100). All animal food items with the exception of rotifers were identified, if possible, to family level with a dissecting microscope following Merritt et al. (2008) and Pennak (1978); moinid cladocerans were considered phylogenetically nested within Daphniidae and were thus counted as such. A phytoplankton clump comprising a 25 µm x 25 µm area (the area about equal to that occupied by a rotifer) was counted as one phytoplankton unit under a compound microscope. Diatomaceous phytoplankton and rotifers were also counted under a compound microscope. The volume of detritus in the gut (which was only necessary for common carp) was estimated as the area of the identification plate covered by detritus. Gut contents were analyzed via the numerical-percentage and frequency-of-occurrence methods per Bowen (1980). Frequency-of-occurrence and numerical-percentage values were calculated as

$$Frequency\ of\ \ Occurrence = \frac{number\ of\ \ fish\ sampled\ with\ gut\ contents\ containing\ diet\ item\ x}{total\ number\ of\ \ fish\ sampled\ with\ gut\ contents}$$

and

$$Numerical\ Percentage = \frac{sum\ of\ diet\ item\ x\ from\ all\ sampled\ fish}{sum\ of\ all\ diet\ items\ from\ all\ sampled\ fish.}$$

To assess feeding activity level, the following ranks corresponding to stomach fullness were given: 1 if the gut was empty; 2 if the gut contained food but was not distended; 3 if the gut was distended but the identity of the contents could not be discerned through the gut wall; and 4 if the gut was distended and the identity of the contents could be discerned through the gut wall.

Frequency-of-occurrence and numerical-percentage values for each species, life-history stage, and site were graphed and compared.

Results

Water Quality

Summer water temperatures for the Occidental Road Reach and the SRLC sites in 2008 were not appreciably different from those in 1988 (Smith et al. 1989), although the temperature in the Occidental Road Reach was slightly higher in 1988 than in 2008 (about a 3°C difference; Smith et al. 1989). As in 1988, the Occidental Road Reach was more turbid than the SRLC site in 2008 (ranges = 20.8 - 33.1 NTU and 14.7 - 25.0, respectively; Smith et al. 1989); however, the difference between the two reaches and the absolute values for the Occidental Road Reach were greater in 2008 (Table 2). Considerably higher levels of chlorophyll a were detected at SRLC in 1988 (Station 2, Smith et al. 1989) than in 2008 (Figure 3). In 2008, temperature and specific conductivity were about the same for the three sites, while Secchi depth, turbidity, pH and chlorophyll a were substantially different between the Occidental Road Reach and SRLC sites (Table 2, Figure 3).

Table 2: Average 2008 water-quality values (sample sizes in parentheses) for the three Laguna de Santa Rosa gillnet survey sites. Turbidity and pH values were from CCWI, while the remaining values were from the fish-survey crew.

Site	Secchi Depth (cm)	Turbidity (NTU)	pH	Temperature	Specific Conductivity
ORPS	24 (2)	86.2	8.2	21.4 (2)	695 (2)
ORPN	26.5 (2)	73.4	8.5	22.9 (2)	695 (2)
SRLC	56.5 (2)	12.6	7.8	22.2 (2)	609 (2)

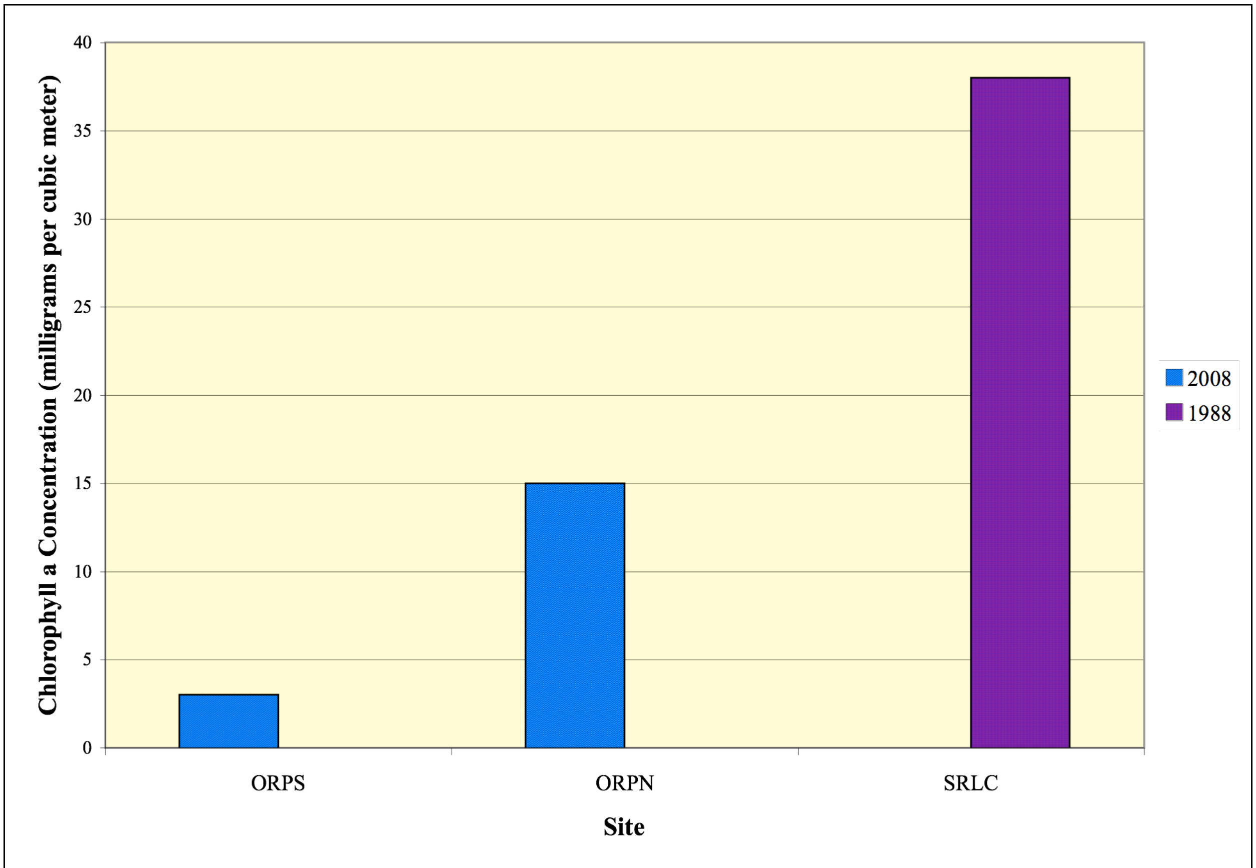

Figure 3. Mean August chlorophyll a values (mg/m^3) per sampling reach. No 1988 data were available for Occidental Road Reach sites. No chlorophyll a was detected in 2008 at SRLC.

The difference in oxygen concentration between the Occidental Road Reach and SRLC sites between 1988 and 2008 was similar, with the Occidental Road Reach being the more oxygenated (Figure 4). However, the difference (about 10 mg/L) between the two reaches was greater in the Smith et al. (1989) study, mainly due to a very high value (about 17 mg/L) measured at the Occidental Road Reach. Oxygen concentration decreased with greater depth at all sites (Figure 4). The ORPN gillnet site was deepest (2.3), followed by the ORPS site (1.7 m) and the SRLC site (1.5 m).

We detected no significant amounts of NO_3 at concentrations of 0 or < 0.01 mg/L at all sampling reaches in August 2008, consistent with 1988 summer NO_3 measurements (Smith et al. 1989). In some samples along all three reaches, a hint of NO_2 was detected. PO_4 values were close to twofold lower at the Santa Rosa Creek-Laguna confluence and about threefold lower at the Occidental Road Reach sites than concentrations measured in 1988 (Smith et al. 1989; Figure 5). PO_4 concentrations ranged between 0.12 and 0.26 mg/L at all reaches in 2008. Average PO_4 values were slightly higher (0.06 mg/L) along the banks than in the reach center at the ORPS site.

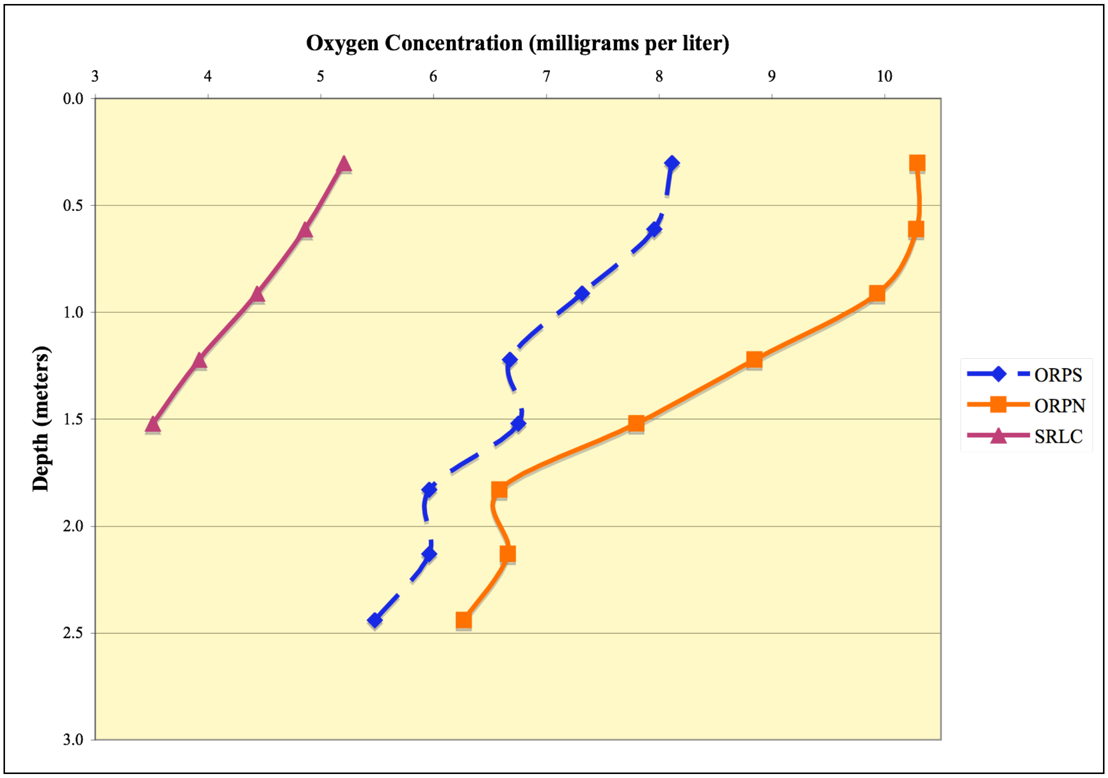

Figure 4. Hypsograph of depth (meters) versus 2008 oxygen concentration (mg/l) for the three Laguna de Santa Rosa sites.

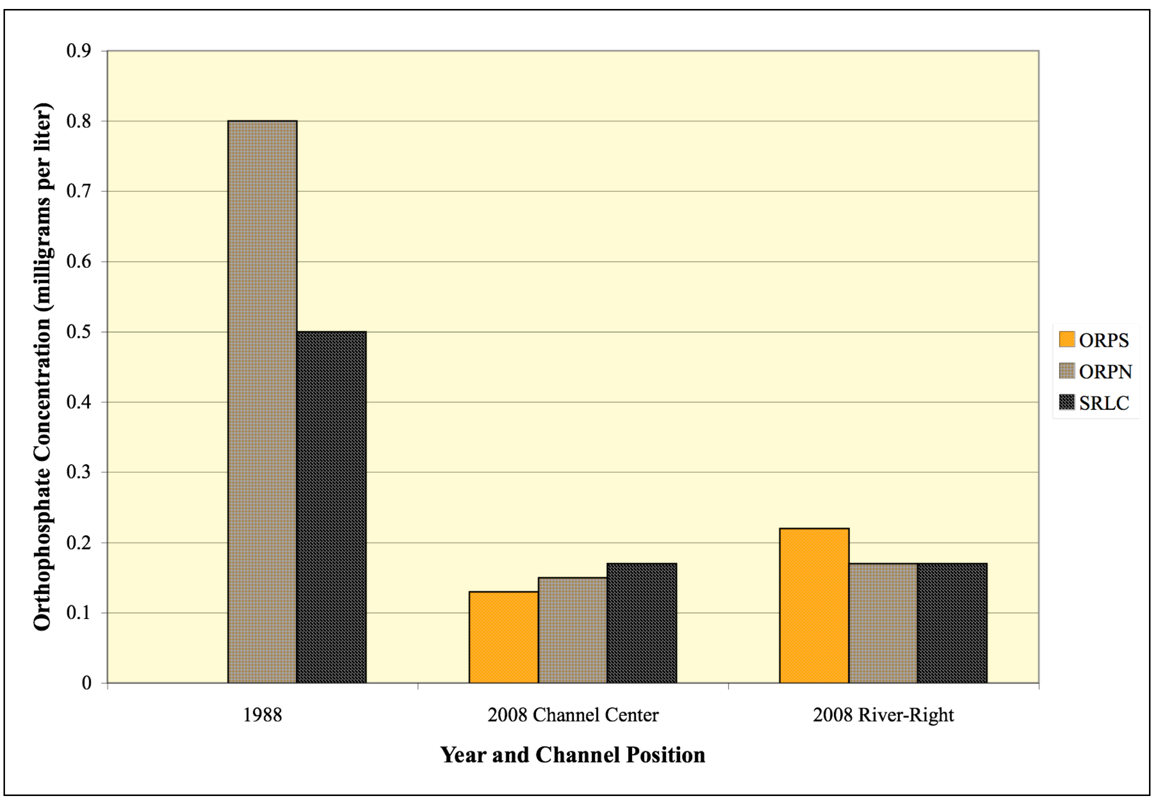

Figure 5. Average orthophosphate (PO_4) concentrations at all 2008 sampling sites along the river-right bank and the channel center. 1988 data from Smith et al. (1989).

Fish Community Survey

Gillnet Surveys

We fished gillnets for almost 10 hours and captured a total of 30 fish consisting of four species: common carp (18 fish), Sacramento blackfish (7 fish), black crappie *Pomoxis nigromaculatus* (4 fish), and Sacramento sucker *Catostomus occidentalis* (1 fish). This is the first known documentation of black crappie in the Laguna de Santa Rosa. The 2008 catch was much higher than the gillnet catch made by Smith et al. (1989) at the same sites during the summer in 1988, when only 6 fish were captured (1 common carp, 4 green sunfish *Lepomis cyanellus*, and one bluegill *Lepomis macrochirus*) despite 48 hours of effort. All common carp and Sacramento blackfish were adults; some of the carp contained well-developed testes and ovaries. 83 percent of the fish were caught at ORPN; this site also had the most diversity (Figure 6). Although we saw fishermen with both white catfish *Ameiurus catus* and black bullhead *Ameiurus melas* at the Occidental Road Reach during a presurvey site inspection, we captured neither of these species in gillnets nor seine hauls. The nocturnal nature of catfishes, coupled with the full moon, may have rendered these species inactive during our sampling and thus invulnerable to our nets

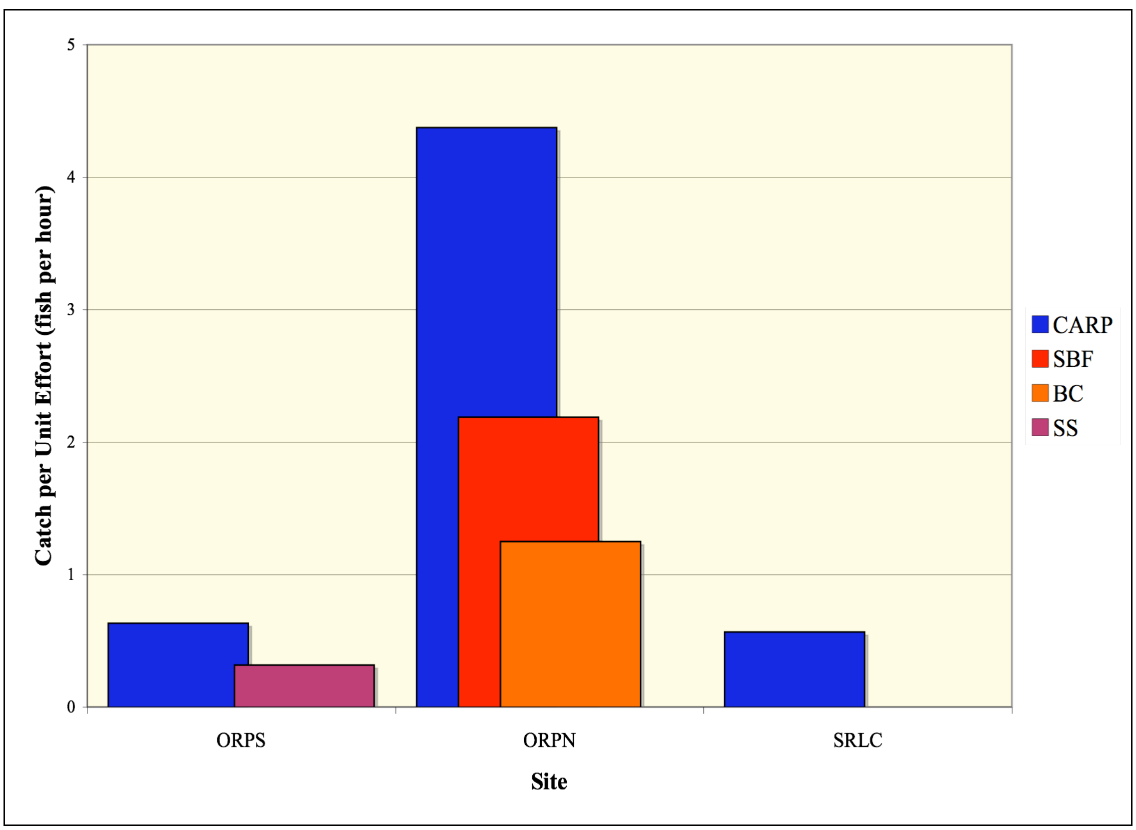

Figure 6. Catch-per-unit-effort values (fish per minute) for fishes captured by gillnetting in 2008 (CARP = common carp, SBF = Sacramento blackfish, BC = black crappie, and SS = Sacramento sucker).

(Moyle and Cech 2004, Moyle 2002). None of the common carp, all of the Sacramento blackfish, one of the Sacramento suckers, and two of the black crappies were infected with anchor worms *Lernaea* spp.

The abundances of the fishes caught in 2008 bear a resemblance to all the fishes captured by gillnetting during all sampling months at the Occidental Road Reach and SRLC in 1988 (Figure 7). In both years, common carp was the most frequently captured fish, followed by Sacramento blackfish, a sunfish species (green sunfish in 1988 and black crappie in 2008), and Sacramento sucker. The pattern in the 2008 catch is also similar to the gillnet catch made in 1988 for all sites and all sampling months: we captured three of the four most abundant fishes gillnetted in 1988 (Figure 8). The only disparities were that our third most-abundant species was black crappie instead of green sunfish, and our most abundant species was common carp rather than Sacramento blackfish.

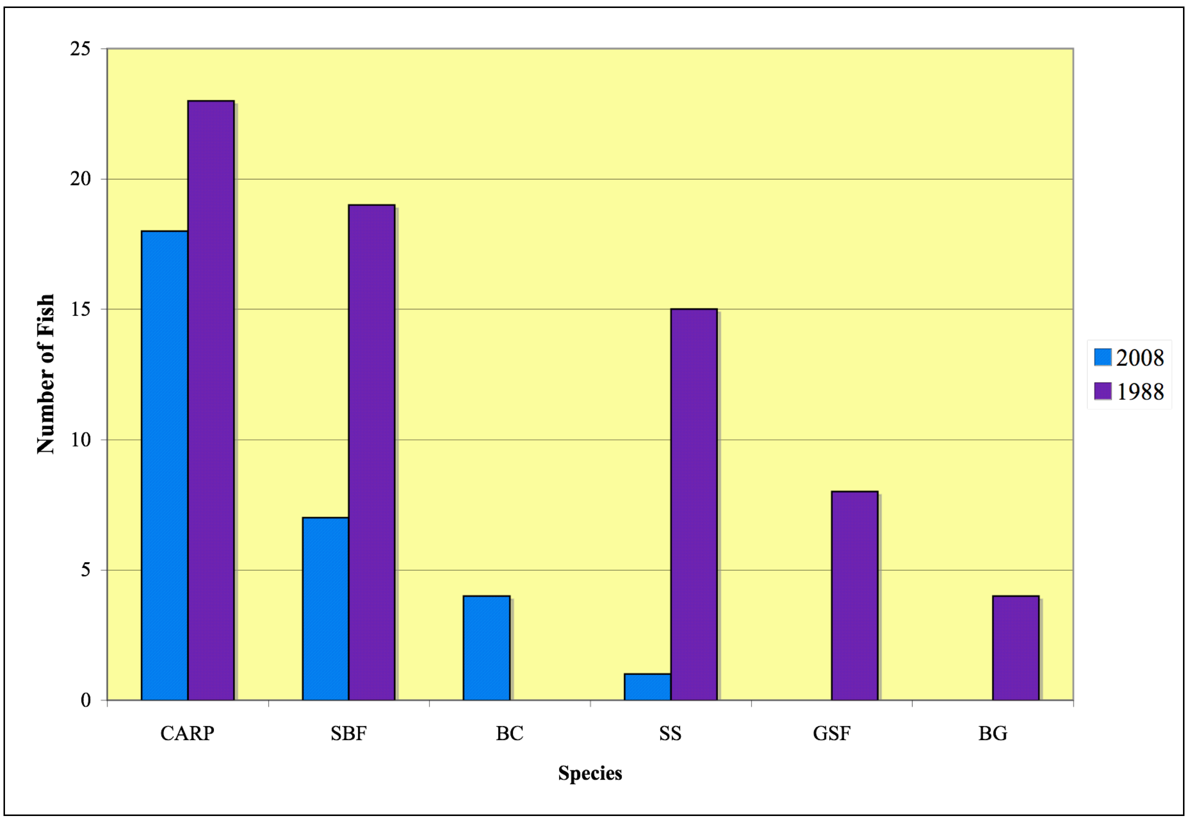

Figure 7. Number of fishes captured by gillnet for all sites in 2008 (turquoise bars) and for the Occidental Road Reach and SRLC during all sampling months in 1988 (purple bars; GSF = green sunfish, BG = bluegill; other acronyms same as in Figure 6). Data from 1988 taken from Smith et al. (1989).

Seine Surveys

We captured 1,250 fish, of which 89 percent (1,110) were western mosquitofish. Aside from western mosquitofish, we caught eight other species in the seine hauls: Sacramento blackfish (3 fish), black crappie (6 fish), Sacramento sucker (2 fish), bluegill (23.5, of which one fish was a green sunfish-bluegill hybrid), riffle sculpin *Cottus gulosus* (1 fish), largemouth bass *Micropterus salmoides* (6 fish), fathead minnow *Pimephales promelas* (13 fish) and green sunfish (5.5 fish). This is the first known documentation of fathead minnow and riffle sculpin in the Laguna de Santa Rosa.

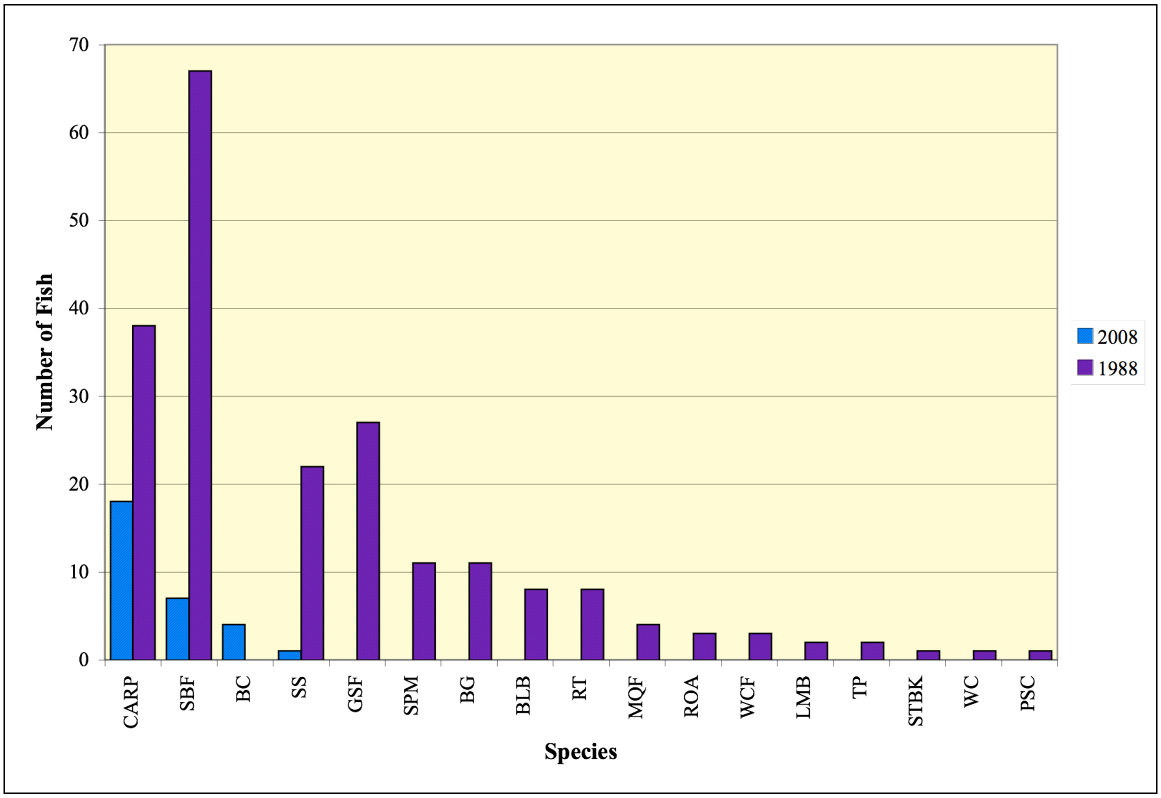

Figure 8. Number of fishes captured by gillnet for all sites in 2008 and for all sites and sampling months in 1988 (SPM = Sacramento pikeminnow *Ptychocheilus grandis*, BLB = black bullhead, RT = rainbow trout *Oncorhynchus mykiss*, MQF = western mosquitofish, ROA = California roach *Lavinia symmetricus*, WCF = white catfish, LMB = largemouth bass, TP = tule perch *Hysterocarpus traski*, STBK = threespine stickleback *Gasterosteus aculeatus*, WC = white crappie *Pomoxis annularis*, PSC = prickly sculpin *Cottus asper*; all other acronyms the same as in figures 6 and 7). 1988 data taken from Smith et al. (1989).

We also caught a number of small minnows (21 fish), sunfishes (57 fish), and sculpins (2 fish) that were not identified to the species level. Abundance of fishes other than mosquitofish was somewhat lower at the SRLC site than at the Occidental Road Reach sites (Figure 9), while mosquitofish were much more abundant at the ORPN and SRLC sites than at the ORPS site (Table 5). Like the gillnet survey, we seined many more fish than did Smith et al. (1989) in 1988 at the same sites. Additionally, we captured 18 red swamp crayfish *Procambarus clarkii* and 4 bullfrog *Rana catesbeiana* tadpoles. All Sacramento blackfish, green sunfish, and largemouth bass were young-of-year; the bluegills were mostly young-of-year, although a few were juveniles and adults; the sculpin and Sacramento suckers were probably juveniles; and the black crappie, fathead minnows, and western mosquitofish were a mixture of juvenile and adult fish (Moyle 2002). The bluegill-green sunfish hybrid was an adult that appeared gravid. Of seined fishes analyzed for gut contents, greater proportions of smaller species and young-of-year fishes were infected with anchor worms than larger, older fish (Table 4). 50 percent of the mosquitofish from the SRLC site that were analyzed for gut contents contained hookworms in their digestive tracts.

Table 3. Catch-per-unit-effort values (fish per seine haul) for mosquitofish only and all fishes for each site seined in 2008.

Site	ORPS	ORPN	SRLC
MQF CPUE	41	205	187
All Fishes CPUE	59	224	200

Table 4. Percentage of fishes from seine hauls analyzed for gut contents that were infected with anchor worms (YOY = young-of-year).

Species/Life-History stage	Number Analyzed	Number Infected	Percent Infected
Sacramento blackfish/YOY	3	1	33%
Fathead minnow/adult	13	7	54%
Western mosquitofish/adults	57	11	19%
Black crappie/juveniles, adults	6	0	0%
Largemouth bass/YOY	4	2	50%
Bluegill/YOY	25	4	16%
Bluegill/juveniles	7	0	0%
Green sunfish/YOY	5	1	20%

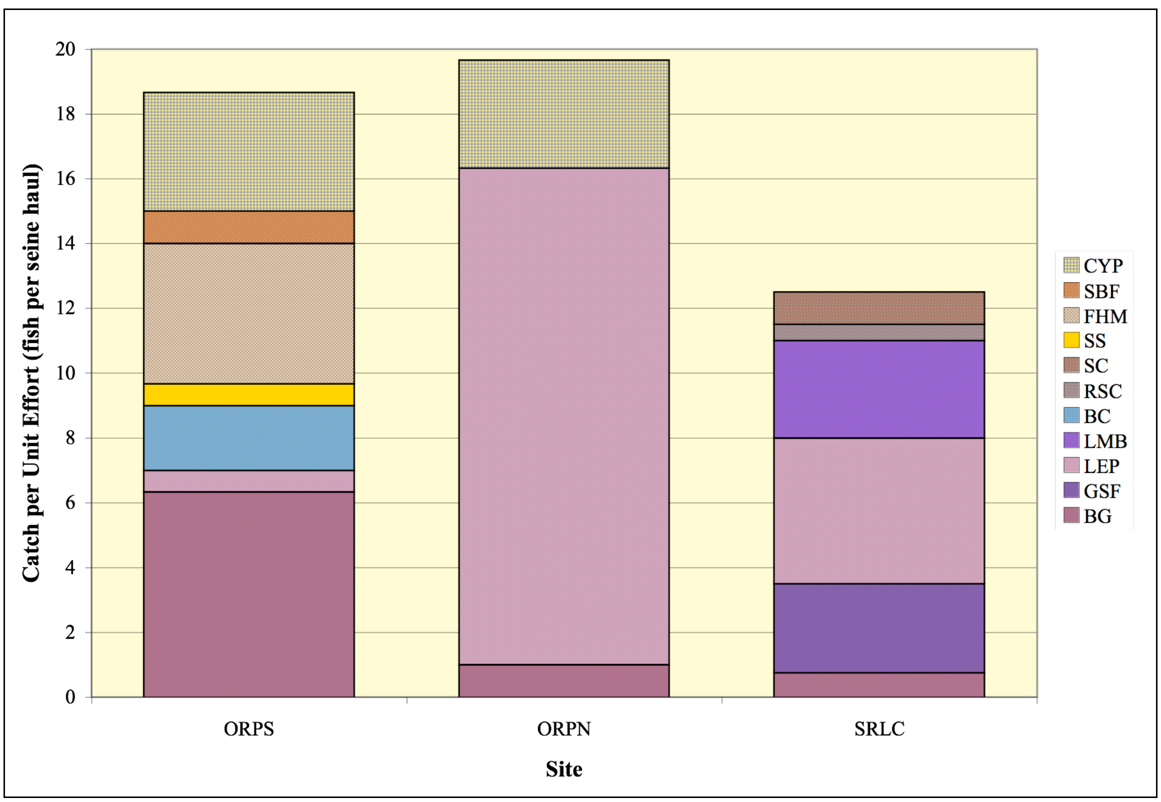

Figure 9. Catch-per-unit-effort values (fish per seine haul) for fishes other than mosquitofish seined from ORPS, ORPN, and SRLC in 2008 (CYP = unknown minnow species, FHM = fathead minnow, SC = unknown species from the genus *Cottus*, RSC = riffle sculpin, LEP = unknown species from the genus *Lepomis*; all other acronyms the same as in figures 6 - 8).

There were more differences in the seine catches between our and the Smith et al. (1989) surveys than in the gillnet catches. The major disparity in the seine catches at the Occidental Road Reach and the SRLC sites between the two surveys was the low number of mosquitofish captured in 1988 (Figure 10). The seine catches from 1988 incorporating all sites was more similar to that of the 2008 seine catches in that western mosquitofish and *Lepomis* species were the dominant species in both surveys. A substantial amount of California roach was captured in 1988, while none were caught in 2008; however, virtually all of these fish were caught in one seine haul in a reach by Todd Road that was not sampled in 2008.

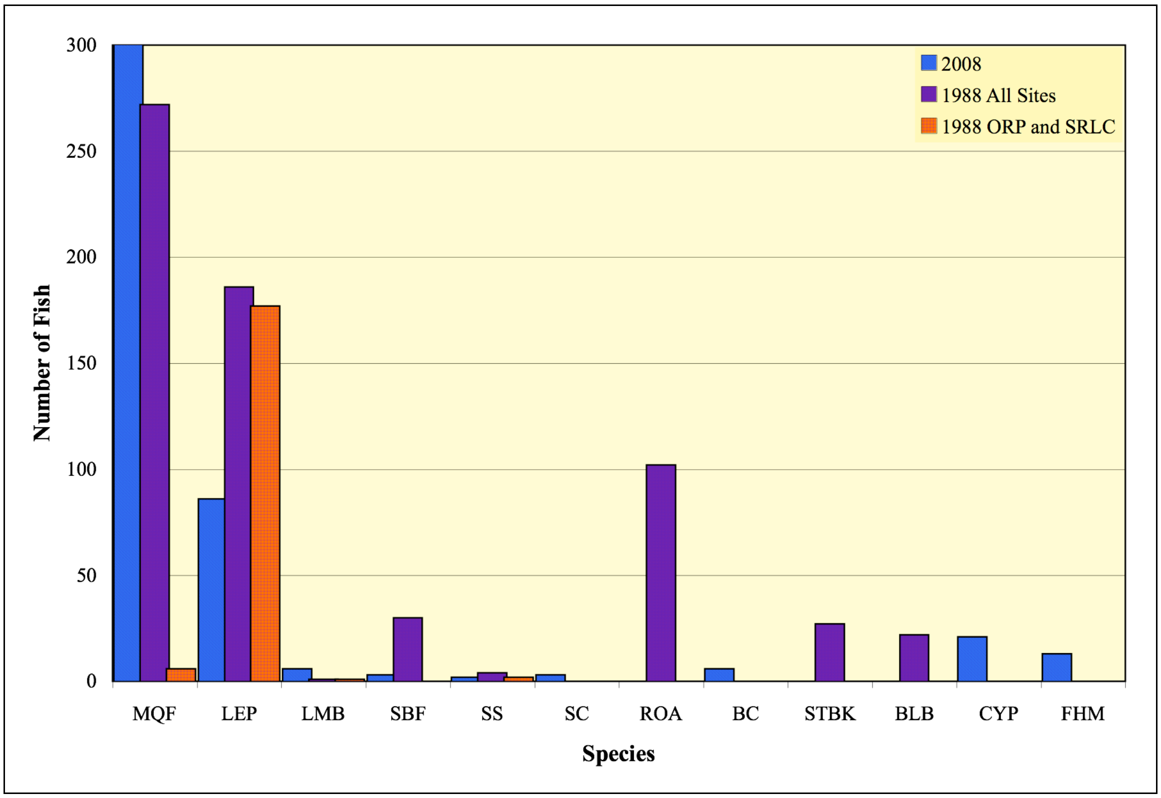

Figure 10. Number of fish seined from the 2008 survey (blue bars), from the Occidental Road Reach and the SRLC sites in 1988 (orange bars), and from all sites in 1988 (purple bars). Green sunfish and bluegill were pooled in one category, LEP, while riffle sculpin were pooled with unidentified *Cottus* species in SC. Total number of mosquitofish captured in 2008 was 1,110. Acronyms same as in figures 6-9. 1988 data taken from Smith et al. (1989).

Gut Content Analyses

All Sacramento blackfish and 12 common carp from the gillnet sets were sacrificed for gut-content analyses. We also killed all largemouth bass, all black crappie, 32 bluegill, 60 mosquitofish, all green sunfish, all fathead minnows, and all Sacramento blackfish captured in the seine hauls for gut-content analyses. The majority of fish killed were analyzed (Table 5), although a few were retained as type-locality specimens. The diversity of fishes evaluated for gut contents was much higher at the ORPS site (Table 5).

Fullness-rank statistics suggest that sunfishes and Sacramento blackfish were feeding actively during much of the survey (Table 5). However, common carp, fathead minnows, and western mosquitofish varied more in stomach fullness. In particular, mosquitofish appeared to feed more later in the morning and to feed more at the Occidental Road Reach sites than at the SRLC site (Table 6).

Table 5. Sample sizes, total number of diet items counted and identified, and fullness-rank statistics for species and life-history stages of fishes analyzed for gut contents captured from gillnets (common carp and adult Sacramento blackfish) and seine hauls (all other fishes and life-history stages) in 2008.

Species/Life-History Stage	Sample Size			Number of Diet Items	Mean Fullness Rank	Std. Dev. Fullness Rank
	ORPS	ORPN	SRLC			
Sacramento blackfish/adults		4		755,320	3.5	1.0
Sacramento blackfish/YOY	3			126	4.0	0.0
Fathead minnow/adults	13			66	1.8	0.8
Common carp/adults	2	3	2	1460	2.1	0.9
Western mosquitofish/adults	20	19	18	1601	2.8	0.9
Black crappie/juveniles, adults	6			95	4.0	0.0
Largemouth bass/YOY			4	834	4.0	0.0
Bluegill/YOY	10	15		1327	3.7	0.5
Bluegill/juveniles	4	2	1	256	3.5	1.0
Green sunfish/YOY			5	346	4.0	0.0

Table 6. Mean fullness ranks with sample sizes in parentheses for western mosquitofish seined at six site locations and the time seining occurred.

Site Location	Mean Fullness Rank	Sampling Time
ORPNDS	2.4 (7)	7:45
ORPNUS	3.6 (12)	10:35
ORPSDS	3.5 (8)	8:55
ORPSUS	2.4 (12)	7:20
SRLCDS	1.8 (6)	13:38
SRLCUS	2.7 (12)	14:10

Both numerical-percentage and frequency-occurrence values show that zooplankters were the most important diet items for young-of-year fishes and western mosquitofish, although adult chironomids were also frequently eaten by western mosquitofish (Figures 11-13 and Table 5). Of 1,601 diet items found in the western mosquitofish guts, only one was a mosquito. Bosminidae was generally the most important zooplankter in the diets of fathead minnows, western mosquitofish, and young-of-year Sacramento blackfish in the Occidental Road Reach sites, while the diet of young-of-year bluegills was dominated by zooplankters from the family Cyclopidae (figures 11 and 12). Conversely, daphniid zooplankters were most important to western mosquitofish and to young-of-year sunfishes at the SRLC site (Figure 13). In general, larger bluegills and adult common carp were more dependent on benthic and vegetation-dwelling aquatic insects, especially chironomid larvae (figures 11 and 14). Most of the carp had very little food in their guts; additionally, detritus never made up more than 25 percent of the volume of the gut contents. Black crappie was the only species that preyed on other fish, consuming young-of-year common carp and western mosquitofish (Figure 13). The diet of the four adult Sacramento blackfish was substantially different from young-of-year blackfish and all other species by being comprised overwhelmingly of phytoplankton, which, along with rotifers, was present in all of the adult fish (Figure 14).

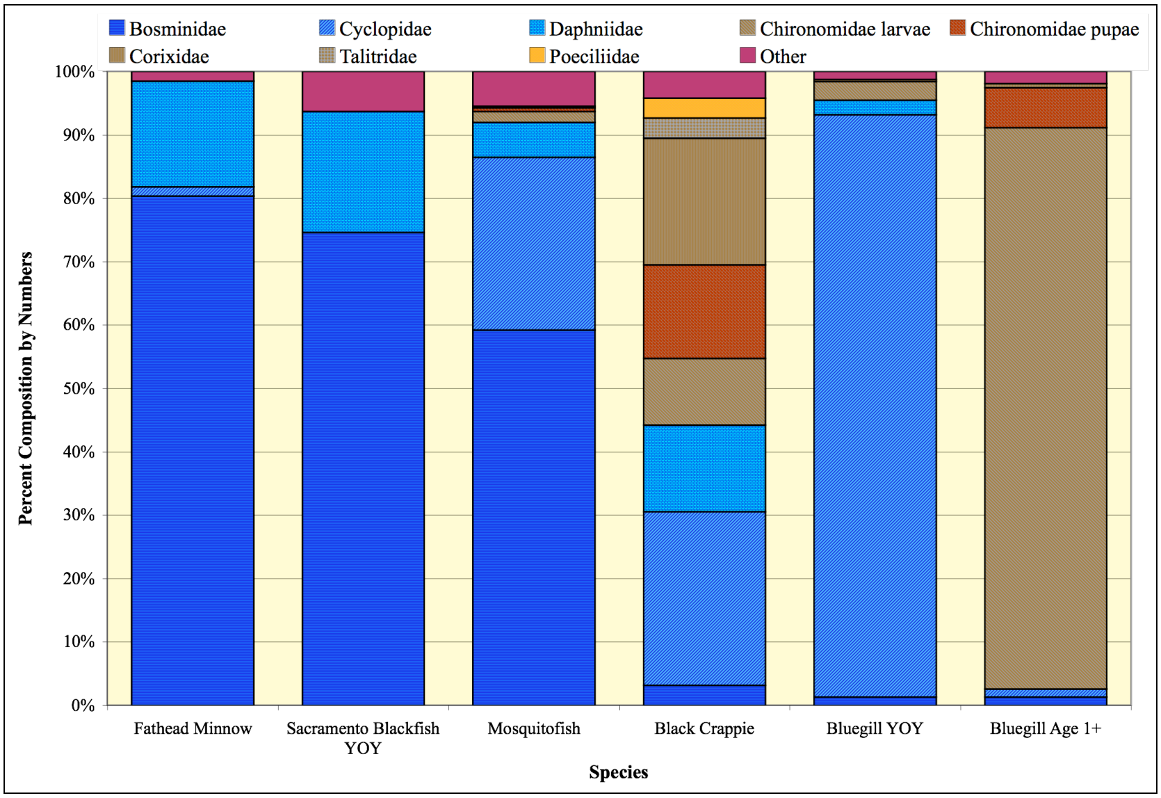

Figure 11. Numerical-percentage values for fishes seined at the ORPS site in 2008; zooplankton taxa are shaded blue, while vegetation-dwelling and benthic invertebrates are colored in shades of brown.

Table 7. Frequency-of-occurrence values for diet items commonly eaten by fishes seined at the ORPS site in 2008.

Diet Item	Fathead Minnow	Sacramento Blackfish YOY	Mosquitofish	Black Crappie	Bluegill YOY	Bluegill Age 1+
Bosminidae	63%	100%	60%	17%	30%	25%
Chironomidae adult			45%			
Chironomidae larvae			20%	100%	50%	100%
Chironomidae pupae			10%	67%		75%
Corixidae				100%	10%	25%
Cyclopidae	13%		45%	83%	100%	25%
Daphniidae	13%	67%	55%	50%	30%	
Osteichthyes				67%		
Talitridae			5%	17%		

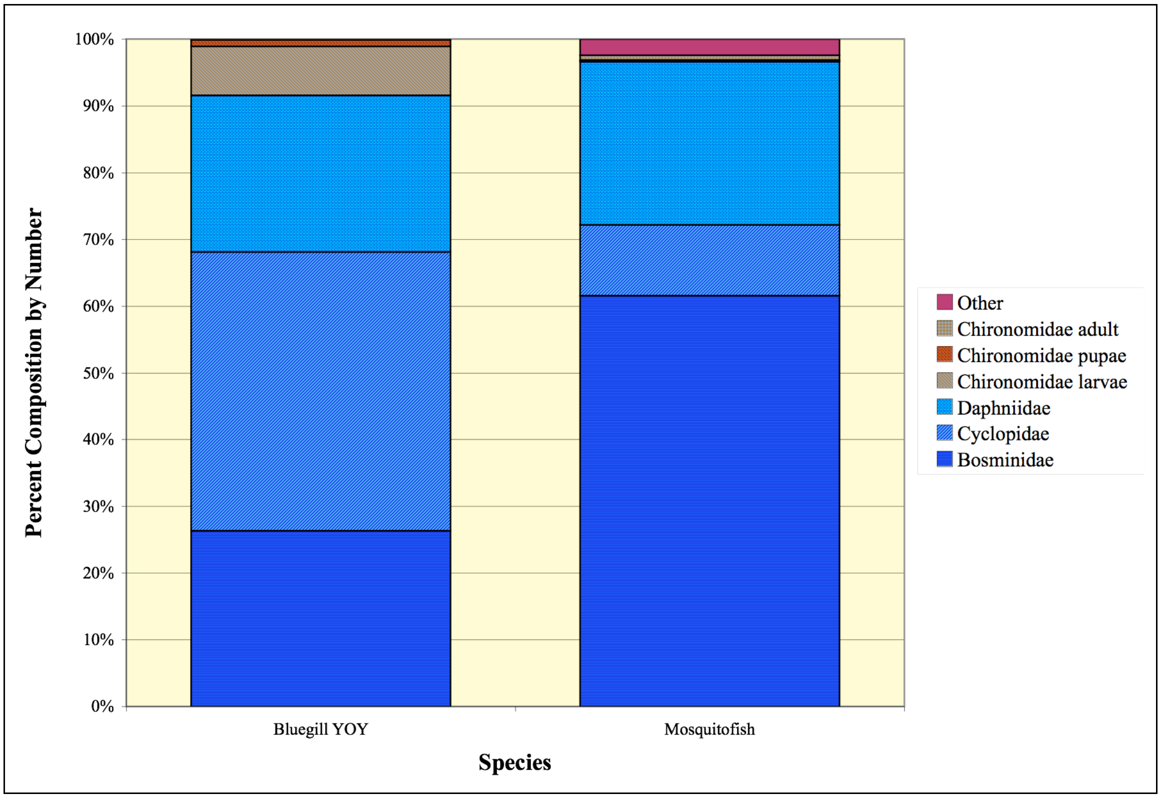

Figure 12. Numerical-percentage values for fishes seined at the ORPN site in 2008; zooplankton taxa are shaded blue, while vegetation-dwelling and benthic invertebrates are colored in shades of brown.

Table 8. Frequency-of-occurrence values for diet items commonly eaten by fishes seined at the ORPN and SRLC sites in 2008.

Diet Item	ORPN		SRLC		
	Mosquitofish	Bluegill YOY	Mosquitofish	Green Sunfish YOY	Largemouth Bass YOY
Baetoidea					50%
Bosminidae	74%	40%	6%	60%	
Chironomidae adult	32%	7%	47%		
Chironomidae larvae	16%	93%	18%		50%
Chironomidae pupae		33%			
Chydoridae			29%	40%	25%
Corixidae					25%
Cyclopidae	68%	93%	18%	100%	25%
Daphniidae	74%	60%	53%	100%	100%
Hymenoptera	16%				
Talitridae	16%				

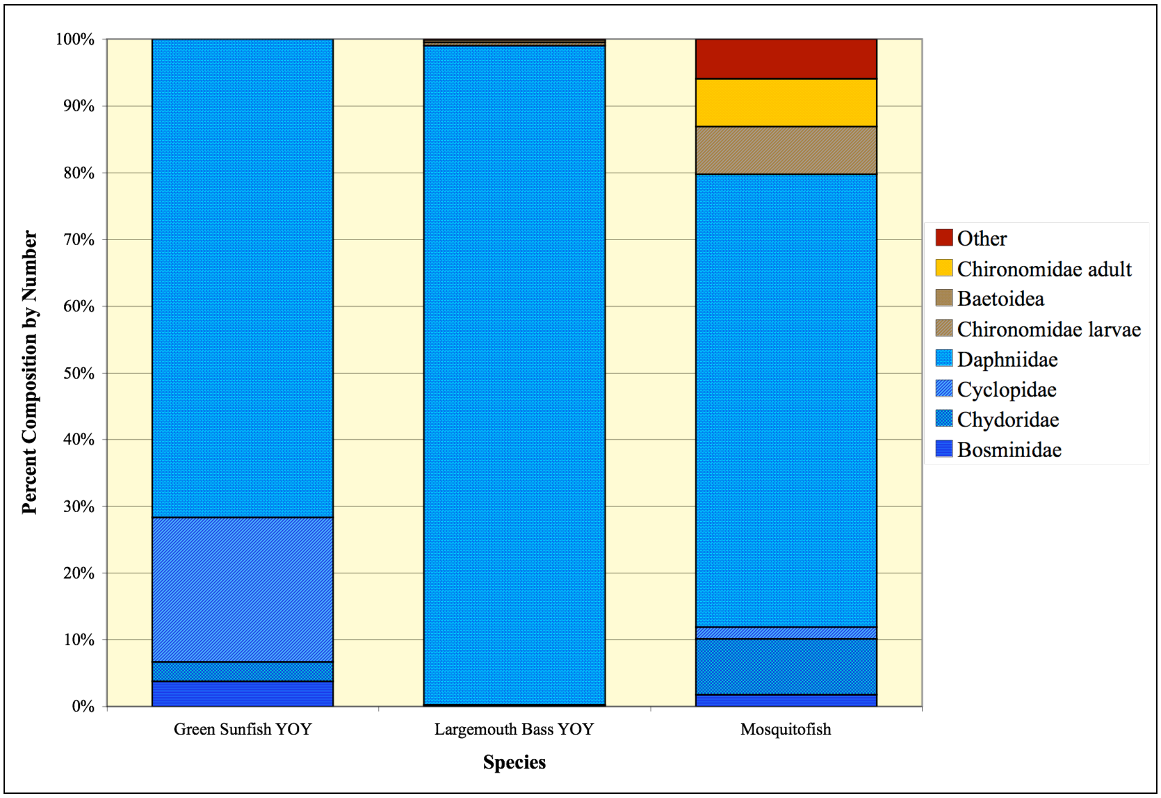

Figure 13. Numerical-percentage values for fishes seined at the SRLC site in 2008; zooplankton taxa are shaded blue, while vegetation-dwelling and benthic invertebrates are colored in shades of brown.

Table 9. Frequency-of-occurrence values for common carp gillnetted at the ORPS and ORPN sites in 2008.

Diet Item	Bosminidae	Chironomidae larvae	Chironomidae pupae	Chydoridae	Corixidae	Cyclopidae	Daphniidae	Fish Eggs	Ostracoda
Frequency of Occurrence	80%	80%	20%	20%	20%	60%	80%	20%	20%

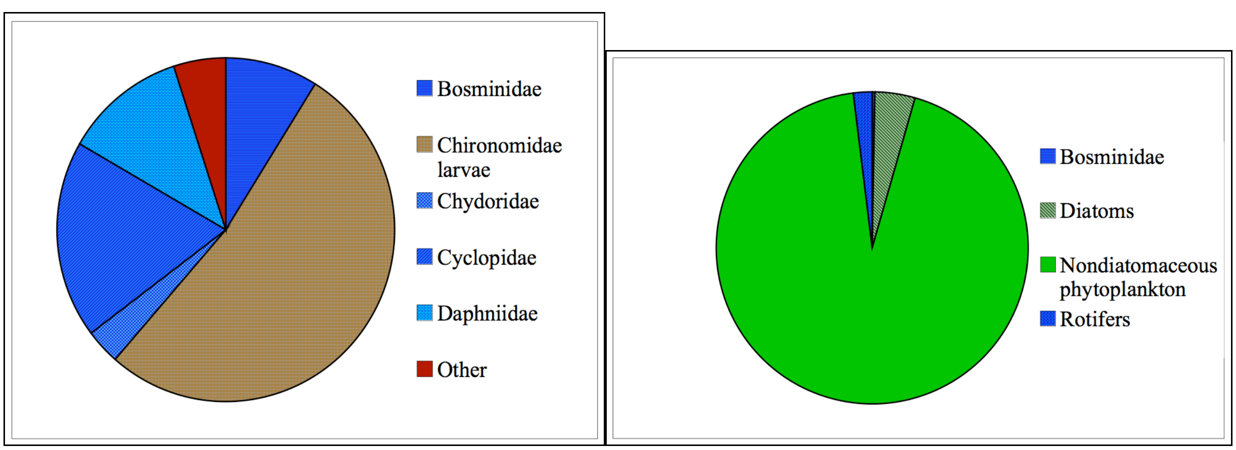

Figure 14. Numerical-percentage values for common carp (left pie chart) and Sacramento blackfish (right pie chart) captured by gillnet at the Occidental Road Reach sites in 2008; zooplankton taxa are shaded blue, while phytoplankton taxa are colored in greens.

Discussion

Water Quality and Phytoplankton Surveys

The patterns in differences in some of the water-quality parameters between the Occidental Road Reach and SRLC sites found in 2008 were also present in 1988 (Smith et al. 1989): turbidity values and oxygen concentrations were higher at the Occidental Road Reach, and water temperatures were about the same for both reaches. However, both chlorophyll a and turbidity measurements at the SRLC site were higher in 1988, suggesting that there was less shading and thus a greater density of phytoplankton. The greater disparity seen in the mean oxygen concentrations measured in the two reaches between 1988 and 2008 could have been due to the timing of sampling: the Occidental Road Reach was sampled in the morning during 2008, while the higher temperature at this reach in 1988 intimates that sampling occurred in the afternoon. Photosynthetic activity was probably higher in 1988, resulting in the very high oxygen reading.

PO_4 concentrations were noticeably lower in 2008 than in 1988 at both reaches, and, unlike in 1988, they were about the same for both reaches during 2008. NO_3, however, was virtually nonexistent at all sites for both years. Because nitrogen is usually the limiting nutrient in highly eutrophic systems (Downing and McCauley 1992), the absence of NO_3 and the presence of PO_4 during the growing season is an expected result. However, if the pool of PO_4 is the same, sites with larger phytoplankton populations should have lower PO_4 concentrations. Although this may have been the case in 1988 (chlorophyll a was not measured at the Occidental Road Reach), it was not in 2008: the Occidental Road Reach sites had PO_4 concentrations about the same as those for the SRLC site, while chlorophyll a was much lower at SRLC.

In 2008, the Occidental Road Reach was much more turbid than in 1988 and than the SRLC site in both surveys. The daytime oxygen measurements, pH, and chlorophyll a data show that this was partly due to greater phytoplankton densities at the Occidental Road Reach, which is much wider and much more exposed to sunlight. Additionally, the more open water of the Occidental Road Reach subjects it to greater wind-induced currents, which can stir up the fine-grained sediment and cloud the water. Moreover, common carp were far more abundant at the Occidental Road Reach in 2008 than in 1988 or at the SRLC site. Carp are well known for stirring up sediments through their rooting feeding behavior (Moyle 2002, Sibbing 1988), and thus their higher densities may have also contributed to the very turbid water at the Occidental Road Reach.

Dissolved oxygen concentrations decreased with increasing depth at all three sites, although the disparity between surface and bottom concentrations was greater at the Occidental Road Reach. The decline in oxygen with depth was mainly due to phytoplankton photosynthesis and respiration via decomposition in the sediments. Both of these processes were probably higher at the Occidental Road Reach because of its more still-water environment, which accounts for the differences among sites.

Fish Community Survey

We caught many more fish in August 2008 from the Occidental Road Reach and at the Santa Rosa Creek-Laguna de Santa Rosa confluence than did Smith et al. (1989) in the summer of 1988. At first glance, this may not seem surprising: we had six gillnet sets while Smith et al. (1989) had three. However, all of our sets lasted for about 90 minutes while those fished in 1988 lasted for 24 hours. Thus, if we were to standardize catches from 2008 and 1988 by hours fished, the number of fish caught per hour in 2008 was almost 44 times higher than in the summer of 1988. There could be a number of factors responsible for this. First, we may have been fishing our nets in different areas of each reach that had greater concentrations of fish than those sampled in the 1988 survey. Second, conditions for growth and reproduction within the last 20 years may have improved; the turbidity data provide some accompanying evidence that carp might have been more abundant in the Occidental Road Reach in 2008 than in 1988. Third, Smith et al. stated that crayfish occasionally ate much of their gillnet catch; if this were the case, then their results would have been biased low. However, the effect of crayfish on the catches would be contingent on at least three factors: (1) how quickly they could devour a captured fish; (2) the period between crayfish consumption of the captured fish and the end of the set; and (3) the time of fish capture. In order for crayfish to have the greatest effect on catches, all fish would have to be captured and attacked immediately after gillnet deployment. Because this is very unlikely to be the case, then losses of catches to crayfish cannot solely explain the discrepancy between the two years' catches.

The similarity in the gillnet catches from all sites in 2008 and from the Occidental Road Reach and SRLC sites for all sampling months in 1988 is striking (Figure 7). All but two of the fishes captured by gillnet in 2008 came from the Occidental Road Reach (Figure 6), which is the largest body of open water in the Laguna de Santa Rosa. Thus, the Occidental Road Reach may be large enough to provide a refuge during dry periods for the majority of the Laguna de Santa Rosa's fish species. Additionally, the Occidental Road Reach is roughly the center point in the longitudinal profile of the Laguna de Santa Rosa. Consequently, the Occidental Road Reach may be relatively representative of the Laguna mainstem. As a result, our intensive sampling of the Occidental Road Reach could be why our pattern of gillnet catches so closely resembles the combined catches that Smith et al. (1989) made on many reaches of the Laguna de Santa Rosa (Figure 8). Most importantly, the similarity in the catches between the two surveys intimates that the composition of the fish community has changed little in the last 20 years.

We captured a greater diversity of fish by seine in 2008 relative to that caught by Smith et al. (1989) at the SRLC and Occidental Road Reach sites in 1988 (Figure 10). However, we pulled twice as many seine hauls at those sites, so the difference in diversity was probably due to the different effort levels. Additionally, we captured far more western mosquitofish than Smith et al., which may have been due to recent plantings by the Marin-Sonoma Mosquito and Vector Control District. The 2008 seine catches better resemble the seine catches from all sites and all sampling months in 1988 in that western mosquitofish and lepomids (i.e., bluegills and green sunfish) were the dominant fishes (Figure 10). Since the bulk of our catch came from the Occidental Road Reach, then the explanations given for the similarity in the gillnet catches between the two years also applies to the seine catches.

There were substantial differences in the gillnet sets among the three sites, with the ORPN site hosting both the largest catch and greatest species richness (Figure 6). This site was generally wider and contained more open water than the ORPS site. As a result, the ORPN site received more sunlight and more wave action via wind-generated currents than the ORPS site, which would explain the higher chlorophyll a concentrations at ORPN (Figure 3). Consequently, our relatively high catch of Sacramento blackfish at the ORPN site was probably due to the abundance of their major food item, phytoplankton (Figure 14). In addition to being wider, the ORPN site was a little over a meter deeper than the ORPS site. Although we only analyzed three carp for gut contents from the ORPN site, two of these fish contained almost no food items. Thus, our larger catch of common carp at ORPN may have been due to a higher density of fish using the site as a refuge during an inactive period.

We caught only two common carp and no Sacramento blackfish in the gillnet sets at SRLC. When considered in the context of food availability, this is an expected result. The greater shading of the water at SRLC probably limited phytoplankton growth (Figure 3) and hence the amount of food available to adult Sacramento blackfish. Less aquatic vegetation was present at SRLC; consequently, chironomids - the most important food item for common carp (Figure 14; Table 9) - were probably less abundant at the SRLC site (Merritt et al. 2008, McCafferty 1981) than the Occidental Road Reach sites. Additionally, the substrate at the SRLC site was substantially coarser than at the Occidental Road Reach. Since common carp are most commonly found on soft substrates (Moyle 2002, Brown 2000), which they suck in and from which they selectively retain certain food items with their dexterous throat (Sibbing 1988), then the SRLC site provided both a poorer food supply and feeding substrate than the Occidental Road Reach sites for this species.

Like the gillnet surveys, the catches in the seines differed substantially among the three sites. The ORPS site had the richest seine hauls, which, as for gillnets, was likely partially due to food availability. The ORPS site had lush growths of aquatic vegetation that contained abundant chironomid larvae; chironomids were important in the diets of black crappie and the larger bluegill captured at this site (Figure 11 and Table 7). The ORPS site also contained a greater diversity of habitats than the other two sites. Large woody debris and several species of macrophytes (e.g., water primrose, pennywort, tules *Typha* sp.) were present. The site was also more confined, forming two small cove-like fingers near the inlet. Consequently, a variety of cover was available to fishes for both hunting (i.e., black crappie) and evading predation (i.e., small minnows).

The species seined at the SRLC site were quite different from those captured at the Occidental Road Reach. For the sculpins and green sunfish, this is mainly due to the fact that SRLC had a coarser substrate and more riverine conditions than the Occidental Road Reach sites. Green sunfish are more streamlined than bluegills and thus better adapted to flowing waters; sculpins, with their cryptic coloration and large mouths, are geared for lying motionless among rocks and ambushing unsuspecting invertebrates (Moyle 2002). The presence of largemouth bass young-of-year and the relatively sedentary nature of the species (Moyle 2002) imply the presence of adult largemouth bass at or near SRLC. Although our dissolved-oxygen-concentration readings were lower at SRLC than the Occidental Road Reach sites, the more abundant phytoplankton at the Occidental Road Reach probably results in greater swings in oxygen concentration throughout the course of the day. Because largemouth bass are much larger than bluegills and green sunfish the first time they reproduce, and larger fish have greater oxygen demands than smaller fish (Moyle and Cech 2004), then oxygen concentrations at SRLC may be more tolerable for adult bass than at the Occidental Road Reach. Sculpins also require well-oxygenated water (Cech et al. 1990), which also supports oxygen concentrations remaining higher at the SRLC site.

The mesh sizes and type of sampling (e.g., active versus passive) bias the gillnets and seines for catching larger and smaller fish, respectively; however, when used concurrently, the two methods provide information on the lateral distribution of fishes. Adult Sacramento blackfish were only present in the gillnets set at the ORPN site, suggesting that these fish reside predominantly in open water with high densities of phytoplankton. We only caught carp in the gillnet sets, which intimates that this species was also predominantly using the deeper, open-water areas. Although we captured four black crappie in the gillnets, we noticed that these fish were netted very close to macrophyte beds. Since this species was also caught in seine hauls, it appears that black crappie were probably most common in the open water adjacent to macrophyte beds. Conversely, we captured several relatively large bluegills (with body depths equal to the crappies) in the seine hauls and none in the gillnets, suggesting that these fish were holding much closer to the macrophytes.

Of the 10 species we captured, only three were native fishes: Sacramento sucker, Sacramento blackfish, and riffle sculpin. Together, the abundances of these fishes make up less than one percent of the 2008 gillnet and seine catches combined. Similarly, the proportion of the catches consisting of native fishes from these sites during summer in 1988 was also much less than one percent (Smith et al. 1989). The most abundant native fish captured at both sites in 1988 and 2008 was Sacramento blackfish. Unlike other fishes from the order Cypriniformes native to the Russian River watershed (e.g., Sacramento pikeminnow, Sacramento sucker, California roach), Sacramento blackfish spawn on vegetation in slow-moving or still water rather than in riffles (Moyle 2002). Additionally, Sacramento blackfish have an extraordinary ability to withstand very low levels of dissolved oxygen (Moyle and Cech 2004). With the exception of the three Sacramento suckers we captured, all fishes caught in 2008 (in addition to white catfish and black bullhead) can also handle low oxygen concentrations and spawn either in still-water nests or in vegetation. Thus, our catches suggest that the major abiotic factors contributing to the composition of the Laguna de Santa Rosa's fish community are low dissolved oxygen concentrations and lack of riffle habitat.

With the exception of two black crappies captured in the gillnet, the fishes infected with anchor worms were all smaller scaled (Table 4). The Sacramento blackfish from the gillnets, the species with the smallest scales, were heavily especially infested with the parasite (Figure 15).

Figure 15. Adult Sacramento blackfish captured by gillnet showing anchor worm infestation (photo by Amber Manfree).

At first glance, it appears that fishes with larger scales (i.e., juvenile and adult sunfishes and common carp) may be better protected from attacks by anchor worms. However, common carp and larger sunfishes have both been found infected with anchor worms in other systems (Whitaker and Schlueter 1975, Amin et al. 1973). As a result, it is possible that these fishes may in fact have an immunity protecting them from the parasite (Whitaker and Schlueter 1975) rather than a physical defense.

Although some of the anchor worm infections looked grisly (Figure 15), the negative effects of the parasite on the fishes appeared to be minimal. None of the adult Sacramento blackfish were unusually thin, and the presence of young-of-year indicates that this species is spawning successfully. Additionally, several of the infected mosquitofish had both full guts and well-developed eggs. Likewise, there was no difference in the gut fullness between infected and uninfected largemouth bass, green sunfish, and young-of-year bluegill. Few of the seined fish had been attacked by more than one anchor worm, suggesting that the intensity of the infections may not have been large enough to substantially affect body condition or behavior (Barson et al. 2008). Because anchor worms are usually only prevalent when water temperatures are at their maximum (i.e., late summer; Adams 1984, Whitaker and Schlueter 1975, Amin et al. 1973), the otherwise apparent good health of the adult blackfish may have been due to the small part of the year when the parasite is active.

Gut Content Analyses

The diets of Sacramento blackfish and bluegill exhibited considerable changes from young-of-year to older fish. The young-of-year of both species fed almost exclusively on zooplankters, although cyclopids dominated the bluegill's diet while the blackfish ate only cladocerans (figures 11 and 12). The adult Sacramento blackfish fed heavily on phytoplankton such as diatoms and chlorophytes; the diet of larger and older bluegills was dominated by chironomids (figures 11 and 14). Despite the fact that our sample sizes were relatively low, especially for Sacramento blackfish, these shifts in diet with age have been commonly observed elsewhere (Moyle 2002).

Although the diets of both black crappie and the larger bluegill consisted primarily of aquatic insects (Figure 11, Table 7), there was apparently some food-resource partitioning between the two species. Black crappie focused on water boatmen from the family Corixidae and chironomid pupae, while chironomid larvae were overwhelmingly the most important food item for older bluegills (Figure 11, Table 7). The numerical-percentage method overestimates the value of small items (Hyslop 1980); consequently, measuring the mass or volume rather than the number of diet items better reflects the importance of the food types, although such methods are much more labor intensive. Hence, had we weighed the food items, the disparity in the diets between older bluegills and black crappie would have been even greater because of the much larger size of the water boatmen relative to the chironomids. Additionally, the diet data indicate habitat partitioning between the two species as well, which complements the seine and gillnet catches. Chironomid larvae usually burrow into soft sediments or macrophytes (Merritt et al. 2008); the larvae eaten by the bluegills were a bright green, a color that would provide good camouflage in aquatic vegetation. This suggests that the older bluegill were feeding on chironomid larvae within the macrophytes (e.g., pennywort) that lined the banks. Conversely, water boatmen can often be at the periphery of macrophyte beds, while chironomid pupae are eaten most frequently as they rise through the water column to emerge into adults (Merritt et al. 2008). Thus, it appears that the black crappie were feeding in the open water adjacent to the macrophyte beds, which is consistent with their behavior in other locations (Moyle 2002).

The diet of western mosquitofish was dominated by zooplankton taxa at both the Occidental Road Reach sites and at the SRLC site. Most importantly, the diet of western mosquitofish at the ORPS site overlapped most with that of young-of-year Sacramento blackfish and that of fathead minnows (Table 7). If population densities of one or more of these species are high enough, and shared food resources are in short supply, then the possibility of competition for food is greatest among these three species. Additionally, western mosquitofish fed on a wider range of items than any other species (tables 7 and 8), although this may be partially due to the larger sample size. However, their ability to utilize a diversity of food resources, coupled with their high density in the Laguna de Santa Rosa, suggests that they could compete with other species (that we did not analyze) for different food items.

The fullness ranks for mosquitofish show that they fed less in the early morning hours at the Occidental Road Reach and less at the SRLC site. The pattern seen at the Occidental Road Reach could have been partially the result of a lowering of activity due to a high threat of predation. Black crappie were most abundant at the upstream ORPS site and had eaten both western mosquitofish and small minnows. Fathead minnows and western mosquitofish both had relatively low fullness ranks at this site location, while young-of-year bluegill - which are deeper bodied and hence less susceptible to predation than fathead minnows and western mosquitofish - were full of zooplankters. However, the fullness ranks among the three species may have been because of differences in the availability of zooplankton taxa, since young-of-year bluegill fed mostly on cyclopids while the other two ate cladocerans (i.e., bosminids and daphniids). Western mosquitofish from the SRLC site had eaten far fewer organisms than fish from the Occidental Road Reach; however, this was primarily due to hookworms within the intestinal tract of half the fish analyzed from the SRLC site.

Chironomid larvae were the most important food item for common carp, although zooplankters were eaten as well. The dominance of benthic invertebrates and zooplankton taxa in the diet of common carp is a usual occurrence, especially considering the morphological specializations this species has for feeding on such food items (Sibbing 1988). It should be noted that the chironomid taxa in the guts of the carp appeared to be different than those eaten by the other fishes. If the carp we caught had been foraging when captured, then the chironomids they had eaten had probably come from the sediments near the channel center. Since it is very unlikely that the chironomid species in the sediments were the same as those in the macrophytes (Merritt et al. 2008), then the diet overlap between carp and larger bluegills was probably minimal.

Conclusions and Synthesis

Our results show that the Laguna de Santa Rosa is a highly eutrophic, low-velocity waterway that has not changed substantially since 1988. Water-quality data from both 1988 and 2008 revealed that decomposition and photosynthetic rates were very high and strongly affected dissolved oxygen concentrations. Concomitantly, most of the Laguna de Santa Rosa's fishes also persist in oxygen-deficient water and utilize aquatic vegetation in still water for spawning.

The gillnet and seine catches, coupled with the gut-content analyses, showed that there are two major pathways of energy flow through the food web of the Occidental Road Reach during summer (Figure 16). (We did not draw a food-web diagram for the SRLC site due to low sample sizes.) The first is based on aquatic insects that live in macrophytes or sediments and are fed upon by larger fishes (e.g., common carp, bluegills). The second is based on plankton, with zooplankton supporting smaller-sized species and young-of-year fishes and phytoplankton supporting adult Sacramento blackfish. Competitive effects over food resources are most likely for small fishes that feed heavily on zooplankters.

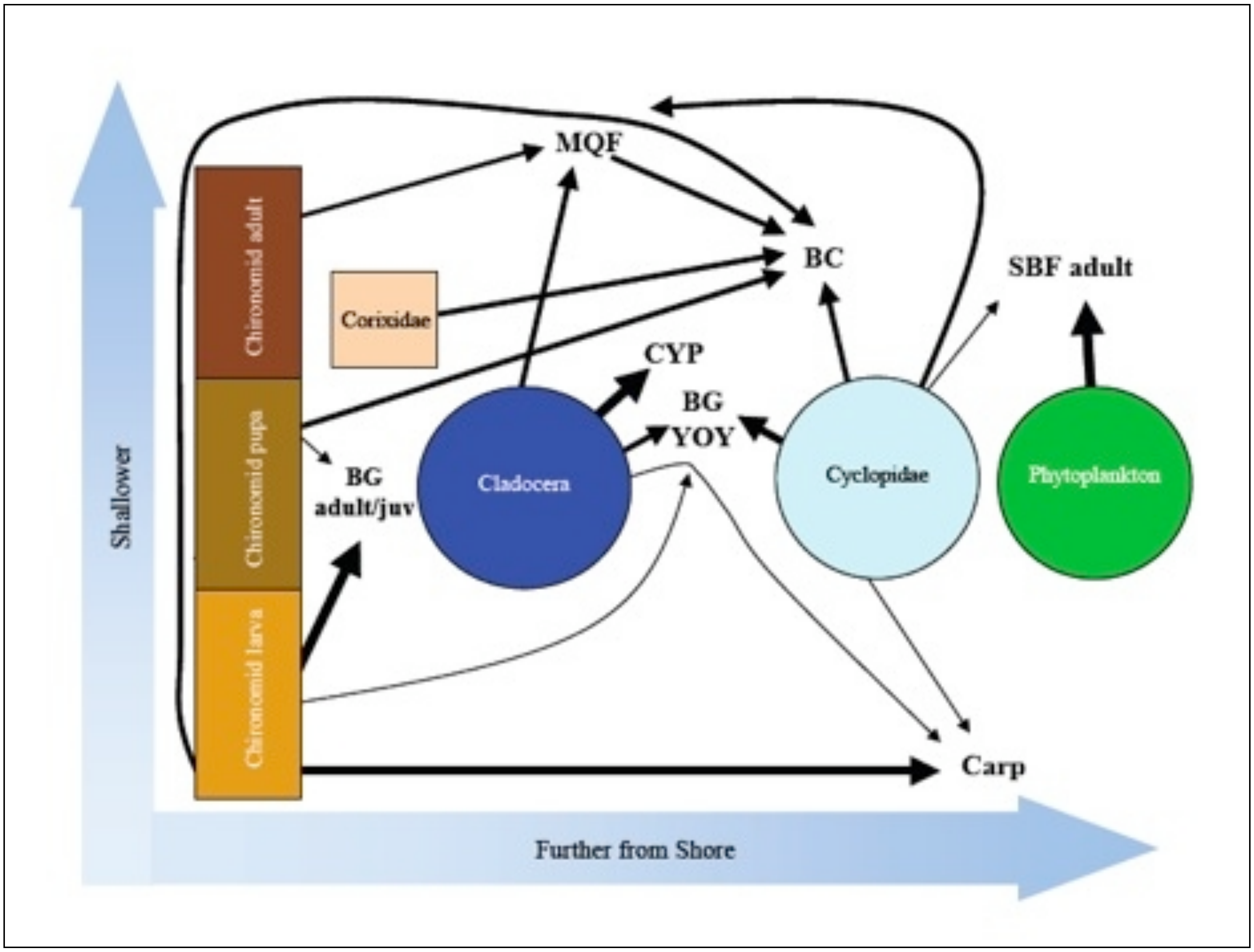

Figure 16. Food web for the Occidental Road Reach during the summer of 2008 (zooplankton taxa are in shades of blue, and aquatic insects are in shades of brown; size of arrows reflects relative importance of each food item based on frequency-of-occurrence and numerical-percentage values; acronyms the same as in figures 8 and 9 except for CYP, which includes both Sacramento blackfish young-of-year and fathead minnows).

The 2008 survey achieved our goals by providing insight on the Laguna de Santa Rosa's aquatic ecology and by providing data useful for restoration efforts. Additionally, it is remarkable that the results of the 2008 survey, which was conducted over a period of only two days, were quite similar to those obtained by the much more spatially and temporally comprehensive survey of 1988 (Smith et al. 1989). However, the information provided by the 2008 survey is limited in applicability. First, we sampled only two reaches for two days in the morning and afternoon, which makes extrapolating our results to different seasons, times, and reaches tenuous. Second, our small sample sizes predisposed our results to random effects. Third, inferences based on the family level of aquatic invertebrates are weakened because of the significant biological variation that can exist below that taxonomic level (Merritt et al. 2008). Fourth, we sampled neither the zooplankton nor crayfish appropriately. Fifth, the energy flow at lower trophic levels (e.g., phytoplankton to zooplankton) was not studied. A standardized sampling program, conducted each season at more reaches and sites, would alleviate the weaknesses of the 2008 study. Additionally, surveying crayfish and zooplankton with barrel traps and Schindler traps, respectively, would further clarify the food web of the Laguna de Santa Rosa.

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