Yosemite National Park

Division of Resources
Management and Science

Looking Downstream

2009 Update

Physical and Ecological Responses to an Experimental Pulse Flow Downstream of Hetch Hetchy Reservoir, Yosemite National Park

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Summary

The Looking Downstream project is an interdisciplinary study designed to better understand the physical processes and ecology of the mainstem Tuolumne River corridor between O'Shaughnessy Dam and the Yosemite National Park boundary. The project consists of hydrology, vegetation, bird, and benthic macroinvertebrate study components. An overarching goal of the Looking Downstream project is to provide information that water managers can use to manage environmental water releases in ways that will more closely replicate natural physical processes and benefit dependent ecosystems downstream of the dam.

This status report details findings from the 2009 field season, in particular the physical and ecological responses to an experimental "pulse flow event" from O'Shaughnessy Dam. This approximately 14 day-long event, beginning on approximately May 8 culminated in a peak discharge of approximately 212 cubic meters per second (cms), or approximately 7,500 cubic feet per second (cfs). This peak was larger than in previous pulse flows and allowed mapping of a larger area of inundation.

The primary hydrologic objective of 2009 was to develop flow criteria for wetland maintenance, including flow magnitude, duration, frequency, and timing. Investigations centered on a 14-day experimental flood in May the purpose of which was to investigate lateral and vertical infiltration of the wetland areas in the lower portion of Poopenaut Valley. These data were used to calibrate a two-dimensional variably-saturated groundwater model in order to investigate different flow scenarios and their ability to maintain minimum wetland saturation requirements in the lower part of Poopenaut Valley.

Wetland maintenance provides one avenue for making quantitative recommendations for the magnitude, duration, frequency, timing and rate of change of discharges from O'Shaughnessy Dam. Vegetation work in 2007 and 2008 revealed that wetland habitats are present, but that many are transitioning to drier, upland plant community types. However, wetland areas do not require complete inundation; thus, we are able to place an upper limit on the discharge required to maintain wetlands in Poopenaut Valley. In general, willow seed dispersal begins in late April and persists well into August. Seed production of willows associated with the tributaries peaks in May while species associated with the higher terraces of the Tuolumne River peak in June and those on the sand bars peak in July. It appears that the timing of seed production correlates well with expected peak flows and recession of a river with an unimpaired snowmelt hydrograph.

Results from bird surveys indicate that Poopenaut Valley provides important breeding areas for a diverse group of birds representing a variety of breeding niches and differing seasonal strategies (resident species, short-distance, and long-distance migrants). Birds observed in riparian-associated habitats occupy breeding niches of differing heights in the vertical strata, including understory, mid-story, and canopy. This finding suggests that the available habitat in Poopenaut Valley provides structural integrity beneficial to a wide diversity of birds. Of particular interest, are the riparian focal species detected in Poopenaut Valley that are

understory nesters. Timing and duration of water releases probably has a direct effect on these species nesting success.

Benthic macroinvertebrates are excellent integrators of physical, chemical, and biological processes and are highly valued as indicators of stream health. During the summers of 2008 and 2009, we investigated the response of the assemblage to two experimental spring flood events. The 2008 and 2009 releases were very different in character, and capture many different variables and influences on the benthic macroinvertebrate assemblage. The 2008 release had major immediate effects on the ecology of the river, and some of these effects would be generally viewed as positive changes to the benthic macroinvertebrate community. Total abundance and all order abundances fell in 2008, but dominance decreased and evenness increased. Assemblage dynamics were different in 2009, probably due to recovery of some populations during the falling hydrographic limb and because the 2009 flood occurred later than the 2008 release, and the after-flood sampling captured the annual late summer increase in simuliid black fly abundance. Total individuals decreased only minimally after the 2009 flood and increased dramatically by two months after the flood. Abundances of all orders except Diptera did fall in response to the 2009 release, as in 2008, but dominance increased instead of decreasing. Before-flood algal biomass in 2009 was half that of 2008, possibly due to lack of recovery from the previous year, though green algae grows quickly and proliferates in the constant low flow often found below dams. Most notably, there were no apparent algal losses associated with the 2009 flood, probably because of recovery from the initial scouring during the long falling hydrographic limb.

Chapter 1. Introduction

The primary goals of the Looking Downstream project are 1) to fill in the first-order information gaps by collecting baseline information on the hydrology, vegetation, birds, and benthic macroinvertebrates tied to river flow downstream of O'Shaughnessy Dam, 2) provide a general characterization of the river reach, and 3) assess its overall hydrological and ecological condition. An important overarching goal of these studies is to work collaboratively to produce science-based information and recommendations that the San Francisco Public Utilities Commission (SFPUC) can be used to design environmental water releases that would be most beneficial to maintain and enhance ecosystems downstream of the dam.

Poopenaut Valley, a broad, low gradient valley approximately 5.5 km (3.5 miles) downstream of O'Shaughnessy Dam is one of the most ecologically diverse and productive areas in the river reach between the dam and the Yosemite National Park boundary. As a result, we consider Poopenaut Valley to be the location most sensitive to habitat disruption resulting from an altered hydrologic regime (National Park Service, 2009). For these reasons, we have focused our research efforts primarily in Poopenaut Valley, specifically on the meadow and riparian ecosystems found there.

In the spring of 2009, scientists from the National Park Service, San Francisco Public Utilities Commission, and McBain & Trush collaborated on designing a 14-day-long experimental pulse flow release of water from O'Shaughnessy Dam. The goals of this pulse flow event and subsequent studies in Poopenaut Valley were to:

- Determine the flow magnitudes necessary to inundate meadows and fill the seasonal pond on the north side of Poopenaut Valley.
- Measure meadow soil transmissivity and soil moisture for purposes of determining the time necessary to fully saturate the meadow and maintain soil moisture at typical rooting depths for wetland plants.
- Determine the timing of riparian seed dispersal as it relates to peak river discharge.
- Determine impacts and benefits to wildlife, primarily birds in riparian areas adjacent to the Tuolumne River and benthic macroinvertebrates in the Tuolumne River.

As in earlier years, our 2009 research in Poopenaut Valley consisted of four main subject areas: 1) surface and ground water hydrology, 2) upland, meadow, wetland, and riparian vegetation, 3) riparian-dependent bird species, and 4) benthic macroinvertebrate assemblages. This report presents each subject area in a separate chapter.

Chapter 2. Poopenaut Valley Hydrology Studies and the 2009 Pulse Flow Event

2.1 Introduction

Monitoring of groundwater and surface water in Poopenaut Valley continued for a third season in 2009. The primary objective of this work is to develop flow criteria for wetland maintenance including flow magnitude, duration, frequency, and timing. Investigations centered on a 14-day experimental flood in May of 2009, the purpose of which was to investigate lateral and vertical infiltration of the wetland areas in the downstream portion of the valley. Specifically, we sought to determine:

1) rates of lateral infiltration of wetland soils from the river without inundation; and
2) rates of soil drainage following inundation

We then used these data to calibrate a two-dimensional variably-saturated groundwater model in order to investigate different flow scenarios and their ability to maintain minimum wetland saturation requirements in the lower part of Poopenaut Valley.

Precipitation during the spring of 2009 was average to above average (1930-present) for the Hetch Hetchy area, with rainfall totaling 30.7 cm (12.1 inches) from March through May. Snow pack was slightly below normal (94%) on April first as averaged among snow course data from within the Hetch Hetchy watershed. The onset of spring runoff was March 18th as determined using the maximum negative cumulative deviation from annual average flows at the USGS gage in the Grand Canyon of the Tuolumne River upstream of Hetch Hetchy Reservoir. The centroid of annual runoff, the date at which half of the annual flow has passed the gage was May 15th. The seasonal pond in Poopenaut Valley appeared to have filled during the winter from local hillslope runoff and contained water at least 1 meter deep at the time of the experimental flood.

2.2 Methods

Monitoring groundwater and surface water conditions continued in 2009 using the monitoring array initially installed in 2007 plus eight additional drivepoint piezometers and two soil moisture arrays (Figure 2-1, wells 12-19). Piezometers are constructed of 3.18 cm (1.25-inch) diameter schedule-80 galvanized steel pipe and a 60-cm screened section at the bottom. These wells were driven to a depth below the water table in early April, 2009 so that pre-flood groundwater elevations could be determined. A summary of wells and their installation elevations is shown in Table 2-1.

Figure 2-1. Poopenaut Valley study area with well locations (red dots) and stage recorders (white dots). Wells 3 and 13 are co-located, as are wells 2 and 15.

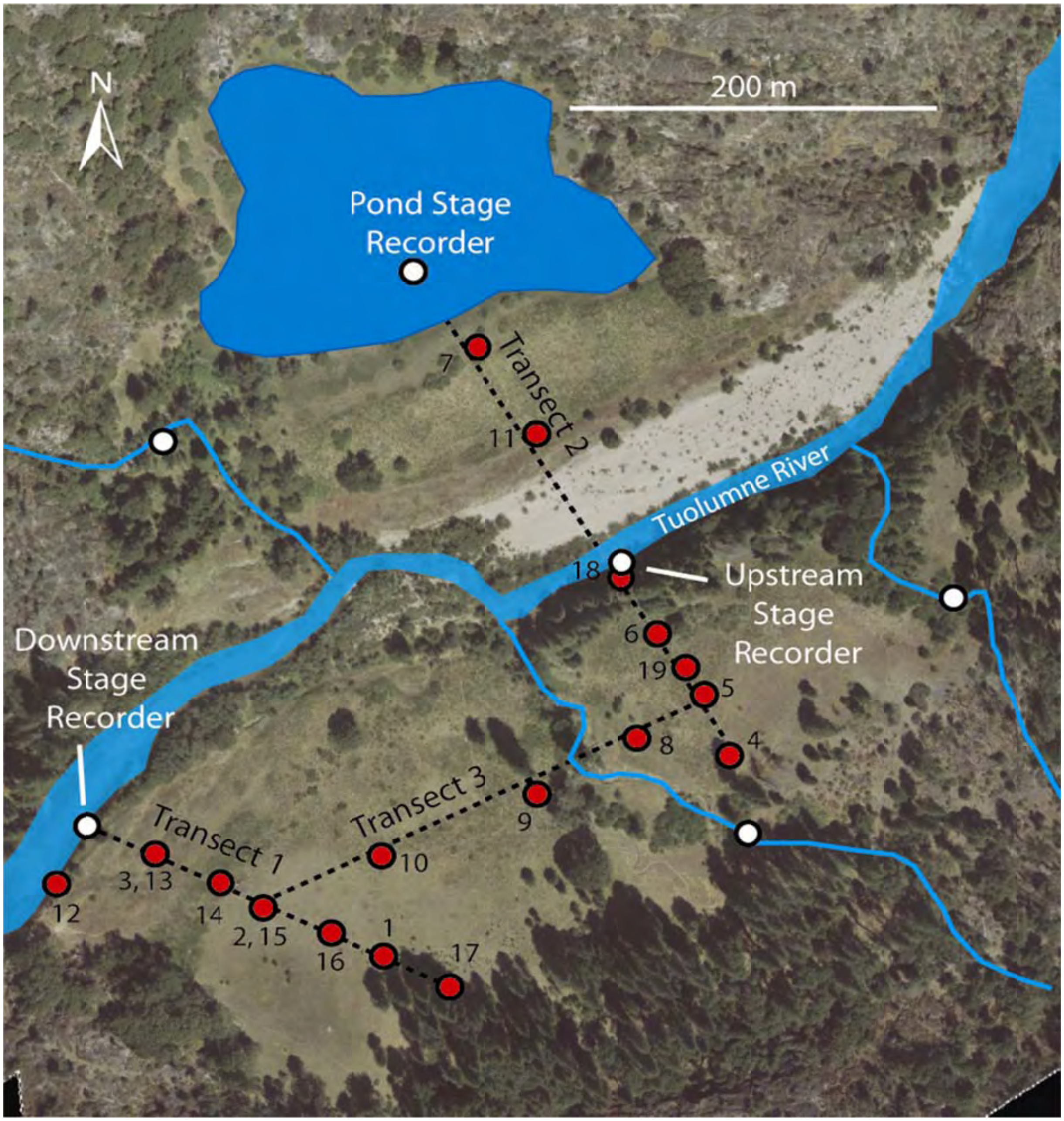


Table 2-1. Well depths and elevations (local elevation reference)

Well Number[1]	Top of Casing Elevation[2] (m)	Stickup[3] (m)	Ground Elevation (m)	Total well depth below ground surface (m)
1	29.299	0.167	29.132	3.730
2	28.961	0.171	28.790	3.960
3	27.358	0.109	27.249	3.540
4	30.439	0.220	30.219	2.930
5	30.384	0.185	30.199	3.970
6	30.997	0.190	30.807	3.800
7	29.363	0.182	29.181	3.510
8	29.281	0.215	29.066	2.720
9	30.503	0.150	30.353	3.800
10	29.747	0.185	29.562	3.770
11	28.199	0.205	27.994	3.650
12	27.248	0.569	26.679	2.833
13	27.693	0.285	27.408	3.099
14	29.262	0.404	28.858	4.396
15	29.241	0.466	28.775	4.863
16	29.232	0.364	28.868	4.898
17	30.061	0.433	29.628	4.828
18	26.693	0.537	26.156	1.609
19	31.173	0.385	30.788	5.789
Upstream recorder	24.553	-	-	-
Downstream recorder	24.605	-	-	-
Pond recorder	27.489	-	-	-
SW Tributary	28.470	-	-	-
SE Tributary	27.998	-	-	-
North Tributary	26.660	-	-	-

1. A fourth stage recorder, not shown here, is located on the southern tributary (SE and SW are part of the same tributary) approximately 1000 meters upstream from the meadow.
2. Top of Casing (TOC) elevation refers to the elevation of the rim of the PVC or steel pipe used to construct the well.
3. Stickup refers to the vertical distance between the top of casing and the ground surface. All well casings in this study extend above the ground surface.

We used dataloggers to collect hourly water level and temperature data throughout the winter and spring of 2008-2009 at 10 wells, 2 river stage recorders, 1 pond stage recorder, and 4 tributary stage recorders. Additionally, we collected air temperature and relative humidity with a data logger placed in a tree in Poopenaut Valley. The eight additional piezometers were installed and instrumented in late April 2009. Prior to the 2009 experimental flood, all dataloggers were checked and reset to 15 minute logging intervals for the duration of the flood.

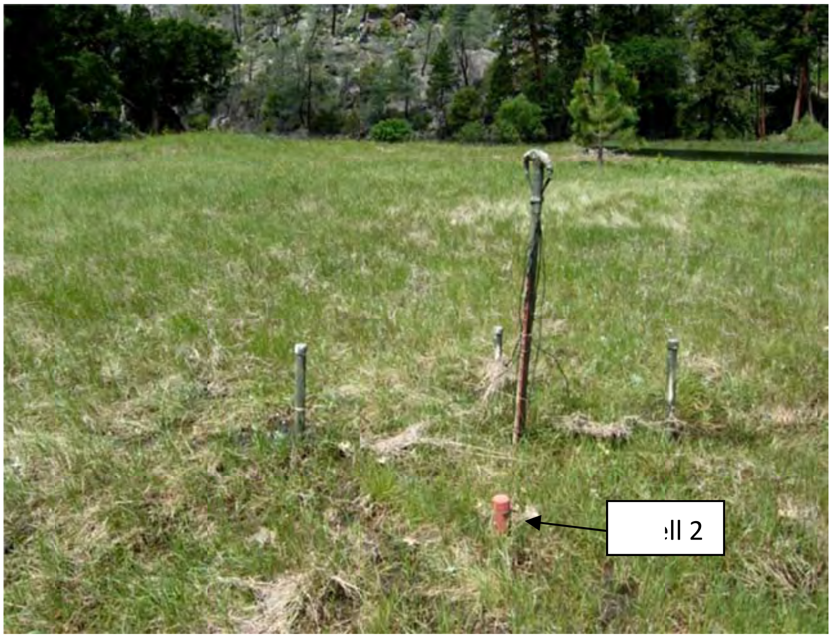
The primary experimental flood design components relevant to this work included:

1) An initial high flow of 43 cms (1,500 cfs) for 3 days (May 4th – 7th)
2) Followed by an increase to 99-113 cms (3,500-4,000 cfs) for 11 days (May 7th – 18th)

The total high flow release duration was 62 days, peaking at 214 cms (7,570 cfs) on May 18th. The total release was 3.36×10^8 m^3 (273,000 acre-feet). We sought to map inundation extent forhigh flows greater than 177 cms (6,250 cfs), the highest flow in 2007 and 2008, using GPS. Wells were read manually as access allowed during the course of high flows.

We also installed temporary soil moisture content sensors at depths of 40, 70, and 100 cm below the soil surface at wells 2 and 3 (Figure 2-2). We determined grain-size distribution in soils near wells 1, 2, and 3.

Figure 2-2. Soil moisture content measurement array at well 2. The three sensors surround the fence-post which served as means of elevating wiring junctions above the potential inundation level. Sensors were wired to a Campbell Scientific CR1000 datalogger located on a high point nearby (to left of this photo).



2.3 Results

Figure 2-3 depicts provisional 15-minute2009 spring flood hydrograph data as recorded at the USGS gage below Hetch Hetchy Reservoir (USGS Gage 11-276500) April 22 – July 13, 2009. Experimental elements are the initial flows at 43 and 113 cms (1,520 and 3,990 cfs) as well as the peak of 214 cms (7,560 cfs). Subsequent flow variations were the result of balancing operational and downstream rafting needs and were not part of the experiment.

Transect 1 water surface elevations are depicted in Figure 2-4. As we had seen in 2008, wells 1 and 3 react more quickly to changes in water surface elevation in the river than well 2. This is shown in more detail in Figure 2-5, which shows the approximate groundwater level during different parts of the flood hydrograph. The approximate water table for April 29, 2009 is the base groundwater level prior to the onset of the experimental flood. Areas in the middle of transect 1 saturate and drain more slowly than areas on either end of the transect.

Inundation area and flow are shown in Figure 2-6. Each inundation line took approximately 1-2 hours to complete using a handheld GPS unit during which time flow was changing. Therefore each line in Figure 2-6 is approximate to within 5 meters given uncertainty in flow and GPS accuracy. The peak flow of 214 cms (7,557 cfs) appears to exceed the mapped wetland extent along the south bank of the river in all but a small portion of the area.

Figure 2-3. Tuolumne River discharge at USGS gage 11-276500 below Hetch Hetchy Reservoir

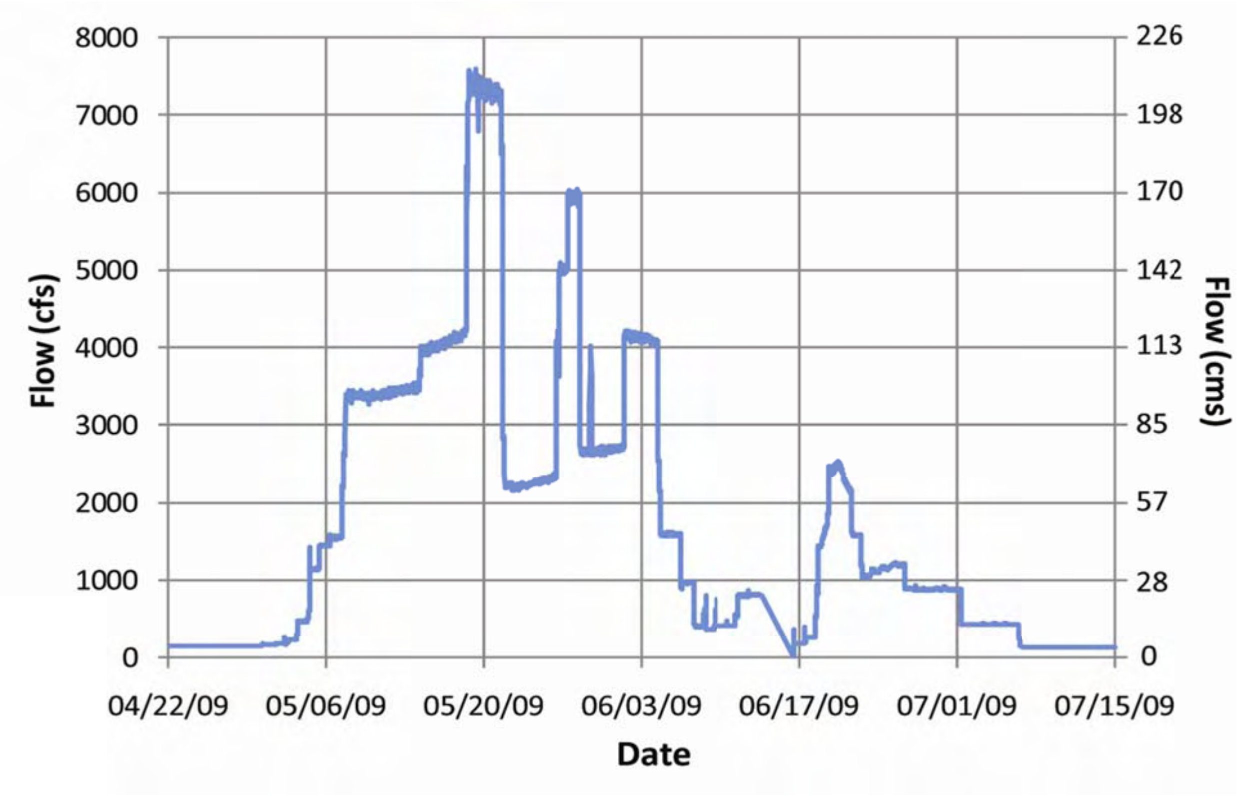


Figure 2-4. Well response to 2009 high flows along Transect 1.

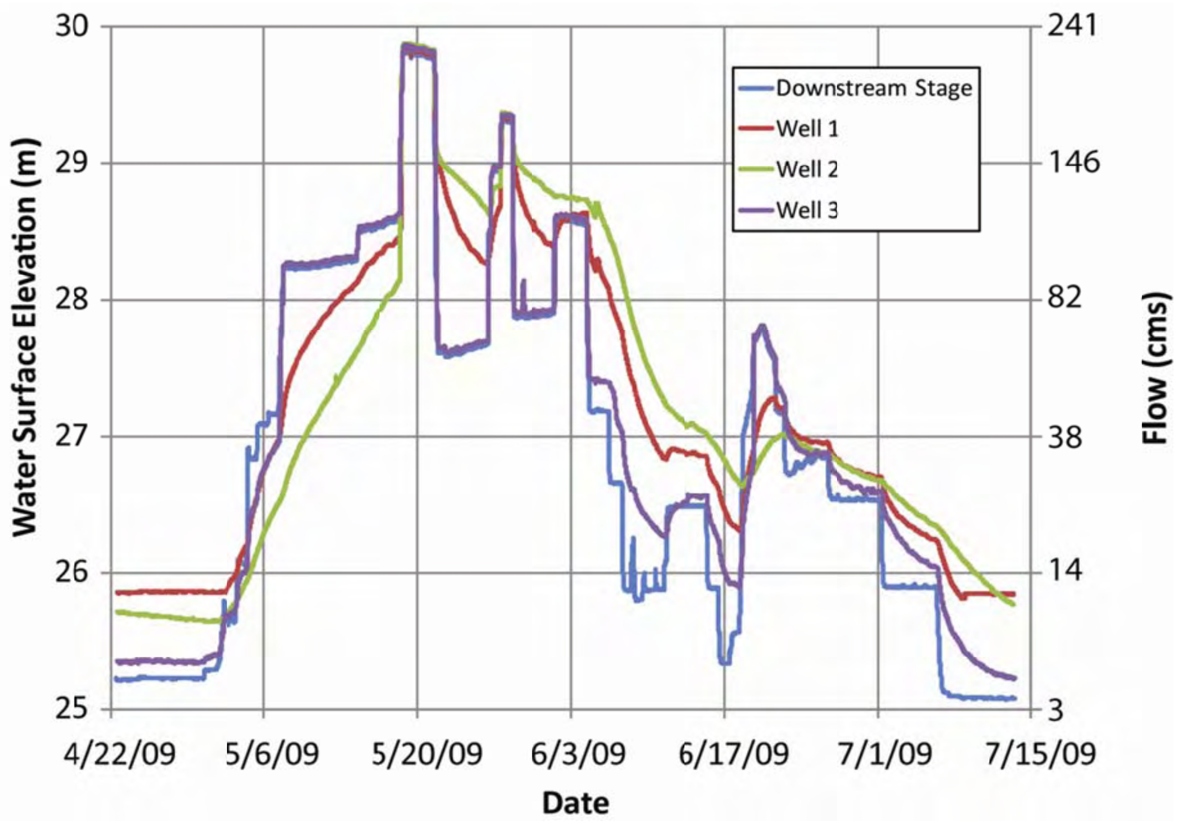


Figure 2-5. Groundwater levels along Transect 1 at select phases of 2009 high flows. Water levels A-D represent the sequence of ascending and receding flows during the experimental flood.

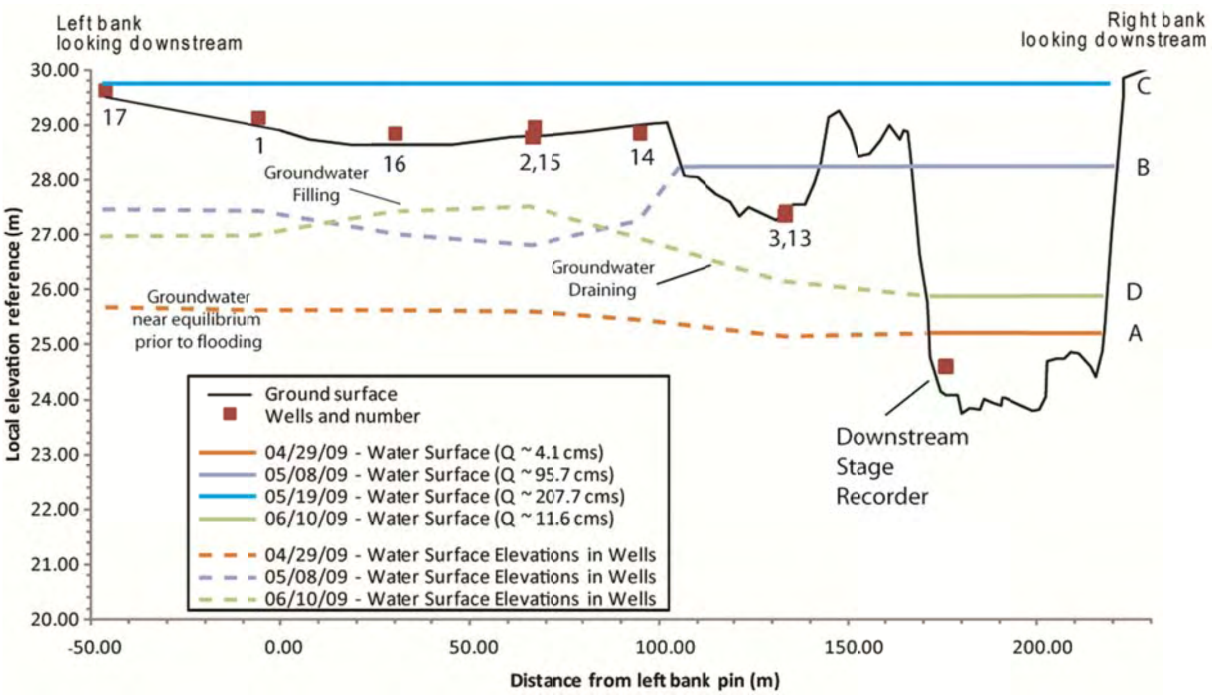
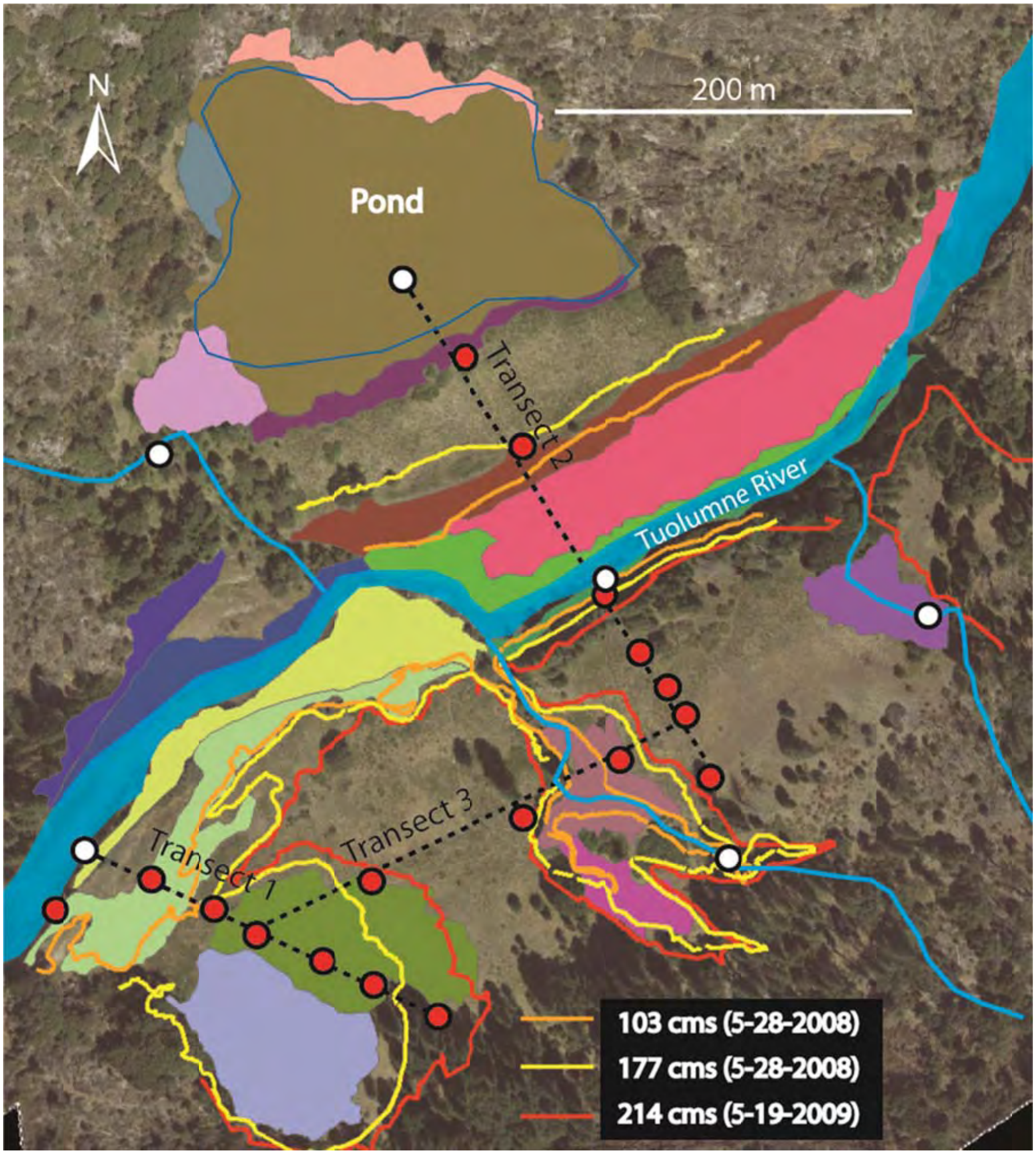
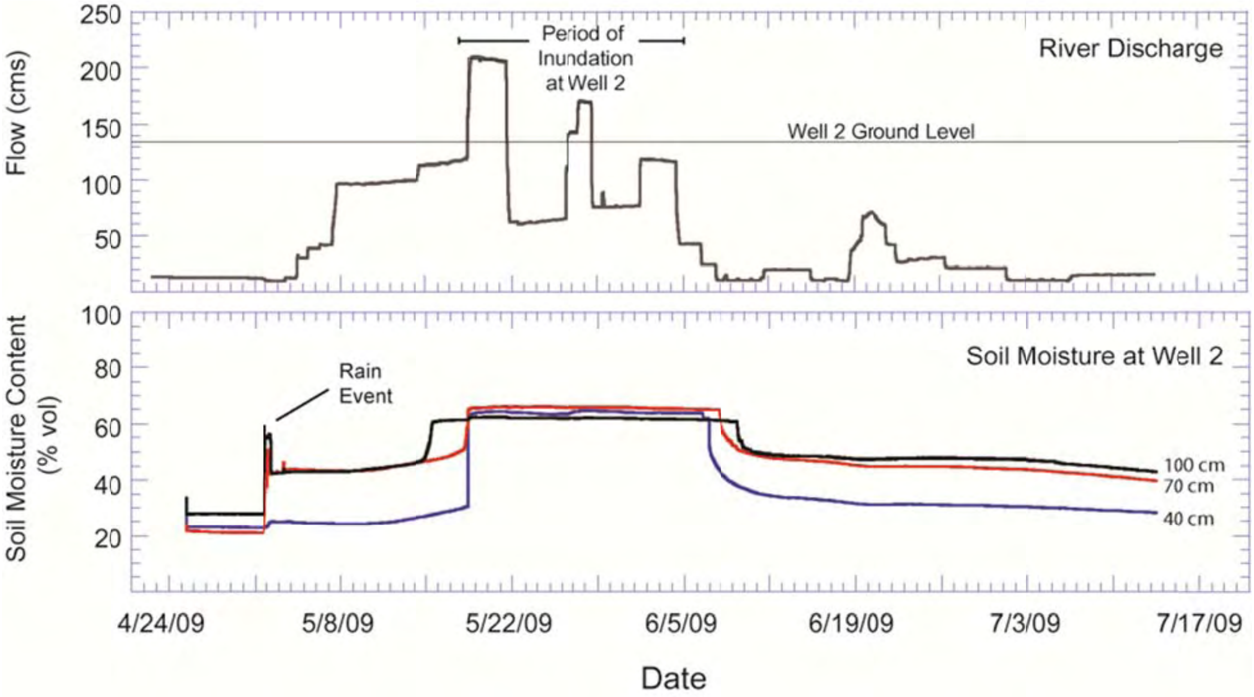


Figure 2-6. Mapped inundation area at different flow rates from 2008 and 2009 floods. Colored polygons represent different wetland types mapped in 2007 (NPS, 2009). See text for details on mapping techniques and limitations.



Soil moisture content results for the well 2 array are shown in Figure 2-7. The soil at the 100-cm depth saturates when flows are raised from 99 to 113 cms (3,500 to 3,990 cfs). The 70 and 40-cm depths saturate only when the area is inundated. All depths remain saturated when flows are dropped to 71 cms (2,500 cfs) for up to 4 days at a time, presumably because the area is ponded. River stage falls below the level of the meadow at well 2 for the final time during the flood on 5-28-2009. The 40-cm level becomes unsaturated about 10 days later. Overall, the 40-cm level of soil remained saturated for 19 consecutive days, 14 of which when the surface was not inundated.

Figure 2-7. Soil moisture content at Well 2 with concomitant river discharge. Soil moisture content exceeding 60% represents saturated conditions.



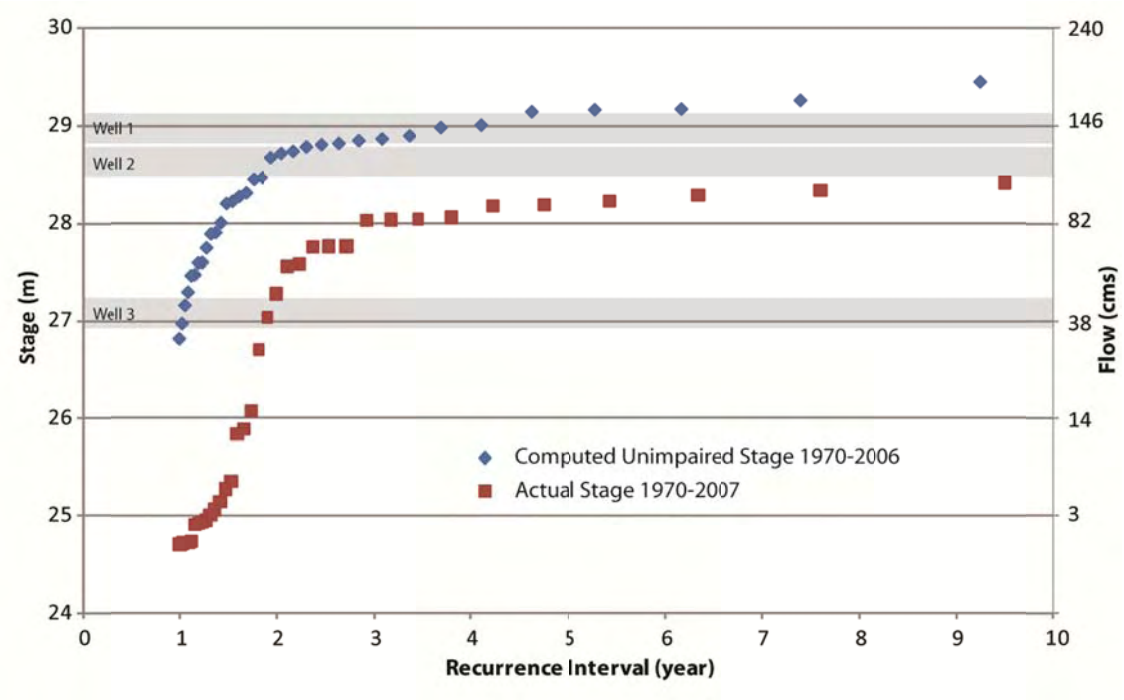
2.4 Discussion

The minimum hydrologic requirements for a wetland in the western mountains region is defined by the US Army Corps of Engineers to be soil saturation within 30 cm (12-inches) of the ground surface for a period of 14 consecutive days during the growing season 5 out of every 10 years (USACOE 2008). We reassessed the stage-duration-frequency along Transect 1 to assess the difference between regulated and reconstructed 'natural' high flows. Additionally, we examined the timing of high flow events. Finally, using the soil moisture and well data from transect 1, we calibrated a two-dimensional variably-saturated groundwater flow model to test alternative high flow scenarios necessary to achieve the above requirement for wells 1, 2, and 3.

Stage-Duration-Frequency

Figure 2-8 shows the 14-day high flow frequency for actual (USGS gaging station #11-276500) and reconstructed daily flows (provided by Bruce McGurk) below O'Shaughnessy Dam since diversions to the Canyon Tunnel began in 1968. The 14-day high flow was determined by finding the maximum stage during a water year (October – September) that was equaled or exceeded for 14 consecutive days. We determined the frequency of exceedence by ranking annual 14-day high flow stage from highest to lowest and dividing the ranking by the number of years of record. Given the hydrologic criteria that define a wetland above, we would expect that reconstructed 14-day high stages for wells 1-3 would be at least 30 cm below ground surface every 2 years. While this appears to be the case for wells 2 and 3, it is important to note that the reconstructed 14-day high stage at well 1 occurs every 2.6 years. Construction of a stage-innundation hydraulic model for the valley will be essential to establish this relationship for other wetland areas in Poopenaut Valley in order to understand the range of stage durations that would have occurred under 'natural' conditions. Note that only wetlands around well 3 meet the minimum wetland standard under actual flows and areas around wells 1 and 2 rarely see necessary conditions once in a decade.

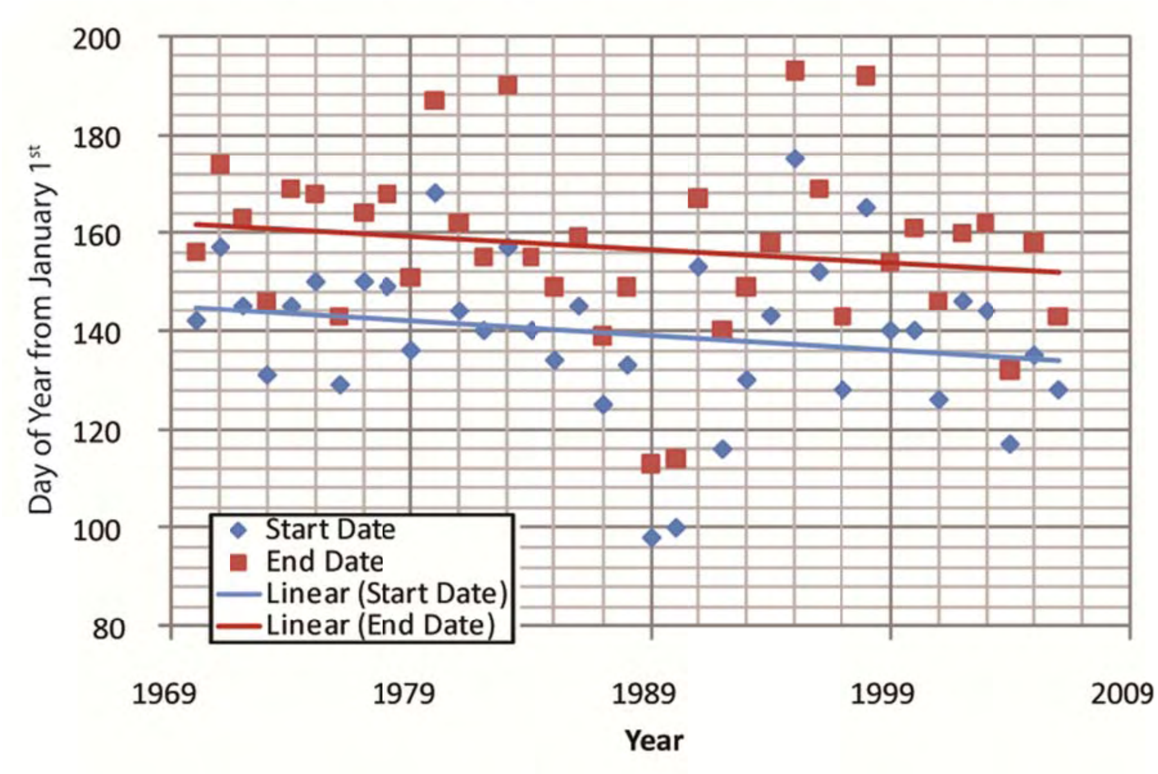
Figure 2-8. 14-day high flow and stage frequency on the Tuolumne River in Poopenaut Valley for reconstructed and actual flows. Grey bands represent the elevation range between the ground surface and 30 cm below ground surface for wells 1-3. Date ranges for each data set correspond to available data at the time of analysis.



Flow Timing

Reconstructed 14-day high flow duration for each year between 1970 and 2006 also allows us to determine the onset and ending date for each year's high flows (Figure 2-9). Average onset date is May 19th and ending date is June 6th. However, the data indicate that in 2006 the onset and ending dates are 5-6 days earlier than the 36-year average, up to 10 days earlier than in 1970. Though the data are suggestive of a trend, no statistically significant trends were detected.

Figure 2-9. Onset and ending dates of reconstructed 14-day high flows below Hetch Hetchy (1970-2006). Day of Year indicates number of days from January 1st of each year. Lines are ordinary least squares fits of the data.

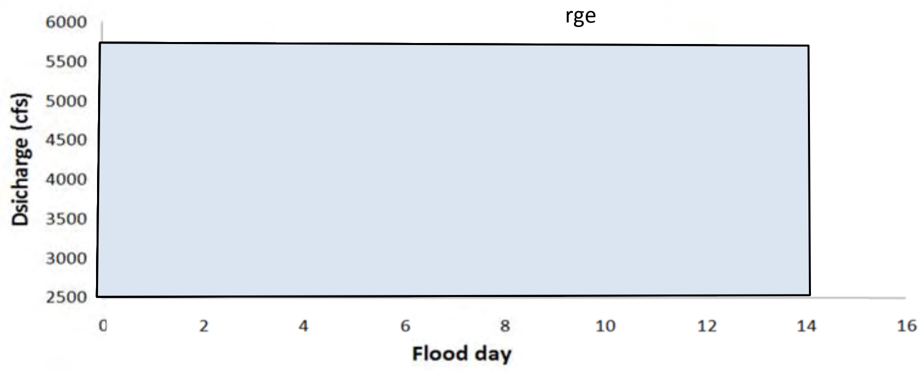


Flow Scenarios

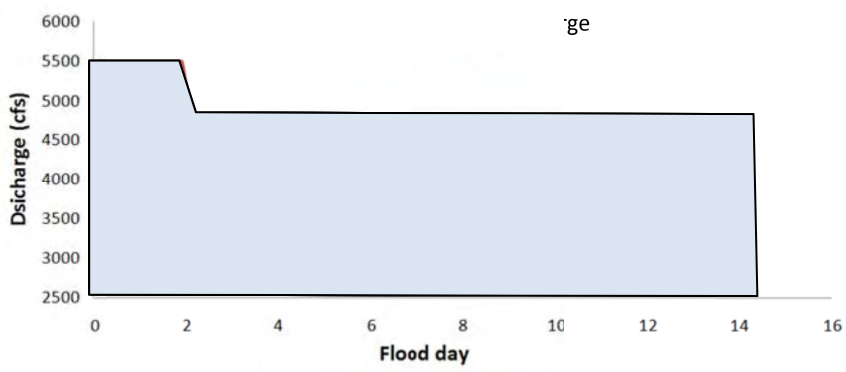
The first three of the following controlled flood scenarios meet requirements for maintaining saturation at 30 cm at Well 1 for 14 days. Scenario 4 examines the effects of higher flow fluctuations. This scenario does not meet specified wetland requirements around Well 1, but does meet these requirements around Well 2. It will be important to consider the discharge – inundation area relationship in the valley, in combination with the wetland boundaries, in order to determine an optimal strategy for managing flood discharge while meeting park objectives of preserving, and, if possible, enhancing, wetland habitats.

1. Inundate up to Well 1 and maintain constant discharge for 14 days
2. Inundate up to Well 1 and then lower the discharge to a constant level for 14 days
3. Cycle higher and lower flood discharge over a period of 14 days
4. Cycle higher and lower flood discharge to provide lower flow for rafters on weekends

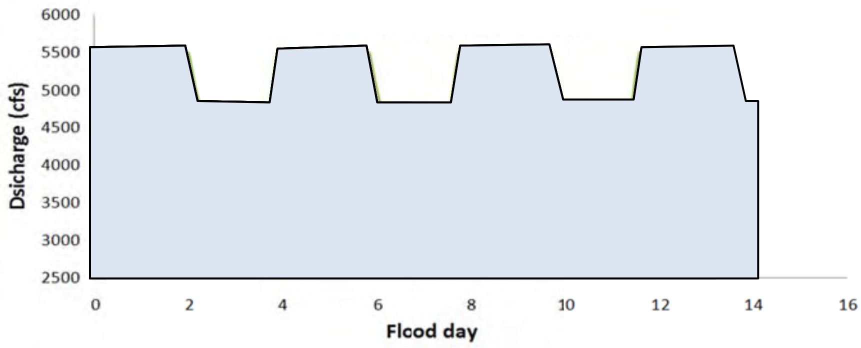
Scenario 1 requires the river stage to be held constant at 29.15 m, or 156 cms (5,500 cfs). This will maintain saturation to the surface at Well 1, thus meeting requirements for saturation at 30 cm below ground level for 14 days. This scenario requires 1.89 x 10^5 m^3 (153 k-af,thousand acre-feet) of total discharge, or 55% of the total released during the 2009 flood event.



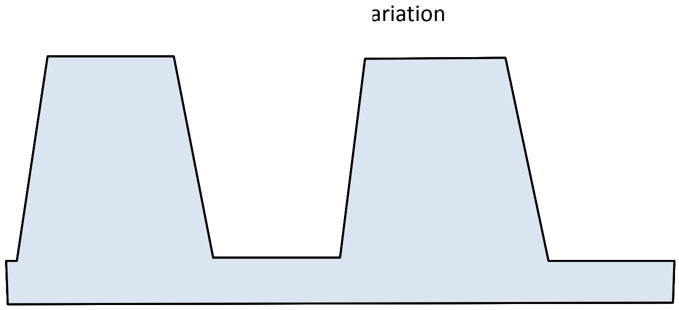
Scenario 2 is a down-stepping scenario that begins with two days of inundation at Well 1 and is followed by 12 days of a lower discharge and inundation at Well 2, 156 and 136 cms (5,500 and 4,800 cfs), respectively. This is the lowest flood discharge that will maintain saturation at 30 cm below ground at Well 1 according to the model. We do not have observational soil moisture data at this location; therefore we have estimated drainage properties based on grain size analysis from samples at this location. This scenario requires 1.68 x 10^5 m^3 (136 k-af) of total discharge, or 48% of the total released during the 2009 flood event.



Scenario 3 is a fluctuating discharge scenario that begins with two days of inundation at Well 1 and is followed by approximately 1.5 days a lower discharge, 156 and 136 cms (5,500 and 4,800 cfs), respectively. During the periods of lower discharge, soils near Well 1 are no longer inundated, but they retain sufficient moisture during this time to satisfy the wetland criteria described earlier. Ramping rates for the Tuolumne River based on the amplitude of diurnal snowmelt cycles were used for increases and decreases in river discharge, 5.5 and 3.7 cms/hr, respectively (approximately 200 and 130 cfs/hr). The entire cycle including ramping periods lasts just under 4 days. Saturation is maintained at a 30 cm depth for all 14 days, but the wetland surface around both Wells 1 and 2 would only saturate for eight out of 14 days. This may be amenable to plants with shallower root structures. The scenario requires 1.79 x 10^5 m^3 (145 k-af) of total discharge, or 52% of the total released during the 2009 flood event.



Scenario 4 is also a fluctuating discharge scenario, but with larger, less frequent fluctuations. This scenario prescribes a lower limit of 71 cms (2,500 cfs) coming from the Hetch Hetchy Reservoir. Our current modeling predicts that lowering discharge to 71 cms (2,500 cfs) using natural ramping rates would not maintain saturation at 30 cm depth at Well 1. The wetland defined by Well 2 also does not retain saturation during the three day period at 71 cms (2,500 cfs). Raising the river discharge to 85 cms (3,000 cfs) would be sufficient to maintain wetland conditions at Well 2. This scenario requires 1.44 x 10^5 m^3 (117 k-af) of total discharge from Hetch Hetchy Reservoir, or 42% of the total released during the 2009 flood event.



Several challenges remain for applying these and related results to the Poopenaut Valley wetlands. Available data is limited to a small number of monitoring sites, models are highly idealized, and natural wetland systems are heterogeneous and complex. In addition, modeling completed thus far is two dimensional, but stream seepage and well data indicate a more complex, three dimensional flow pattern across and along valley soils during flood events. Nevertheless, model results suggest that optimization for wetland benefit could allow the water released during controlled floods to meet wetland criteria, and could help to maintain wetland conditions within Poopenaut Valley even during years when less water is available for release than was available in 2009.

2.5 Conclusions and future work

Stage and groundwater level data along with groundwater modeling have brought us close to being able to describe an envelope of hydrologic conditions necessary for maintenance or enhancement of wetland conditions in Poopenaut Valley. These include frequency and duration of high flows, timing of these flows, and flow scenarios that maintain saturated soil conditions within 30 cm of the soil surface. While there are limits to this analysis, particularly with regard to model uncertainty and specific wetland plant community requirements, these observations inform initial flow recommendations and provide a foundation for future adaptive management. Remaining steps include 1) more closely defining the wetland plant community – hydrologic regime relationship across the elevation distribution within Poopenaut Valley using a surface water inundation model such as HEC-RAS, and 2) targeted wetland sampling to validate and refine this model.

Chapter 3. 2009 Vegetation Studies in Poopenaut Valley

3.1 Introduction

The wetland delineation and description of existing vegetation types in Poopenaut Valley, completed in 2007 (National Park Service, 2009) and refined in 2008 and 2009, provide a baseline of the composition and spatial distribution of plant communities and wetlands. Vegetation dominance, frequency, abundance and distribution vary widely between years due to fluctuations in annual temperature and precipitation. Therefore, detection of a plant community response is likely to take many years of monitoring. In order to refine these assessments additional vegetation work continued in the 2009 season. These efforts include a woody riparian plant seed dispersal study and invasive plant species survey and removal. Monitoring of transects and plots established along the cross sections in 2008 did not occur in 2009 but will continue in 2010.

3.2 Woody Riparian Plant Seed Dispersal Study

Riparian vegetation provides important habitat for wildlife, particularly birds, and requires further investigation to assess current conditions and to establish the relationship to the hydrologic regime. Reproduction for many riparian tree and shrub species (such as willows) depends on certain hydrologic (moist with a receding water table) and seedbed (bare mineral ground) conditions for successful germination.

Assessments of the timing and rate of seed dispersal of five species of willow (*Salix ssp*.) and black cottonwood (*Populus balsamifera ssp. trichocarpa*) can help determine the timing of seed production and dispersal as related to the peak flows on the Tuolumne River. The seed dispersal information may help refine recommendations for altering the hydrograph to improve conditions for riparian vegetation germination and establishment. For example, changes in spill management could change the elevation that riparian vegetation can germinate and persist.

Access to riparian vegetation in Poopenaut Valley is limited when river flows are higher than 8.5 cms (300 cfs) because it is not possible to cross the river and many willows are partially inundated. Restricted access and inconsistent seed data collection, due to weather and scheduling, compromised data for two willow species, arroyo willow *(Salix lasiolepis)* and red willow *(Salix laegivata)*. Seed data for shiny willow *(Salix lucida),* dusky *(Salix melanopsis)* and narrow-leaf willow *(Salix exigua)* is presented below. Black cottonwood did not produce seeds in 2009 but phenological information for this species as well as all the willows is presented below.

3.2.1 Methods

Seed traps consisting of $8^{1/2}$ x 11” pieces of plywood with a Vaseline coated piece of paper (the trap) were hung in six female trees or shrubs. Willows and cottonwoods are dioecious, having male and female reproductive structures (catkins) on different plants Twenty-four traps were hung (six arroyo willows, six shiny willows, six red willows and six dusky and narrow-leaf willows combined and no traps in black cottonwood) and collected weekly from late April to early August. To collect the traps, we inserted the sticky paper (the trap) into a Ziploc bag, counted seeds in the office and entered numbers into an Excel spreadsheet. Additionally, we recorded life cycle stage for males and females of each species including; release from dormancy, leaf production and maturity, catkin production, flowering, seed dispersal and end of the reproductive period. When access to willows or cottonwoods was limited by high water, we used binoculars to estimate the phenological stage.

3.2.2 Results

Seed Production

Arroyo Willow

Arroyo willow occurs along the tributaries and these shrubby willows begin dispersing seeds earliest in the year as compared to other willow species. Due to heavy rains, access issues and inconsistent site visits, seed data are not available for 2009. Seed collection data for 2008 is summarized in the 2008 Looking Downstream update.

Red Willow

Red willow grows in tree form along the tributaries, next to the pond and within the bed and banks of the Tuolumne River. Due to our inability to access red willow throughout the entire seed production period, seed data are not available for 2009. Observations indicated that seed production of the large willow trees near the pond was much higher and continued much longer than willows established within the bed and banks of the Tuolumne River. Seed collection data for 2008 is summarized in the 2008 Looking Downstream update.

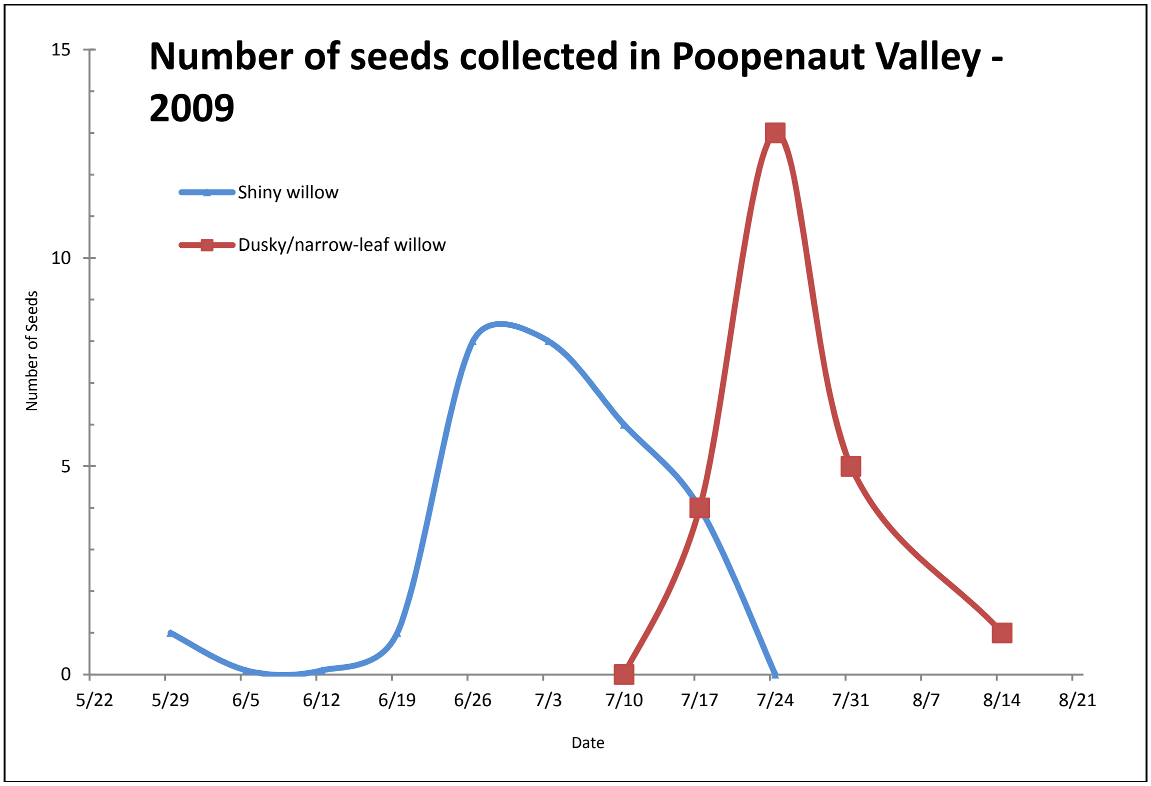
Shiny Willow

Shiny willow grows along the intermediate bank terraces of the Tuolumne River and most established trees experience inundation at flows above 85 cms (3,000 cfs). High flows hampered access to these traps periodically, but enough traps were collected for consistent data. Numbers of seeds collected is generally low (as compared to numbers collected in 2008). This is likely because field technicians did not use enough Vaseline on the traps coupled with some extremely high temperatures (above 38 C/100 F) that caused the Vaseline to melt. Despite the low numbers, the general trend of seed production is presented in Figure 3-1.

Dusky Willow and Narrowleaf Willow

These two willow species occupy the sandbars within the bed and banks of the Tuolumne River, experience some inundation at flows above 28 cms (1000 cfs), and complete inundation at 85 cms (3,000 cfs). Only one set of traps (six) represents both species as the timing and duration of seed production is so similar. This is likely because field technicians did not use enough Vaseline on the traps, coupled with some extremely high temperatures (above 38 C/100 F) that cause the Vaseline to melt. Seed collection data from 2009 are presented in Figure 3-1.

Figure 3-1. **Shiny and Dusky/Narrow-leaf Willow seeds collected in Poopenaut Valley**



Black Cottonwood

Black cottonwoods are typically prolific seed producers on an annual basis. In both 2008 and 2009, both male and female black cottonwood produced catkins in April but most trees dropped catkins before maturity in 2008, and all trees dropped catkins in 2009 resulting in little or no seed production. Additionally, on the male trees (catkins develop earlier than female trees) many leaves became blackened and stunted. Figures 3-2 and 3-3 displays the temperature range in Poopenaut Valley between March 11 and April 21 for 2008 and 2009, the period of time that catkins and early leaves are developing. Below freezing nights occurred on three different occasions in 2008 (lowest at 4C) and four different occasions in 2009 (lowest at 5C), temperatures that could be lethal to catkins. The temperature recorder is located in the mixed conifer forest at the south edge of Poopenaut Valley so temperatures may be lower out in exposed areas. General observations indicate that black cottonwood along the Merced River did produce catkins and seeds but temperature data are not available.

Figure 3-2. Temperature in Poopenaut Valley from March 11 – April 21, 2008.

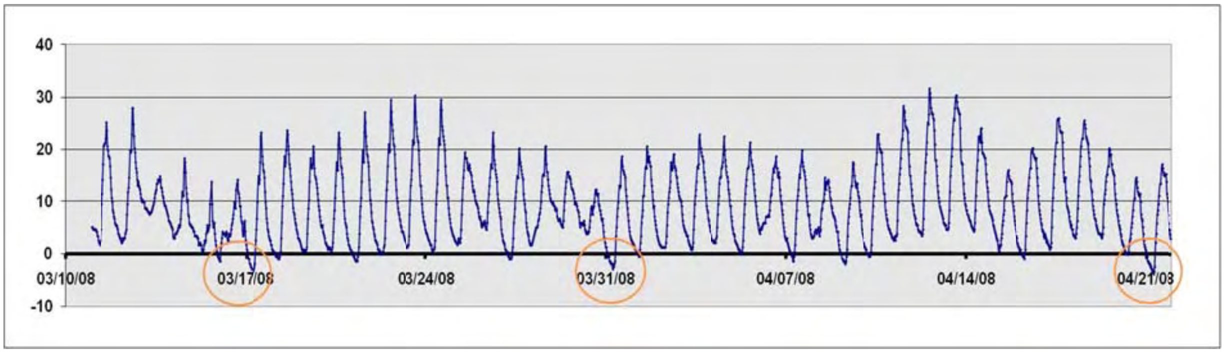
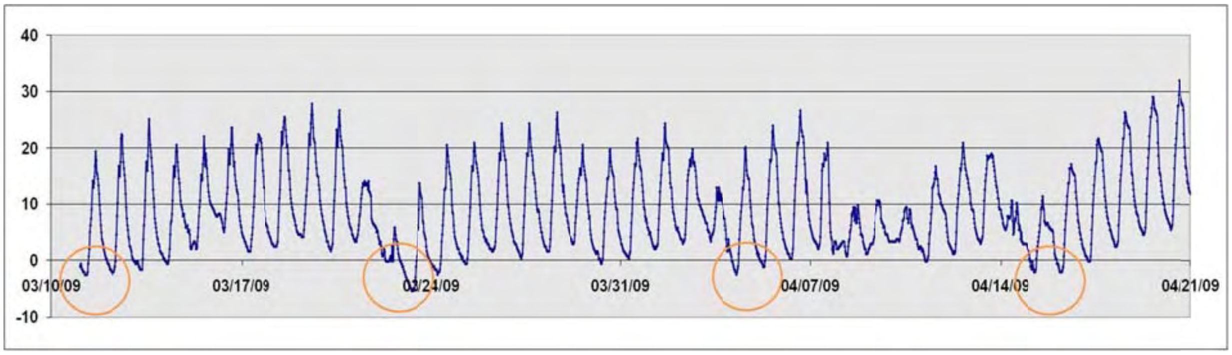


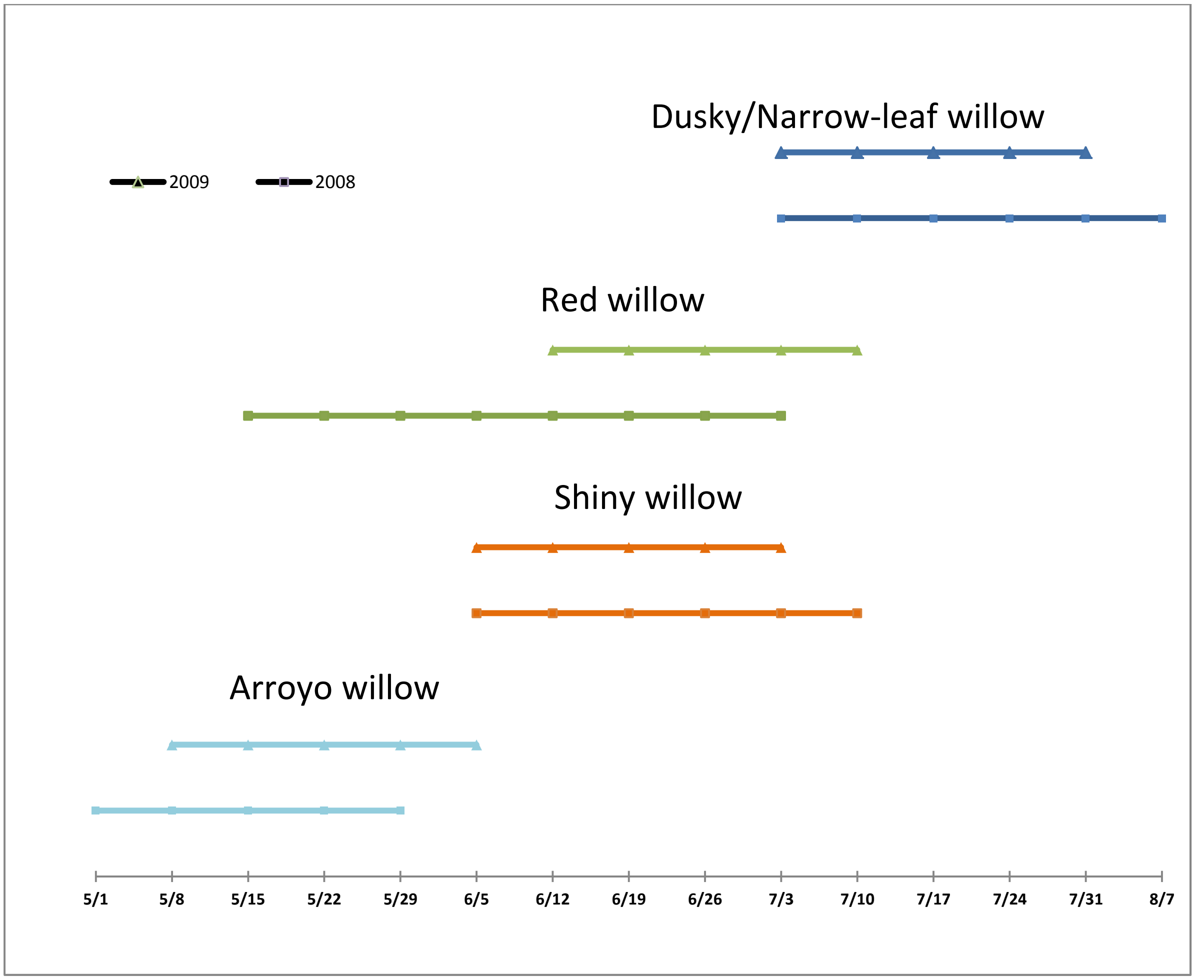
Figure 3-3. Temperature in Poopenaut valley from March 11- April 21, 2009



Timing and Duration of Seed Production

Willow seed dispersal begins in late April and persists well into August. Each week, we documented reproductive stage and recorded the beginning and end of seed production (Figure 3-4). Arroyo willow seed production peaks in May, red and shiny willow peak in June and dusky and narrow-leaf willow peak in July. Arroyo willow has the earliest and shortest seed production period, red willow the longest duration and dusky/narrow-leaf the latest. Dusky/narrow-leaf willow had a second wave of seed production (common for these species) beginning the second week of August (also observed in 2008), but seed collection ended at this time. Timing and duration of seed production was similar between 2008 and 2009 for shiny and dusky/narrow-leaf willow with a delayed onset and end for arroyo willow seed production and a much longer duration of seed production for red willow in 2009. This is likely weather related as 2009 had a cooler May and June.

Figure 3-4. Timing and Duration of Willow Seed Production in Poopenaut Valley, 2008 and 2009



3.3 Invasive Plants

A comprehensive survey completed in 2009 for invasive plant species above and below Poopenaut Valley provides information on the frequency and spatial distribution of target invasive plant species, particularly Himalayan blackberry (Rubus discolor). Previous surveys were limited to Poopenaut Valley, areas with roads below the dam and the housing area. Target survey species include, velvet grass (Holcus lanatus), bull thistle (Cirsium vulgare), common mullein (Verbascum thapsis) and cheat grass (Bromus tectorum). Documentation of other non-native species and treatment of some invasive plant populations continued in Poopenaut Valley.

3.3.1 Methods

Survey methods and documentation followed the Invasive Plant Program's Parkwide Weed Mapping Protocol. When a population or plant is discovered, species, number of plants, phenological stage, vegetation type and associated species are documented in a Trimble GPS data dictionary. A point, line or polygon is recorded to document the spatial extent and location. Technicians focused survey for high and medium-high priority plants (Table 3-1) although in most cases, mapping of invasive annual grasses did not occur.

Table 3-1: High and medium priority species mapped

Species	# times mapped	2009	Species	# times mapped	2009
Rubus discolor	93	X	Aira caryophyllea	1	
Verbascum thapsus	53	X	Avena fatua	1	X
Bromus tectorum	17	X	Bromus sterilis	1	
Bromus diandrus	14		Galium parisiense	1	
Cirsium vulgare	6	X	Herniaria hirsuta ssp. hirsuta	1	
Holcus lanatus	5		Lactuca serriola	1	
Bromus hordeaceus	4		Melilotus indica	1	
Hypericum perforatum	4		Melilotus officinalis	1	
Brassica rapa	2		Poa pratensis ssp. pratensis	1	
Erodium cicutarium	2		Sonchus arvensis	1	
Melilotus alba	2		Tragopogon dubius	1	
Poa bulbosa	2		Vulpia myuros var. hirsuta	1	
Vulpia myuros var. myuros	2				

Invasive plant removal techniques vary depending on the species, size, density and location of a population. The most effective treatment for Himalayan is mowing and spraying with glyphosate. Shovel shearing and/or spraying is most effective treatment for bull thistle, hand pulling or shovel shearing is effective for common mullein and effective treatment methods for velvet grass are in development. Additionally, flowering heads of bull thistle and common mullein are cut, bagged and disposed of to prevent seed dispersal. No effective treatment for cheat grass is available.

3.3.2 Results

Himalayan blackberry patches occur along the entire corridor below the O’Shaughnessy Dam to Early Intake (Figure 3-4 and 3-5). The terrain below Poopenaut Valley is very steep and inaccessible, thus limiting surveys, but it is likely that Himalayan blackberry also occurs in that reach. Some data were lost in a short reach of river downstream of Poopenaut Valley due to poor GPS function, so these locations are approximate. The largest patches occur just below the dam (very difficult to access), the disturbed area north of the bridge below the dam, a flat area approximately 1 km below the dam, in Poopenaut Valley and just north of the park boundary. Other high priority invasive plants detected include patches of common mullein and scattered populations of Klamath weed and bull thistle in Poopenaut Valley and scattered populations of common mullein, Klamath weed and bull thistle along the river corridor. Some medium priority species were also mapped and their occurrence is listed in Table 3-1.

Figure 3-5. Map of invasive plant surveyed east of Poopenaut Valley 2009

Figure 3-6. Map of invasive plant surveyed west of Poopenaut Valley 2009

Extremely difficult terrain; unable to access for survey

Himalayan blackberry was observed here, along all sections of river surveyed however, data was lost and therefore not displayed here.

Removal of invasive plants including, bull thistle, common mullein and Klamath weed established in Poopenaut Valley, as well as along the trail to Poopenaut Valley, continued in 2009. These populations are scattered and typically have low cover so treatment acreage is negligible. However, it is extremely important to treat these areas before populations spread, expand or become denser.

3.4 Discussion

As expected, it appears that the timing of willow seed production correlates well with peak flows and recession of a river with an unimpaired snowmelt hydrograph. If timing, duration, frequency and magnitude of regulated floods mimic the unimpaired hydrograph, riparian vegetation will possibly change in structure and spatial distribution. However, this requires assessments of the current woody riparian vegetation structure, condition (live to dead ratio), spatial distribution and location in terms of avian habitat and that relationship to the hydrograph.

Willow populations are well established and produced abundant seeds in both 2008 and 2009. Black cottonwood produced very few seeds in 2008 and none were observed in 2009. Likely reasons for catkin drop and leaf wilt could be from lethal freezing temperatures or drought conditions. In general, cottonwoods can withstand very cold temperatures (up to – 70C) in winter but are much more vulnerable to frost damage in spring and fall (Friedman et al. 2008). Temperatures did drop to -4C in 2008 and -5C in 2009 during peak catkin development. It is unknown if these are lethal temperatures, but the black cottonwood in Poopenaut Valley may be more vulnerable due to drought stress. All of the female trees occur on the north side of the river and the majority of the male trees occur on the south side of the river, with only an isolated patch established on the north side. Black cottonwood has low drought tolerance and based on well data in Poopenaut Valley, groundwater levels in March through April are typically 2-3 meters below the ground surface on the south side of the river, where most male trees are established. Female trees are located adjacent to the pond where groundwater levels are higher in March and April when the pond is full (observed in 2008 and 2009). It is unknown if observed groundwater levels on the south side of the river causes drought stress as cottonwoods are deeply rooted, but it could play a role in reproduction, allocation of resources and vulnerability to cold temperatures. It is also possible that male catkin survival is not sufficient (since they develop earlier and experience more freezing periods) to pollinate the female catkins that do develop. Monitoring other black cottonwood populations, determining when of black cottonwoods established in Poopenaut Valley and hydrograph at that time (i.e. did they establish when flows were consistently at 17 cms (600 cfs) or prior to dam construction) and investigating further into why catkins are not fully developing (i.e. lethal temperatures) may help us understand why they are not reproducing.

Much of the Himalayan blackberry is growing within the bed and banks of the Tuolumne River, making treatment with glyphosate difficult and managers are working on developing an effective treatment strategy at this time. Additionally, the very large patch of Himalayan blackberry established just below the dam provides a substantial seed source and full treatment cannot occur until this population is eradicated.

3.5 Future work

The woody riparian seed dispersal study will continue in 2010. However, data collection is difficult in Poopenaut Valley due to access, time demands (weekly trips) and field methods. In 2010, we plan to use “Tanglefoot”, a resin based adhesive, instead of Vaseline because it is less likely to melt in hot temperatures. Further investigation by expanding the study in 2010 to assess willows and particularly black cottonwood along the Merced River or other areas along the Tuolumne River can improve data quality. Additionally, assessments of the riparian vegetation structure, condition (live to dead ratio), spatial distribution and location in terms of avian habitat and that relationship to the hydrograph will be under the direction of McBain and Trush staff in 2010. These data will also point to the time of establishment and the hydrologic conditions of that time.

Invasive plant treatment in Poopenaut Valley will continue and may expand to cheat grass if an effective treatment is developed, as well as treatment of medium priority species that pose a threat to native plant communities.

Other future vegetation work includes re-measurement of the vegetation monitoring plots and transects installed in 2008, refining delineated wetland boundaries and investigating ways to correlate soil moisture gradients and plant community spatial distribution.

Chapter 4. 2009 Passerine Bird Studies in Poopenaut Valley

4.1 Introduction

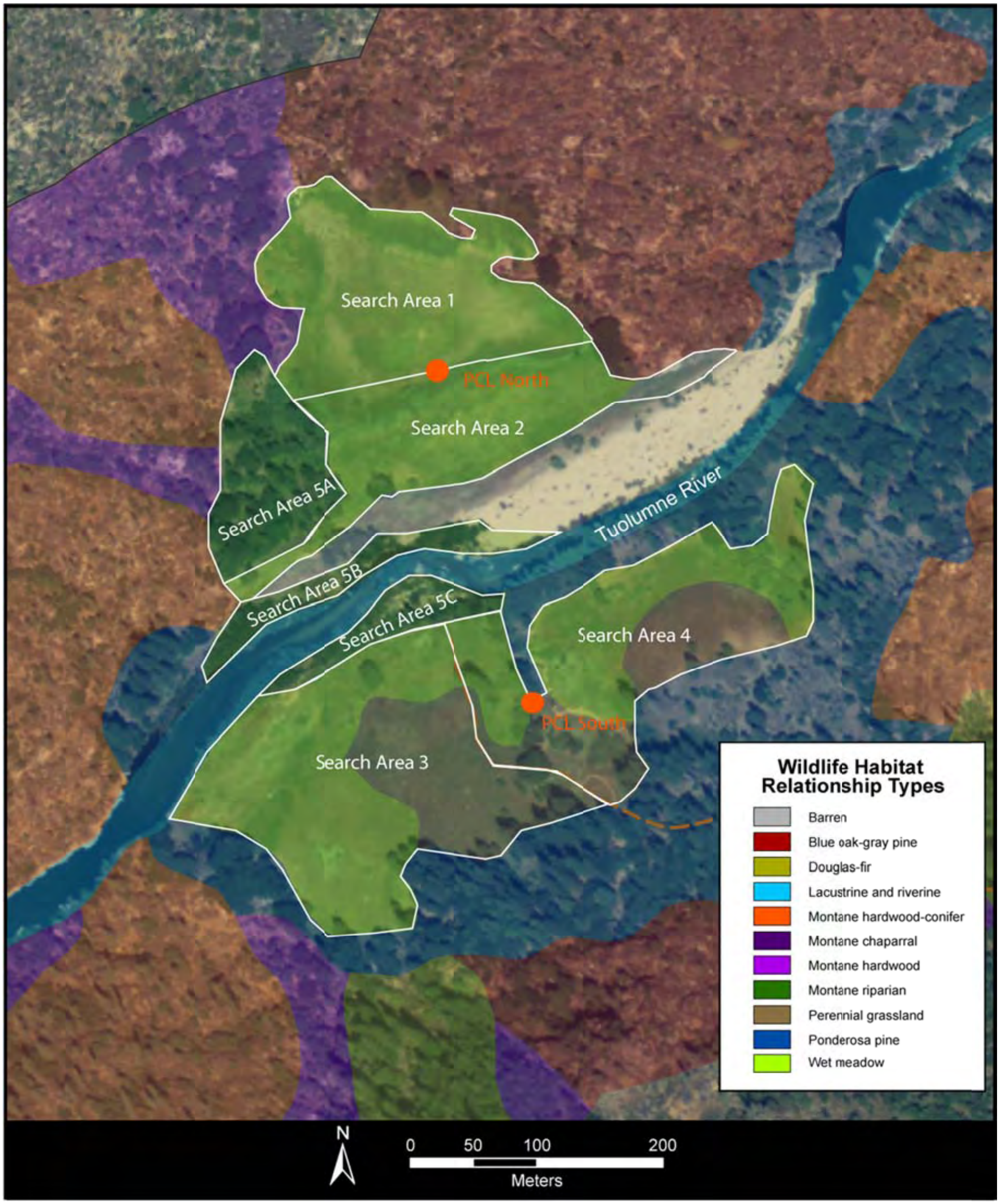
The sensitivity of bird populations to changes in the ecosystem makes them an important indicator of overall habitat quality (Marzluff and Sallabanks 1998). Long-term monitoring of birds, particularly during the breeding season, can be used to effectively assess habitat health (Ralph et al. 1993). Bird population dynamics have been used as scientifically viable surrogates for evaluation of ecosystem condition because (1) birds are conspicuous, easily observable, and monitoring and analysis are cost effective; (2) as secondary consumers (i.e. insectivores), birds are sensitive indicators of environmental change; and (3) knowledge of the natural history of many bird species has a rich basis in literature. In human-altered riparian areas, bird monitoring can be a valuable tool for gauging changes in habitat quality incurred from activities such as restoration efforts, river diversion and channelization projects, water impoundment, and flooding events.

To understand potential effects of altered hydrology below O'Shaughnessy Dam on wildlife in Poopenaut Valley we are pursuing multiple objectives: (1) model predicted occurrence of vertebrate species between O'Shaughnessy Dam and the park boundary and in Poopenaut Valley using California Wildlife Habitat Relationships (CWHR) system models and validation tools, (2) characterize the bird community in Poopenaut Valley, (3) and assess the Poopenaut Valley riparian habitat in relation to bird riparian focal species breeding in Poopenaut Valley. In 2007, we completed our first objective by completing the CWHR model (NPS 2008). Since 2007, we have been continuing to characterize the bird community in Poopenaut Valley and assess the Poopenaut Valley riparian habitat in relation to bird riparian focal species breeding in Poopenaut Valley.

4.2 Methods

We conducted the third year of standardized area search surveys and the second year of point count surveys to estimate bird community species abundance, composition, and habitat use in Poopenaut Valley wet meadow and montane riparian habitats. We conducted area searches in five distinct areas, each comprising approximately 0.03 km^2 (3 hectares); see the 2007 Looking Downstream Report (National Park Service, 2009) for a thorough description of protocols and search areas. In 2008 we established two point count locations, one on either side of the river in Poopenaut Valley at locations intersecting Areas 1 and 2; and Areas 3 and 4 (Figure 4-1). We used the standardized point count protocol for monitoring landbirds (Ralph et al. 1993, Nur et al. 1999), including the use of a standardized datasheet (Appendix 1). Use of standardized methods will allow data to be compared among point count survey results in subsequent years, as well as in areas outside of Poopenaut Valley. Each set of surveys were spaced at least 10 days apart and were completed by 10 am. Point counts were conducted for 5-minutes each, during each of the three visits, following the area searches. For both survey methods, the observer recorded observed species, method of detection (visual, song, or call), and indications of breeding status, such as copulation, courtship or territorial display, food carrying, and any observed fledglings. Data analysis of area searches and point counts included relative abundance, species richness, species diversity index, evenness, and dissimilarity (see 2007 Report for description of data analysis methods).

Figure 4-1. Bird search areas and point count locations (PCL) relative to Wildlife Habitat Relationship types in Poopenaut Valley.



4.3 Results

4.3.1 Area Searches

The third consecutive year of area search surveys in Poopenaut Valley took place during summer 2009 and comprised three separate visits (5/6/2009, 5/22/2009, and 6/11/2009). During all three visits, the north side of the river (Areas 1, 2, 5A, and 5B) was inaccessible due to high water, and those Search Areas and Point Count Location were omitted from analyses accordingly. During the three visits, flow was approximately 42 cms (1,500 cfs), 65 cms (2,300 cfs) and 12 cms (415 cfs), respectively. For area searches, a total of 192 individuals of 31 species were observed in Poopenaut Valley (Table 4-1). Accounting for possible duplicate observations among visits, we estimated relative abundance to be 120 individuals (Table 4-1). The most frequently encountered species were Red-winged Blackbird (*Agelaius phoeniceus)* (15 individuals), Mallard (*Anas platyrhynchos*) (9 individuals)**,** Black-headed Grosbeak (*Pheucticus melanocephalus)*, Song Sparrow (*Melospiza melodia)*, and Yellow Warbler (*Dendroica petechia)* (8 individuals each).

In 2007, 2008, and 2009 combined, we detected 54 species, comprising 24 probable and 4 confirmed locally breeding species, 6 riparian focal species (Black-headed Grosbeak, Song Sparrow, Warbling Vireo (*Vireo gilvus)*, Wilson's Warbler (*Wilsonia pusilla)*, Yellow-breasted Chat (*Icteria virens)*, and Yellow Warbler (RHJV 2004), 2 California Species of Concern (Yellow Warbler and Yellow-breasted Chat), 2 nest predators (Steller's Jay (*Cyanocitta stelleri)* and Western Scrub-Jay (*Aphelocoma californica))*, and 1 invasive nest-parasite species, Brown-headed Cowbird (*Molothrus ater)*.

Bird indices from the wet meadow habitat in Search Area 4 had the highest number of species richness (26 species), diversity index (H = 3.19) and relatively high evenness (J = 0.98). The wet meadow areas averaged 42 individual detections of 24 species (Table 4-2). Search Area 3 had the most number of detections (47 individuals).

Table 4-1. Bird species detected from area searches and their relative abundance in Poopenaut Valley, Yosemite National Park, in May – June 2009.

		Areas					
Common Name	**Status**	**1**	**2**	**3**	**4**	**5C**	**Total**
Acorn Woodpecker		NS	NS	0	1	0	1
American Robin		NS	NS	1	2	3	6
Anna's Hummingbird		NS	NS	1	1	0	2
Brown-headed Cowbird		NS	NS	1	2	1	4
Black-headed Grosbeak	RFS	NS	NS	4	2	2	8
Black-throated Gray Warbler		NS	NS	1	2	1	4
Black Phoebe		NS	NS	0	1	1	2
Bullock's Oriole		NS	NS	1	1	2	4
Cassin's Vireo		NS	NS	0	1	0	1
Chipping Sparrow		NS	NS	0	1	0	1
Common Merganser		NS	NS	2	0	1	3
Dark-eyed Junco		NS	NS	0	1	0	1
House Wren		NS	NS	1	2	0	3
Lazuli Bunting		NS	NS	0	0	1	1
Lesser Goldfinch		NS	NS	3	1	0	4
Mallard		NS	NS	6	1	2	9
MacGillivray's Warbler		NS	NS	1	1	0	2
Nashville Warbler		NS	NS	0	1	0	1
Northern Flicker		NS	NS	2	1	1	4
Northern Rough-winged Swallow		NS	NS	0	0	4	4
Pacific-slope Flycatcher		NS	NS	1	0	0	1
Red-winged Blackbird		NS	NS	8	3	4	15
Song Sparrow	RFS	NS	NS	2	2	4	8
Spotted Towhee		NS	NS	1	2	0	3

Steller's Jay		NS	NS	2	2	0	4
Violet-green Swallow		NS	NS	2	0	0	2
Warbling Vireo	RFS	NS	NS	1	2	2	5
Western Scrub-Jay		NS	NS	1	1	0	2
Western Tanager		NS	NS	0	1	0	1
Western Wood-Pewee		NS	NS	2	1	3	6
Yellow Warbler	CSC, SSC, RFS	NS	NS	3	1	4	8
Total Relative Abundance		**NS**	**NS**	**47**	**37**	**36**	**120**

CSC = California species of special concern; SSC = CDFG Bird Species of Special Concern; RFS = California Partners in Flight Riparian Focal Species

NS = Not sampled

Table 4-2. Species richness (number of species), abundance, bird diversity, and evenness from area searches, by study area in Poopenaut Valley, May – June 2009.

Search Area	***Species Richness***	***Abundance Estimate****	***Species Diversity Index****	***Evenness****
Search Area 3 Wet Meadow	22	47	2.83	0.92
Search Area 4 Wet Meadow	26	37	3.19	0.98
Search Area 5C Montane Riparian	16	36	2.63	0.95

*For each species in a given area, the highest number of individuals detected in the three visits is reported.

Analysis of area search survey data from Search Areas 3, 4, and 5C using the Bray-Curtis Dissimilarity Measure revealed that Areas 3 and 4 differed the most in community assemblage (I_{BC} = 0.396, Table 4-3), meaning they shared the least number of species in common. Areas 4 and 5 shared the highest degree of community similarity (I_{BC} = 0.280, Table 4-3), meaning they had similar species composition.

Table 4-3. Bray-Curtis Dissimilarity Matrix for bird assemblages by study area in Poopenaut Valley, May – June 2009. Numbers in bold type indicate the least and most similar sites.

	Area 3	***Area 4***	***Area 5***
Area 3	0		
Area 4	**0.396**	0	
Area 5	0.311	**0.280**	0

4.3.2 Point Counts

The second year of point count surveys in Poopenaut Valley took place during summer 2009 and comprised three separate visits (5/6/2009, 5/22/2009, and 6/11/2009). Because the river was too high to cross during the entire season, we were not able to conduct surveys on the north side (PCL North). Results were averaged per visit to account for differences in effort. At PCL South, an average of 21.67 individuals of 8.33 species were detected per visit (Table 4-4). Point count surveys for 2009 did not detect any new species not previously recorded during area searches.

Table 4-4. Average bird species relative abundance and species richness, total number of individuals, and species relative abundance by point (PCL South) using 2009 point count data. Data include all detections, excluding flyovers.

Visits = 3	**Count**	**Average**
Total Individuals	**65**	**21.67**
Species Richness	**25**	**8.33**
Acorn Woodpecker	3	1.00
American Robin	1	0.33
Anna's Hummingbird	1	0.33
Black-throated Gray Warbler	2	0.67
Black-headed Grosbeak	1	0.33

Black Phoebe	1	0.33
Brown-headed Cowbird	1	0.33
Bullock's Oriole	1	0.33
Cassin's Vireo	1	0.33
House Wren	1	0.33
Lesser Goldfinch	4	1.33
Mountain Quail	2	0.67
Northern Flicker	4	1.33
Red-winged Blackbird	7	2.33
Song Sparrow	7	2.33
Spotted Towhee	5	1.67
Steller's Jay	3	1.00
Violet-green Swallow	1	0.33
Warbling Vireo	5	1.67
Western Scrub-Jay	1	0.33
Western Tanager	2	0.67
Western Wood-Pewee	5	1.67
Wilson's Warbler	1	0.33
Yellow-rumped Warbler	1	0.33
Yellow Warbler	4	1.33

4.3.3 Breeding Birds

Out of 54 species detected during 2007, 2008, and 2009 area searches and 2008 and 2009 point counts, we identified four confirmed breeding species, 25 probable breeding species, and 54 possible breeding species in all study areas and points combined (Table 4-5). Confirmed breeding species included Black-headed Grosbeak, Bullock’s Oriole, Steller’s Jay, and Western Wood-Pewee (*Contopus sordidulus)*.

Table 4-5. List of 54 bird species detected and their breeding status from area search (AS) and point count (PC) surveys in Poopenaut Valley, Yosemite National Park, in May – June 2007 - 2009.

Species	Possible	Probable	Confirmed	Survey
Acorn Woodpecker	X			AS, PC
American Robin	X	S		AS, PC
Anna's Hummingbird	X	T, P		AS, PC
Ash-throated Flycatcher	X			AS
Belted Kingfisher	X	S		AS
Black-headed Grosbeak	**X**	**S, P**	**CN**	AS, PC
Black-throated Gray Warbler	X	S		AS, PC
Black Phoebe	X	S		AS, PC
Brewer's Blackbird	X			AS
Brown-headed Cowbird	X	S, P		AS, PC
Brown Creeper	X			AS
Bullock's Oriole	X	S, P	F,ON	AS, PC
Bushtit	X			AS
Calliope Hummingbird	X	T, P		AS
Cassin's Vireo	X	S, P		AS, PC
Chipping Sparrow	X	S		AS, PC
Dark-eyed Junco	X			AS
Downy Woodpecker	X			AS
Dusky Flycatcher	X	P		AS, PC
Evening Grosbeak	X			AS
Hairy Woodpecker	X			AS
House Wren	X	S		AS, PC
Hutton's Vireo	X			AS
Lazuli Bunting	X	P		AS

Lesser Goldfinch	X			AS, PC
MacGillivray's Warbler	X			AS, PC
Mallard	X	P		AS
Mountain Quail	X			PC
Mourning Dove	X			AS
Nashville Warbler	X			AS
Northern Flicker	X			AS, PC
Northern Rough-winged Swallow	X	S, P		AS
Nuttall's Woodpecker	X			AS
Oak Titmouse	X			PC
Pacific-slope Flycatcher	X			AS
Red-breasted Nuthatch	X			PC
Red-winged Blackbird	X	T, D, P		AS, PC
Savannah Sparrow	X			AS
Song Sparrow	**X**	**S**		AS, PC
Spotted Towhee	X	S, P		AS, PC
Steller's Jay	X		F	AS, PC
Violet-green Swallow	X	C		AS, PC
Warbling Vireo	**X**	**S**		AS, PC
Western Scrub-Jay	X			AS, PC
Western Tanager	X	S, P		AS, PC
Western Wood-Pewee	X	S, T	ON	AS, PC
White-breasted Nuthatch	X			PC
White-throated Swift	X	C		AS
Wilson's Warbler	**X**			AS, PC
Wrentit	X			PC
Yellow-breasted Chat	**X**			AS

Yellow-rumped Warbler	X			AS, PC
Yellow Warbler	**X**	**P, S, T**		AS, PC

Breeding status for each species is reported as possible, probable, and confirmed breeders (see text from NPS 2007 for description) at Poopenaut Valley, summer 2007, 2008, and 2009. Codes indicating breeding status are: X = detected in study area during the breeding season; P = pair observed during the breeding season; S = more than one singing male in study area or male bird singing during at least 3 visits; D = drumming woodpecker heard; C = courtship behavior or copulation observed; T = Territorial behavior; CN = bird observed carrying nest material or nest building; CF = bird observed carrying food for young; F = recently fledged or downy young observed; ON = occupied nest observed. Partners in Flight riparian focal species are indicated by **bold** print.

4.4 Discussion

Results from bird surveys indicate that Poopenaut Valley provides important breeding and foraging areas for a diverse group of birds representing a variety of breeding niches and differing seasonal strategies (resident species, short-distance, and long-distance migrants). Birds observed in riparian-associated habitats occupy breeding niches of differing heights in the vertical strata, including understory, mid-story, and canopy. This finding suggests that the available habitat in Poopenaut Valley provides structural integrity beneficial to a wide diversity of birds (MacArthur and MacArthur 1961, Karr and Roth 1971).

Of particular interest, are the riparian focal species (RHJV 2004) detected in Poopenaut Valley that are understory nesters. These include Song Sparrow, Yellow-breasted Chat, and Wilson's Warbler, which all need dense, shrubby understory and herbaceous groundcover for successful nesting. Whereas Yellow-breasted Chat does not appear to be resident during the breeding season, Song Sparrow and Wilson's Warbler are probable and possible breeders, respectively, and probably nest in the understory riparian vegetation at the river's edge. Timing and duration of water releases probably has a direct effect on these species nesting success.

4.5 Future work

Further research is needed to gain a greater understanding of potential downstream effects of O'Shaughnessy Dam on bird populations. Future long-term bird monitoring would indicate if localized declines are occurring in riparian associated birds; and focused demographic monitoring (nest-searching or mist-netting) would indicate if productivity is limiting those populations. Nest searching would also yield information pertaining to direct effects of water releases from O'Shaughnessy Dam on nesting birds, particularly understory nesting Song Sparrows and Wilson's Warblers. This information would indicate if the timing and duration of flood events impact certain species' nesting success.

This spring 2010, we will conduct the fourth consecutive year of area searches and third consecutive year of point counts. In addition, we will conduct a pilot nest searching study to determine approximate arrival and nest initiation dates for focal species. We will continue to evaluate habitat elements in Poopenaut Valley for making comparisons between WHR model predictions and actual field observations to better understand the linkages between bird assemblages and habitat attributes. By the end of this year, we should be able to begin comparing bird survey results from Poopenaut Valley to results from other locations in the park, such as the Merced River. Such comparisons may be useful for providing insight into how Poopenaut Valley differs or is similar in bird assemblage, compared to other nearby watersheds.

Chapter 5. Benthic Macroinvertebrate Assemblages and Their Response to Experimental Pulse Flow Events

5.1 Introduction

Although the 100-meter-tall O'Shaughnessy Dam and associated Hetch Hetchy Reservoir are prominent features of Yosemite National Park, the below-dam portions of the Tuolumne River within Yosemite National Park remain something of an ecological frontier. The Poopenaut Valley reach of the river (including Yosemite National Park Planning Segment 5 and part of Segment 6) is close to a major road and is accessible by both a maintained hiking trail and a dirt utility road, but travel along the river is cross-country in nature, which likely explains the comparative lack of visitation. This report provides baseline data on the benthic macroinvertebrate (BMI) assemblage in this river reach and the results of an ecosystem scale experiment designed to test the response of the river's biotic and abiotic elements to two spring flood events.

Macroinvertebrates are excellent integrators of physical, chemical, and biological processes and are highly valued as indicators (Plafkin et al. 1989, Barbour et al. 1999). Invertebrates are also valuable as indicators because these animals include primary, secondary, tertiary, and higher-level consumers (e.g., Wallace and Hutchens 2000) and in turn are a critical food resource for a variety of vertebrate taxa (Allan 1995).

Dams can cause downstream perturbations as a function of reduced and altered river flow, increased water clarity, scouring, and altered temperature regime (Ward 1984, Allan 1995), and ecological effects can cascade throughout the food web and up and down the river corridor (e.g., Holmquist et al. 1998, Greathouse et al. 2006a, b). There can be a reduction of macroinvertebrate species richness, and an increase in abundance, below dams (Stanford and Ward 1989, Allan 1995), although this relationship can be altered if migratory fauna make up a large proportion of the assemblage (Holmquist et al. 1998). Lowest species richness is typically found in the tailwaters just below an impoundment (Stanford and Ward 1989, Armitage and Blackburn 1990). Replacement of certain taxa by others is common; for instance, low flows often result in a reduction of more lotic mayfly taxa and an increase in more lentic taxa (Brittain and Saltveit 1989).

Large experimental or flushing flows have been used increasingly as experiments designed to both better understand effects of river regulation and to improve physical and ecological integrity of regulated rivers (Stanford et al. 1996, Poff et al. 1997, Michener and Haeuber 1998). The experimental release initiative at Glen Canyon/Lake Powell (Andrews and Pizzi 2000, Shannon et al. 2001) was a high profile example of this approach.

For the first year of study, the goal was to develop an understanding of current riffle assemblage structure in this reach of the Tuolumne River. To this end, we conducted spatially and temporally extensive sampling designed to capture year-round variability and to include as many taxa as possible. The second and third years of study assessed the effects of experimental spring floods on the benthic macroinvertebrate assemblage.

5.2 Methods

5.2.1 Assemblage Structure

We sampled the river at approximately six-week intervals from spring of 2007 through winter of 2008, sampling at a different randomly-chosen location on each trip (Table 5-1, Figs. 5-1 through 5-5). We sampled benthic macroinvertebrates, took a variety of physical measurements, and made habitat assessments at each of these stations.

Table 5-1. BMI Sampling sites, dates, and UTM coordinates (WGS84, Zone 11).

1	21 March 2007	11S 253212mE	4201688mN
2	3 May 2007	11S 254007mE	4202441mN
3	15 June 2007	11S 254023mE	4202150mN
4	27 July 2007	11S 254112mE	4202602mN
5	10 Sept 2007	11S 254200mE	4202804mN
6	22 Oct 2007	11S 252931mE	4201265mN
7	3 Dec 2007	11S 254322mE	4203257mN
8	1 Feb 2008	11S 254451mE	4203285mN

Figure 5-1. Location of benthic macroinvertebrate sampling sites.

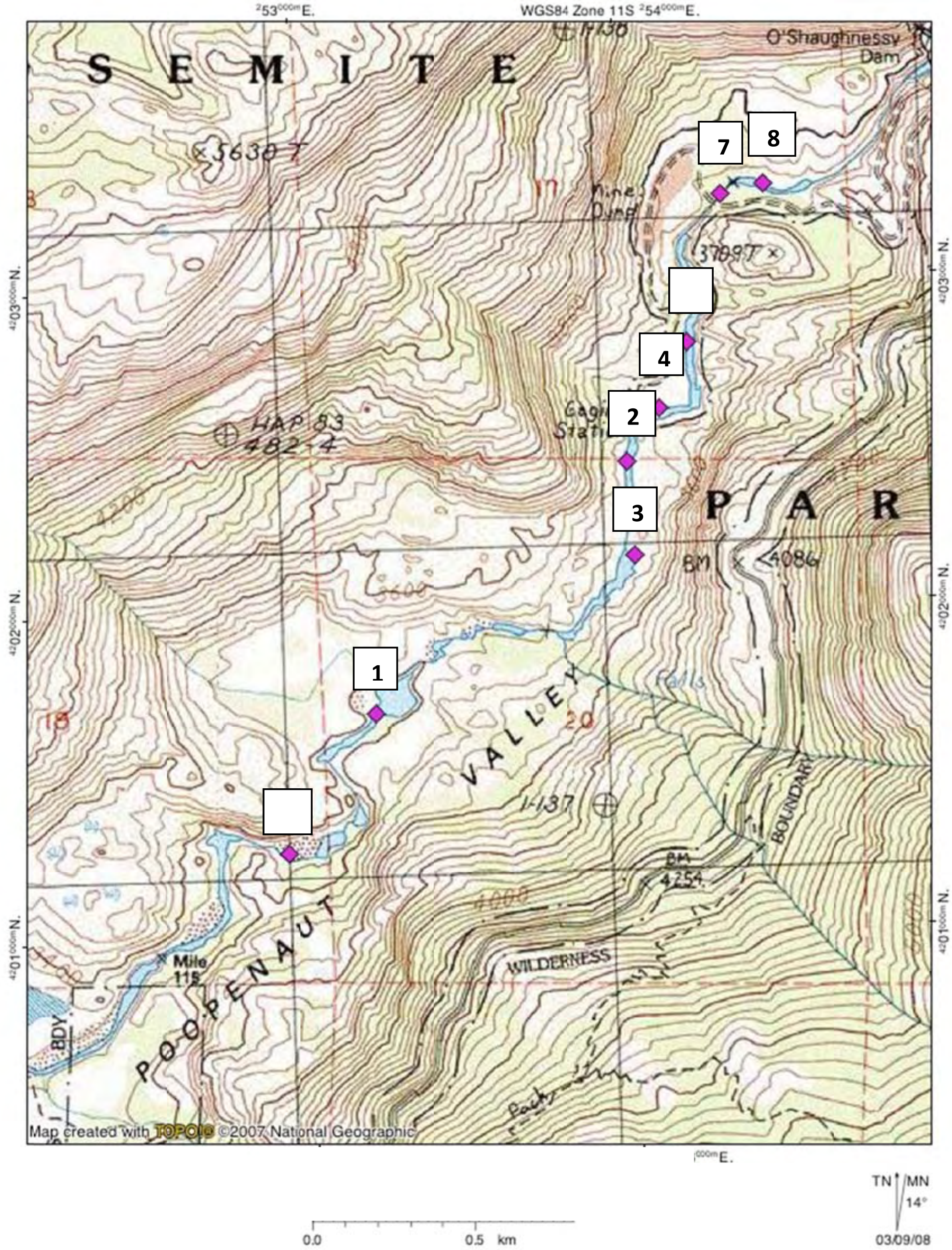


Figure 5-2. Sampling sites 1 (top) and 2 (bottom).

Figure 5-3. Sampling sites 3 (top) and 4 (bottom).

Figure 5-4. Sampling sites 5 (top) and 6 (bottom).

Figure 5-5. Sampling sites 7 (top) and 8 (bottom).

In an effort to ensure comparability with other ongoing sampling in the Tuolumne River, we used the US Environmental Protection Agency rapid bioassessment protocols (Barbour et al. 1999). These protocols emphasize kick netting in riffle habitats (Plafkin et al. 1989, Barbour et al. 1999). The net (with 0.5mm mesh) was held perpendicular to the current, and the upstream substrate was disturbed by vigorously kicking, scraping, overturning, and rubbing large cobbles, and small cobbles, gravel, and silt were dislodged and/or suspended, all while the "kicker" was moving upstream. The composite sample was then rinsed and transferred to a vessel and preserved in 70% non-denatured ethanol, cleaning and removing large pieces of gravel, leaves, and twigs in the process. Each sample consisted of four randomly selected $0.5m^2$ subsamples. Although not part of the EPA protocols, we also collected some limited rock scraping samples on large rock substrata (boulders and submerged slabs). Samples were collected in a 0.3x0.3m Surber sampler.

Samples were sorted completely in the lab, rather than subsampled, because complete sorting reduces the variance of metrics and increases taxon richness (Courtemanch 1996, Doberstein et al. 2000). Sorting was particularly laborious due to the large amounts of filamentous green algae that were present (Figs. 5-2 through 5-4). Taxa were identified to the lowest possible level and entered on EPA Benthic Macroinvertebrate Laboratory Bench Sheets. Kerans and Karr (1994) found that richness, dominance, and trophic metrics were the consistently most useful, and our selected metrics reflect these findings. Calculated metrics include individual family and genus/species densities, total individuals/m^2, species and family richness, species and family richness following Margalef's correction for differential abundance (D_{Mg}= (S - 1)/ln N, where S= number of species or families and N= number of individuals; Clifford and Stephenson, 1975, Magurran 2004), percent species and family dominance (single taxon), %Ephemeroptera-Plecoptera-Trichoptera (for both individuals and taxa), relative contributions of all functional feeding groups (singly and in various combinations and ratios), and the Hilsenhoff biotic index (Hilsenhoff 1987, Barbour et al. 1992, Kerans and Karr 1994). The Hilsenhoff index (HBI) is $S(n_i a_i/N)$, where n_i = number of individuals in the i^{th} taxon, a_i = tolerance value (1-10) assigned to that taxon, and N = total number of individuals in sample with known tolerance values. This index provides an indication of the relative importance of "tolerant' and "intolerant" taxa in an assemblage (those that can and cannot live, respectively, in degraded habitats; tolerant fauna tend to be outcompeted in healthier systems, and "intolerant" taxa predominate). Functional feeding groups are broadly analogous to guilds (Root 1973, Hawkins and MacMahon 1989, Merritt and Cummins 1996). We used Merritt et al. (2008), Aquatic Bioassessment Laboratory (2003), Smith (2001), and Thorp and Covich (2001), among others, as our sources of functional feeding group assignments and Aquatic Bioassessment Laboratory (2003) and Merritt et al. (2008) as our sources for tolerance values. We were able to assign a functional feeding group and a tolerance value for each taxon. The assemblage structure was compared with that found in two other studies using Sorensen's similarity coefficient (S_S= 2a/(2a+b+c), where a= joint occurrences, b= taxa found in group B but not group A, and c= taxa found in group A but not group B; Sorensen 1948, Krebs 1989).

Physical measurements included flow, depth, temperature, stream width, high water mark, percent shade, and coarse estimates of percentages of cobble, gravel, sand, and fines. Flow, depth, temperature, and stream width measurements were made at each of the kick net subsample locations after each subsample was collected, whereas the remainder of the measurements were estimates for the entire site. We measured flow with a General Oceanics rotary flowmeter (with high-speed rotor) on a telescoping wading rod. We took photos and recorded UTM coordinates (WGS84, Zone 11) at each location.

We also completed EPA Habitat Assessment Field Data Sheets (Barbour et al. 1999) at each site at "habitat unit"/reach scales (10-1000m; Frissell et al. 1986, Bauer and Ralph 1999, Fausch et al. 2002). The form includes visual estimates of habitat quality in terms of 1) epifaunal substrate, 2) substrate embeddedness, 3) velocity/depth regime, 4) sediment deposition, 5) channel flow status, 6) channel alteration, 7) frequency of riffles, 8) bank stability, 9) vegetative protection, and 10) width of riparian vegetation zone.

Most metrics demonstrated normality via Lilliefors tests (Lilliefors 1967, Wilkinson et al. 1992), although two metrics required removal of an outlier to meet this assumption. Some initial data exploration was done via multiple regressions. Because of potential collinearity in the multiple regression models, p for entry into, or removal from, the models was set at <0.05 and tolerance was set at 0.1.

Although the study was not designed to test seasonal differences, some trends were apparent, and we wished to examine some unplanned contrasts. Some response variables demonstrated heteroscedasticity ($F_{\max}$ and Cochran's tests; Cochran 1941, Kirk 1982) which for a few variables was not removed by various transformations. We therefore used two-tailed Mann-Whitney U tests for all contrasts. We performed tests for most response variables, so the potential for multiple comparison error should be kept in mind when interpreting these results based on per-contrast error rate. All statistical tests were done in SYSTAT (Wilkinson et al. 1992).

5.2.2 Response to Experimental Releases

We sampled the below-dam reach one day before, one day after, and two months after each of the experimental releases described in Chapters 1 and 2 in order to capture pre-release and post-release conditions and to assess initial persistence of any changes induced by the flood. We sampled sites 2-5 and 7-8 (Figs. 5-1, 5-2 through 5-6, 5-8, 5-9) at each of these three intervals.

We collected 1m^2 kick net samples as described above, and almost all methodology was identical to the Year 1 assemblage characterization described above. We did not do the ancillary rock scrapings in Years 2 and 3, but we added several additional metrics. A great deal of green algae was collected in the process of kick net sampling, and we used the gram dry mass of these samples as a coarse (under)estimate of algal biomass. Algal material was separated during faunal sorting, and algal samples were dried at 90° C for 24 hours prior to weighing. We collected water samples from each site, at each visit, for measurement of pH, total dissolved solids, and conductivity in the lab with a Hanna model HI98129 combination meter. We used Hanna HI7031 conductivity calibration solution (1413μS/cm at 25° C), Orion perpHect buffer 7, (ph 7.00 +/-0.01 at 25° C), and Hanna HI70300 storage solution. We also measured percent tree canopy cover with a convex spherical densiometer (Lemmon 1956, 1957) manufactured by Forest Densiometers.

We analyzed release effects with 1x2 ANOVAs with repeated measures, contrasting metrics as a function of the two releases and three sampling periods in each year. In order to meet assumptions of normality and homogeneity of variance we square-root transformed $((\sqrt{y}) + (\sqrt{y} + 1))$ proportional data and log transformed $(\log y + 1)$ all other data.

5.3 Results

5.3.1 Assemblage Structure

Even the most consistent physical parameters varied by about a factor of two over the course of the sampling year. Depth varied from 24.8 to 59.0cm (mean= 38.0cm, Table 5-2), temperature ranged from 4.5 to 10.5°C (mean= 7.20 °C), and flow ranged from 30.7 to 66.8cm/sec. Other metrics were somewhat more variable (Table 5-2).

Table 5-2. Means and standard errors for physical parameters.

Metric	Mean	SE
Water depth (cm)	38.0	4.01
Water temperature (°C)	7.20	0.671
Flow (cm/sec)	50.7	5.16
Stream width (m)	22.7	4.54
Width (m):Depth (m) ratio	61.5	10.3
High water mark (m)	2.40	0.600
Percent shade	27.0	15.0
Percent cobble	58.0	11.9
Percent gravel	21.0	6.40
Percent sand	13.0	3.74
Percent fines	8.00	5.83

Habitat condition had mean scores that fell in the Optimal range for eight of the ten parameters (Table 5-3). Velocity/Depth Regime fell in the Marginal range because of the frequent lack of diverse flow regimes, and Frequency of Riffles was Suboptimal due to low occurrence of riffles. Although Epifaunal Substrate/Available Cover and Sediment Deposition fell in the Optimal range, these two parameters were close to Suboptimal because of lack of woody debris and sediment deposition, the latter primarily in pools. The overall score was Optimal (mean= 155; SE= 5.13).

The study collected 69 taxa representing 25 families and eight orders. There was a moderate level of evenness at the order level, although Ephemeroptera and Diptera made up the majority of the assemblage (Figs. 5-6, 5-7). There was more evenness at the family level (Figs. 5-8, 5-9) than at the order level, and the distribution lies between the log normal and MacArthur's broken stick models. Mean family richness was 16.3/2m^2, which was reduced to D_{Mg}=2.70 after applying Margalef's correction for abundance, and family level dominance was 39.7% (Table 5-4). Species level rank-abundance showed a similar distribution (Figs. 5-10, 5-11) to family rank-abundance. There was an average of 41.7 species per 2m^2, which converted to 7.04 after Margalef's correction, and species dominance was 21.4% (Table 5-4).

Table 5-3. Habitat characteristics from EPA Habitat Assessment Field Data Sheets with EPA condition categories. Each parameter is scored from 1-20; parameters 8-10 are scored from 1-10 for each bank and combined for the total score for the parameter in question. The overall score for a site is the sum of all ten parameters, with a maximum score of 200. SE= standard error. (Continued next page).

Habitat Parameter	**Mean**	**SE**	**Condition Category**
1. Epifaunal Substrate/ Available Cover	15.4	0.571	**Optimal** Greater than 70% of substrate favorable for epifaunal colonization and fish cover.
2. Embeddedness	16.3	0.808	**Optimal** Gravel, cobble, and boulder particles are 0-25% surrounded by fine

			sediment. Layering of cobble provides diversity of niche space.
3. Velocity/ Depth Regime	7.14	0.459	**Marginal** Only 2 of the 4 habitat regimes present.
4. Sediment Deposition	15.6	1.49	**Optimal** Little or no enlargement of islands or point bars and less than 5% (<20% for low-gradient streams) of the bottom affected by sediment deposition.
5. Channel Flow Status	18.7	0.522	**Optimal** Water reaches base of both lower banks, and minimal amount of channel substrate is exposed
6. Channel Alteration	18.4	0.481	**Optimal** Channelization or dredging absent or minimal; stream with normal pattern.

7. Frequency of Riffles	10.1	1.62	**Suboptimal** Occurrence of riffles infrequent; distance between riffles divided by the width of the stream is between 7 to 15.

Habitat characteristics.

8. Bank Stability (Left)	8.71	0.360	**Optimal**
(Right)	9.14	0.404	Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.
9. Vegetative Protection			**Optimal**
(Left)	8.43	0.429	More than 90% of the streambank surfaces and immediate riparian zone covered by native
(Right)	8.71	0.421	

			vegetation, including trees, understory shrubs, or nonwoody macrophytes; vegetative disruption through grazing or mowing minimal or not evident; almost all plants allowed to grow naturally.
10. Riparian Vegetative Zone Width (Left)	9.00	0.309	**Optimal** Width of riparian zone >18 meters; human activities (i.e., parking lots, roadbeds, clear-cuts, lawns, or crops) have not impacted zone.
(Right)	9.14	0.340	
Overall	**155**	**5.13**	**Optimal**

Table 5-4. Means and standard errors for diversity metrics.

	Mean	**SE**
Family Richness	16.3	0.365
Margalef's Corrected Family Richness	2.70	0.178
Percent Family Dominance	39.7%	4.11
Species Richness	41.7	3.40
Margalef's Corrected Species Richness	7.04	0.365
Percent Species Dominance	21.4%	5.30

Ephemeroptera were found in every sample, and this order was dominated by Baetidae, Ephemerellidae, and Leptophlebiidae (mean individuals/m^2= 60.3, 54.1, and 32.5, respectively; Table 5-5). The only family collected in the study with a higher abundance was Chironomidae. All families had a high frequency of occurrence; the three previously noted families occurred in each sample and the remaining two families, Ameletidae and Heptageniidae, had frequencies of 0.750 and 0.875. Ephemerellidae was particularly speciose with nine taxa represented. The most abundant mayflies at the genus/species level were *Baetis* spp., *Ephemerella excrucians*, and *Paraleptophlebia* sp. (60.3, 48.3, and 32.5 individuals/m^2; Table 5-5). *Baetis* and *Paraleptophlebia* were found in every sample.

Plecoptera were lower in abundance (individuals/m^2= 28.3) but were still found in every sample (Table 5-5). There was a relatively high level of evenness among the stonefly families: Nemouridae, Perlidae, Chloroperlidae, and Perlodidae had 10.8, 8.38, 7.31, and 1.88 individuals/m^2, respectively. Only Chloroperlidae was represented in every sample. The most abundant species were *Hesperoperla pacifica and Malenka* sp. (6.38 and 6.31 individuals/m^2, respectively), and *Hesperoperla pacifica, Calineuria californica,* and *Suwallia* sp. A had the highest frequency of occurrence at 0.625 (Table 5-5).

Trichoptera were similar to Plecoptera in abundance, and the most common caddisfly families were Hydropsychidae, Hydroptilidae, and Philopotamidae (13.6, 4.50, and 1.19, respectively). Hydropsychidae and Hydroptilidae had the highest frequency of occurrence at 0.750. The most common taxa were *Hydropsyche* sp., *Hydroptila* sp. A, and *Dolophilodes* sp. (13.6. 3.88, 1.19 individuals/m^2, respectively; Table 5-5).

Coleoptera were relatively uncommon (4.38 individuals/m^2), and Elmidae (riffle beetles) and Hydrophilidae (water scavenger beetles) were the only families collected (4.31 and 0.0625 individuals/m^2, respectively; Table 5-5). Of the seven collected Coleoptera taxa, six were elmids, and both larval and adult elmids occurred in the samples. The elmids *Cleptelmis addenda* and *Optioservus quadrimaculatus* were the most abundant beetles (2.31 and 1.25 individuals/m^2, respectively); *Optioservus* had the highest frequency of occurrence (0.625).

Atractelmis wawona (the Wawona riffle beetle), a federal species of concern, was not encountered.

Figure 5-6. Rank-abundance by order, plus Class Bivalvia (linear scale).

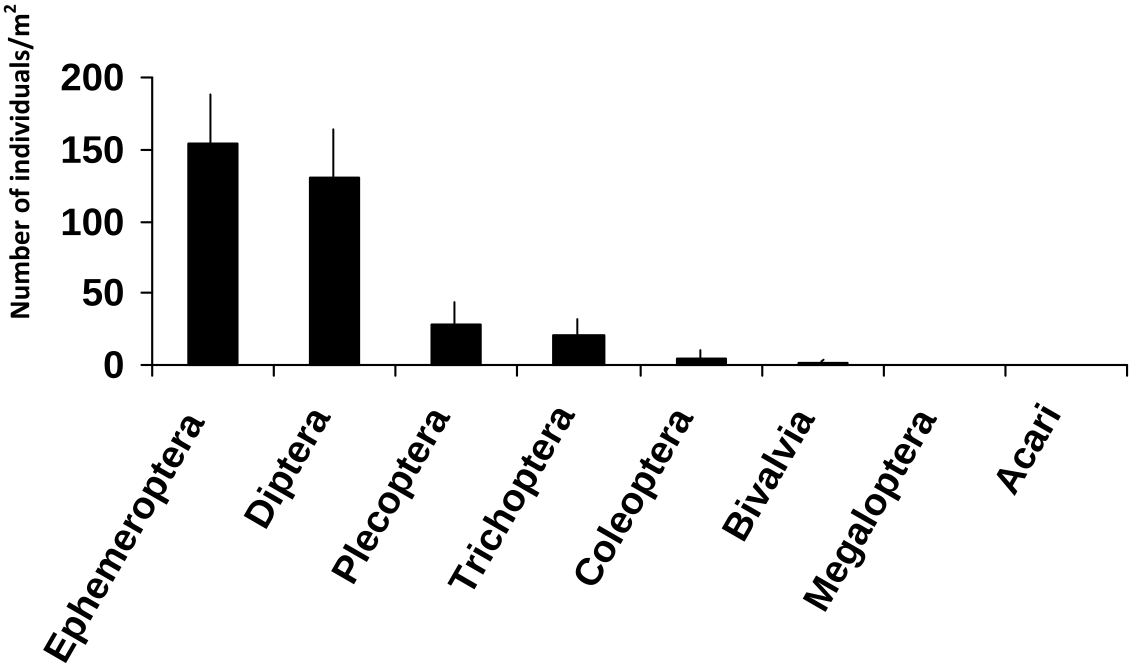


Figure 5-7. Rank-abundance by order, plus Class Bivalvia (log scale).

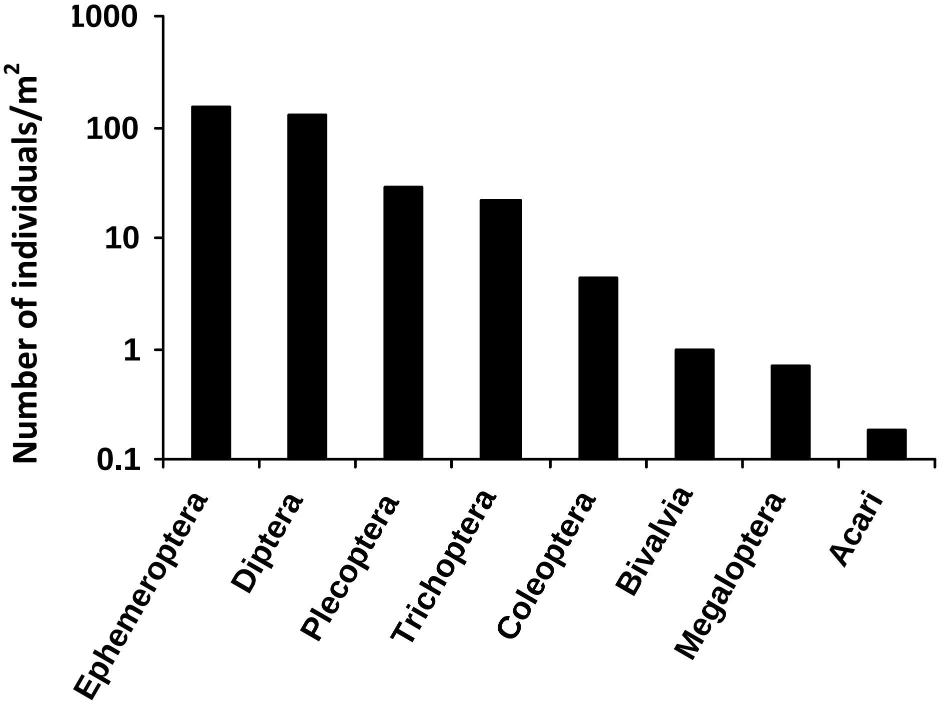


Figure 5-8. Rank-abundance by family (linear scale).

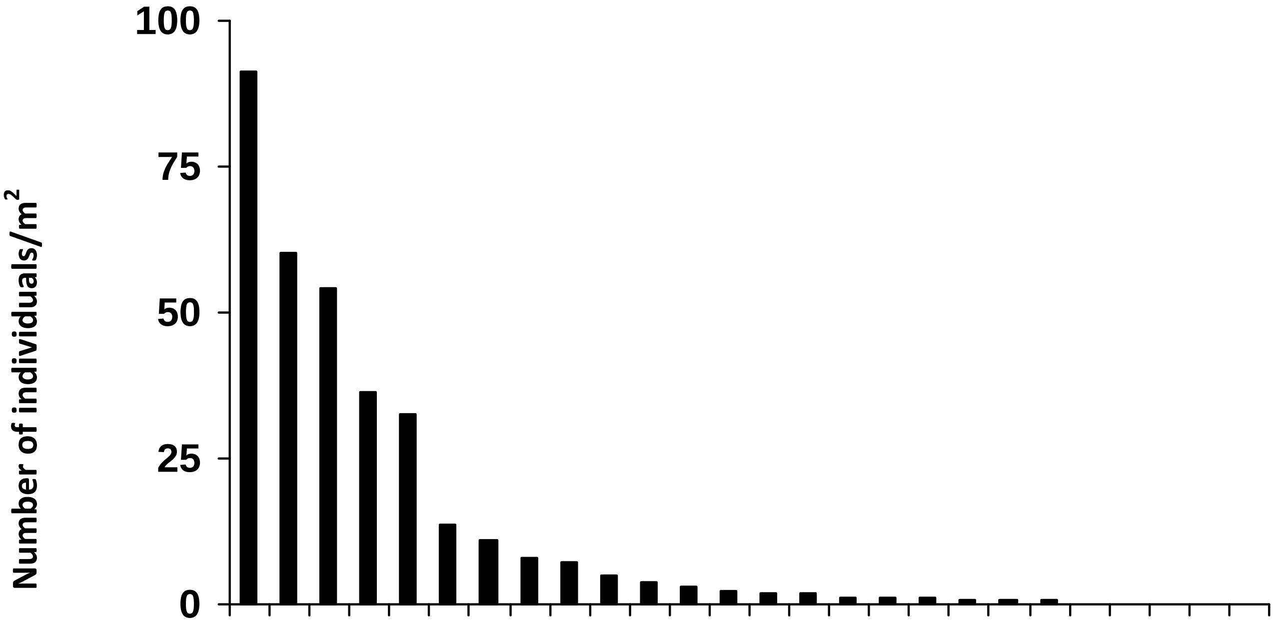
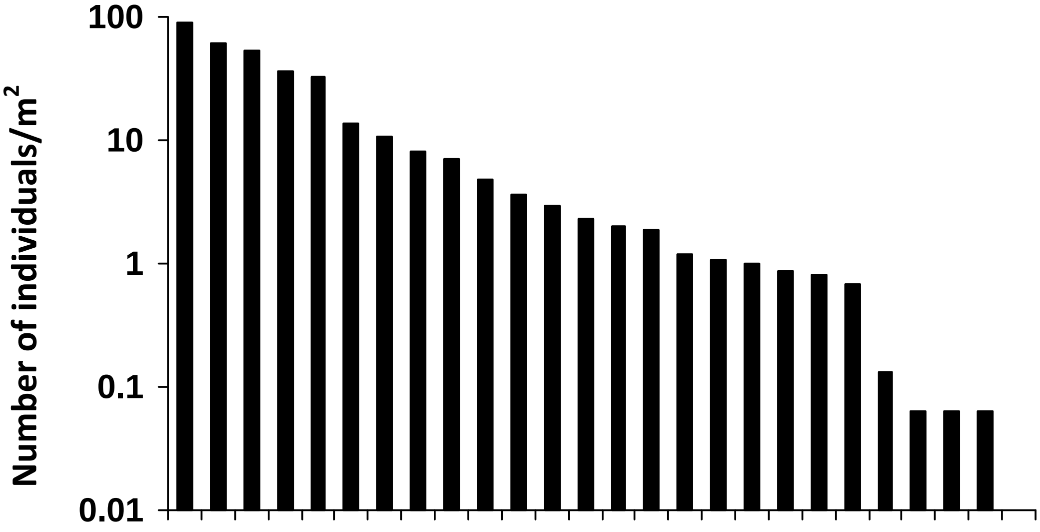


Figure 5-9. Rank-abundance by family (log scale).



Diptera was the most abundant order (132 individuals/m^2), and in turn Chironomidae (midges; 92.1 individuals/m^2) and Simuliidae (black flies; 36.2 individuals/m^2) were the most common dipterans (Table 5-5). Chironomidae was the only dipteran family found in each sample. Tipulidae (crane flies) and Empididae (dance flies) were also important both in terms of abundance and species richness (Table 5-5).

We also collected dobsonflies (Megaloptera), water mites, and clams, all in small numbers (Table 5-5). *Orohermes crepusculus*, the dobsonfly in our samples, was the largest animal that we collected; some specimens reached 4.5cm. No New Zealand mudsnails (*Potamopyrgus antipodarum*), or any other gastropods, were collected.

The sampled taxa represented a variety of feeding groups (Table 5-5). The majority of species were either predators (29) or collector-gatherers (20). There were fewer scrapers (6), shredders (6), collector-filterers (4), and piercer-herbivores (4), although scraping was frequently a secondary functional feeding mode. Important predator groups included stoneflies, crane flies, dance flies, and mites. Ephemerellid mayflies and riffle beetles were generally collector-gatherers. Most of the primary scrapers were heptageniid mayflies, most of the shredders were nemourid stoneflies, most of the piercer-herbivores were hydroptilid caddisflies, and the only collector-filterers were black flies and some of the caddisflies.

The proportional importance of the various functional feeding groups shifted significantly when considered as proportion of individuals (Table 5-6) instead of relative to numbers of taxa. Collector-gatherers accounted for 70.9% of total individuals-- a function of several abundant mayfly species (Table 5-5). Although predators accounted for a majority of taxa, due in large part to the speciose stoneflies (Table 5-5), predators only represented 7.47% of individuals (Table 5-6). In contrast, the four collector filterer taxa represented 13.5% of total individuals (Table 5-6), a function of abundant black flies (Table 5-5). Percent scrapers was notably low at only 1.98% (Table 5-6).

Table 5-5. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1^o and 2^o FFG), and California Tolerance Values (CTV). Ephemeroptera and Plecoptera were all nymphs; Megaloptera, Trichoptera, and Diptera were larvae except for occasional pupae (pu); Coleoptera were either larvae (l) or adults (a); and Acari and Bivalvia were adults. FFGs: p= predator, cg= collector-gatherer, cf= collector-filterer, ph= piercer-herbivore, sc= scraper, sh= shredder. Tolerance values represent a general spectrum of tolerance to poor water quality, scored from 0 (highly intolerant) to 10 (highly tolerant). Continued next page.

	Abundance		**Frequency**	**1^{o}FFG**	**2^{o}FFG**	**CTV**
	Mean	SE				
Ephemeroptera	153	32.1	1.00			
Ameletidae	3.00	1.20	0.750			
Ameletus sp.	3.00	1.20	0.750	sc	cg	0
Baetidae	60.3	21.4	1.00			
Baetis spp.	59.0	21.3	1.00	cg	sc	4
Unknown	1.31	1.06	0.250	cg	sc	4
Heptageniidae	3.56	1.24	0.875			
Cinygmula sp.	0.625	0.246	0.625	sc	cg	4
Epeorus longimanus	0.625	0.498	0.250	sc	cg	4
Ironodes sp.	1.44	0.759	0.500	sc	cg	4
Rithrogena sp.	0.875	0.875	0.125	sc	cg	0

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1^o, 2^o FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		**Frequency**	**1^{o}FFG**	**2^{o}FFG**	**CTV**
	Mean	SE				
Ephemeroptera, cont.						
Ephemerellidae	54.1	23.4	1.00			
Caudatella heterocaudata	0.0625	0.0625	0.125	cg	sc	1
Caudatella hystrix	1.31	0.744	0.500	cg	sc	1
Drunella grandis ingens	0.0625	0.0625	0.125	cg	sc	0
Ephemerella excrucians	48.3	22.8	0.875	cg	sc	1
Ephemerella dorothea infrequens	1.13	0.760	0.250	sh	cg	1
Ephemerella sp. A	0.250	0.250	0.125	cg	sc	1
Ephemerella sp. B	0.0625	0.0625	0.125	cg	sc	1
Ephemerella sp. C	0.188	0.188	0.125	cg	sc	1
Serratella teresa	2.81	2.08	0.375	cg		2
Leptophlebiidae	32.5	10.3	1.00			
Paraleptophlebia sp. A	32.5	10.3	1.00	cg	sh	4
Plecoptera	28.3	8.34	1.00			
Nemouridae	10.8	4.72	0.625			
Malenka sp.	6.31	3.80	0.500	sh		2
Podmosta delicatula	2.38	2.38	0.125	sh		2

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1°, 2° FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		Frequency	1°FFG	2°FFG	CTV
	Mean	SE				
Plecoptera, cont.						
Zapada cinctipes	1.69	1.69	0.125	sh		2
Unknown	0.375	0.375	0.125	sh	cg	2
Perlidae	8.38	3.74	0.875			
Calineuria californica	1.81	0.647	0.625	p		3
Hesperoperla pacifica	6.38	3.74	0.625	p		2
Hesperoperla sp.	0.125	0.0818	0.250	p		2
Unknown	0.0625	0.0625	0.125	p		2
Perlodidae	1.88	0.976	0.500			
Cultus tostonus	0.0625	0.0625	0.125	p		2
Cultus sp.	0.313	0.313	0.125	p		2
Osobenus yakimae	0.938	0.938	0.125	p		2
Skwalla americana	0.125	0.125	0.125	p		2
Isoperla sp. A	0.250	0.250	0.125	p		2
Isoperla sp. B	0.188	0.188	0.125	p		2

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1^o, 2^o FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		**Frequency**	**1^oFFG**	**2^oFFG**	**CTV**
	Mean	SE				
Chloroperlidae	7.31	3.05	1.00			
Alloperla sp.	0.250	0.250	0.125	p		1
Haploperla chilnualna	1.13	0.603	0.625	p	cg	1
Plumiperla sp.	0.938	0.868	0.250	p		1
Suwallia sp. A	3.00	1.46	0.625	p		1
Suwallia sp. B	1.94	1.45	0.250	p		1
Unknown	0.0625	0.0625	0.125	p		1
Megaloptera						
Corydalidae	0.688	0.298	0.500			
Orohermes crepusculus	0.688	0.298	0.500	p		0
Trichoptera	21.3	8.13	0.875			
Philopotamidae	1.19	0.886	0.250			
Dolophilodes sp.	1.19	0.886	0.250	cf		2
Polycentropodidae	0.875	0.337	0.500			
Polycentropus sp.	0.875	0.337	0.500	p	cf	6

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1^o, 2^o FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		**Frequency**	**1^{o}FFG**	**2^{o}FFG**	**CTV**
	Mean	SE				
Hydropsychidae	13.6	7.58	0.750			
Hydropsyche sp.	13.6	7.58	0.750	cf		4
Rhyacophilidae	0.375	0.375	0.125			
Rhyacophila sp. A	0.375	0.375	0.125	p		0
Hydroptilidae	4.50	2.02	0.750			
Hydroptila sp. A	3.88	1.77	0.500	ph	sc	6
Hydroptila sp. B	0.438	0.371	0.250	ph	sc	6
Hydroptila sp. (pu)	0.188	0.132	0.250	ph	sc	6
Lepidostomatidae	0.750	0.423	0.500			
Lepidostoma sp.	0.750	0.423	0.500	sh		1
Coleoptera	4.38	2.27	0.625			
Hydrophilidae	0.0625	0.0625	0.125			
Enochrus sp. (a)	0.0625	0.0625	0.125	ph		5
Elmidae	4.31	2.28	0.625			
Cleptelmis addenda (l)	2.25	1.97	0.375	cg	sc	4

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1^o, 2^o FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		**Frequency**	**1^{o}FFG**	**2^{o}FFG**	**CTV**
	Mean	SE				
Cleptelmis addenda (a)	0.0625	0.0625	0.125	cg	sc	4
Heterlimnius sp. (l)	0.250	0.250	0.125	cg	sc	4
Optioservus quadrimaculatus (a)	1.25	0.366	0.625	cg		4
Rhizelmis nigra (l)	0.375	0.375	0.125	sc	cg	2
Zaitzevia sp. (a)	0.0625	0.0625	0.125	cg		4
Unknown (l)	0.0625	0.0625	0.125	cg		4
Diptera	132	29.0	1.00			
Chironomidae*	92.1	19.0	1.00	cg	p	6
Psychodidae	0.0625	0.0625	0.125			
Pericoma sp.	0.0625	0.0625	0.125	cg		4
Simuliidae	36.2	14.6	0.750			
Simulium spp.	36.1	14.5	0.750	cf		6
Simulium canadense (pu)	0.0625	0.0625	0.125	cf		6

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1°, 2° FFG), and California Tolerance Values (CTV). Continued next page.

	Abundance		**Frequency**	**1°FFG**	**2°FFG**	**CTV**
	Mean	SE				
Diptera, cont.						
Tipulidae	2.25	0.835	0.750			
Antocha sp.	0.125	0.0818	0.250	cg		3
Dicranota sp.	1.25	0.866	0.250	p		3
Hexatoma sp.	0.875	0.515	0.375	p		2
Empididae	1.06	0.427	0.500			
Clinocera sp.	0.188	0.188	0.125	p		6
Hemerodromia sp.	0.438	0.371	0.250	p		6
Wiedemannia sp.	0.0625	0.0625	0.125	p		6
Clinocera/Wiedemannia (pu)	0.188	0.188	0.125	p		6
Unknown Empididae A	0.0625	0.0625	0.125	p		6
Unknown Empididae B	0.125	0.125	0.125	p		6

Table 5-5, cont. Densities (per m^2; SE= standard error) and frequency of occurrence of taxa, primary and secondary functional feeding groups (1°, 2° FFG), and California Tolerance Values (CTV).

	Abundance		**Frequency**	**1°FFG**	**2°FFG**	**CTV**
	Mean	SE				
Acari						
Hydrachnidae	0.125	0.125	0.125			
Hydrachna sp.	0.125	0.125	0.125	p		5
Hydryphantidae	0.0625	0.0625	0.125			
Thyadinae	0.0625	0.0625	0.125	p		5
Mollusca, Bivalvia						
Veneroida 0.875	0.806	0.250				
Sphaeriidae	0.875	0.806	0.250			
Sphaerium sp.	0.875	0.806	0.250	cg		8
Total Individuals	**341**	**45.0**				

* Individual chironomid morphospecies were separated and counted but most were not identified

Table 5-6. Mean percentage of fauna (by individuals) and standard errors for primary functional feeding groups.

	Mean	SE
Percent Scrapers	1.98	0.532
Percent Predators	7.47	1.76
Percent Collector-Gatherers	70.9	5.35
Percent Shredders	4.30	1.61
Percent Collector-Filterers	13.5	4.94
Percent Piercer-Herbivores	1.80	0.796

Tolerance values ranged from 0 to 8, but there were far more intolerant taxa (tolerance from 0 to 3; 36 taxa) than intolerant taxa tolerance from 8-10 (tolerance from 8 to 10; one taxon, the clam *Sphaerium* at a value of 8; Table 5-5). This one tolerant taxon represented 1.4% of taxa and only 0.26% of individuals. Tolerance values for mayflies and stoneflies were low, ranging from 0 to 4 and 1 to 3, respectively. Our one megalopteran species had a tolerance of 0. The caddisflies, beetles, and flies ranged higher (0 to 6, 2 to 5, and 2 to 6, respectively; Table 5-5). The unweighted mean tolerance by taxon was 3.1. Hilsenhoff's biotic index, which effectively weights tolerance by abundance of individual taxa, was 4.01 (SE= 0.338). Another measure of river health, Percent Ephemeroptera-Plecoptera-Trichoptera (EPT), was relatively high at 78.8% of total individuals (SE= 5.04), and 64% of taxa.

Initial data exploration via multiple regression yielded few significant models. Positive predictors included flow for simuliids (black flies), vegetation in the riparian zone (Table 5-3) for chironomids (midges), and lack of sediment deposition (Table 5-3) for baetid mayflies.

Some seasonal trends were apparent, particularly when spring-summer and fall-winter months were compared (Table 5-7). Diptera increased three-fold during the fall and winter (from a mean of 66.9 to 196 individuals/m^2; Table 5-7). Much of this increase was driven by an increase in simuliid black flies from zero to a mean of 71.8 individuals/m^2 (Table 5-7, Fig. 5-12). Chironomid midges, particularly Tanytarsini, also increased from a spring-summer mean of 63.0 to a fall-winter mean of 121 individuals/m^2 (27.4 and 19.3 SE, respectively), although these differences were not significant (Mann-Whitney U test, p= 0.0814). These increases in dipteran abundance were combined with a decrease in number of %Ephemeroptera-Plecoptera-Trichoptera from a mean of 228 to 177 individuals/m^2, e.g., *Serratella teresa* (Table 5-7). In turn, %EPT decreased (from over 80% to 30%; Table 5-7, Fig. 5-13), and %Collector-Filterers, the simuliid functional feeding group, increased (from zero to above 20%; Table 5-7, Fig. 5-14). The dominant functional feeding group, collector-gatherers, decreased from 91% to about 60% during this time (Fig. 5-14), though this was not a significant change (Mann-Whitney U test, p= 0.149). Most dipterans collected in the study had higher tolerance values than the rest of the taxa (Table 5-5), and Hilsenhoff's Biotic Index increased steadily from 2.29 to ~5.0 from spring to winter (Fig. 5-15, Table 5-7). Percent Species Dominance, however, decreased from 56% to ~15% during this time period (Fig. 5-16, Table 5-7), whereas % Family Dominance did not show as steady a decline (Fig. 5-16).

Large rock substrata (boulders and submerged slabs) yielded higher means (mean= 767 individuals/m^2, SE= 719) than cobble substrata, but variability was very high, as some samples had almost no fauna present. Ephemeroptera were abundant in one sample but absent in the others (mean= 294 individuals/m^2, SE= 294). Adult and larval elmid (riffle) beetles were common in the same abundant sample and again absent in the other rock scrapings (mean= 276 individuals/m^2; SE= 276). Diptera were also present in large numbers (mean= 104 individuals/m^2, SE= 68.2). Trichoptera and Plecoptera were less abundant (~50 individuals/m^2 each).

Table 5-7. Mean values (SE= standard error) for selected metrics as a function of period during which sampling occurred: Spring-Summer (March through August) or Fall-Winter (September through February). Most response variables were tested for seasonal differences and the majority were non-significant; only significant results are presented here. P-values are the result of two-tailed Mann-Whitney U tests. *Simulium* is a black fly (Diptera: Simuliidae); *Serratella* is a mayfly (Ephemeroptera; Ephemerellidae); %CF= Percent Collector-Filterers; %EPT= Percent Ephemeroptera-Plecoptera-Trichoptera; %Dominance (Sp)= Percent dominance by the most common species in each sample; HBI= Hilsenhoff's Biotic Index (larger values indicate increased tolerance to poor water quality).

	Spring-Summer		**Fall-Winter**		
	Mean	**SE**	**Mean**	**SE**	**p**
Diptera	66.9	27.9	196	18.6	0.0209
Simulium sp.	0.500	0.354	71.8	11.9	0.0202
Serratella teresa	5.63	3.86	0.00	0.00	0.0472
%CF	2.75	1.78	24.3	5.79	0.0209
%EPT	78.7	5.04	44.8	0.818	0.0209
%Dominance (Sp)	29.9	9.04	12.9	0.890	0.0209
HBI	3.28	0.350	4.75	0.226	0.0209

Figure 5-10. Rank-abundance at the species level (linear scale).

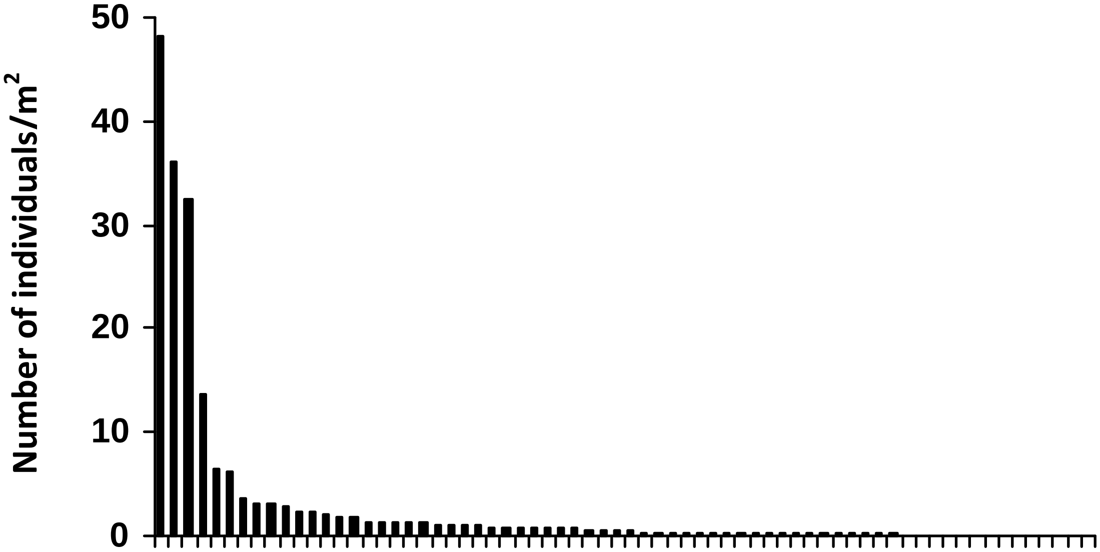


Figure 5-11. Rank-abundance at the species level (log scale).

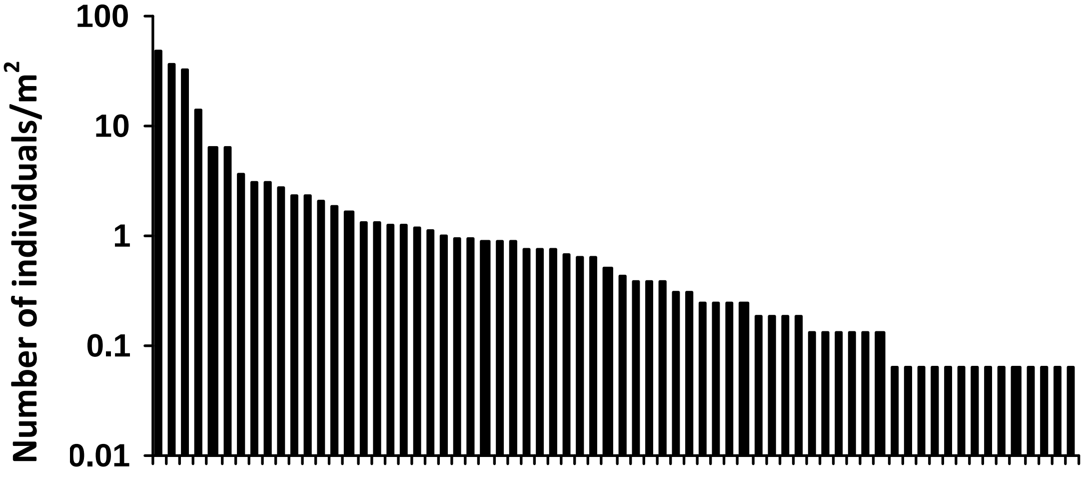


Figure 5-12. *Simulium* (black flies; Diptera: Simuliidae) densities during study year.

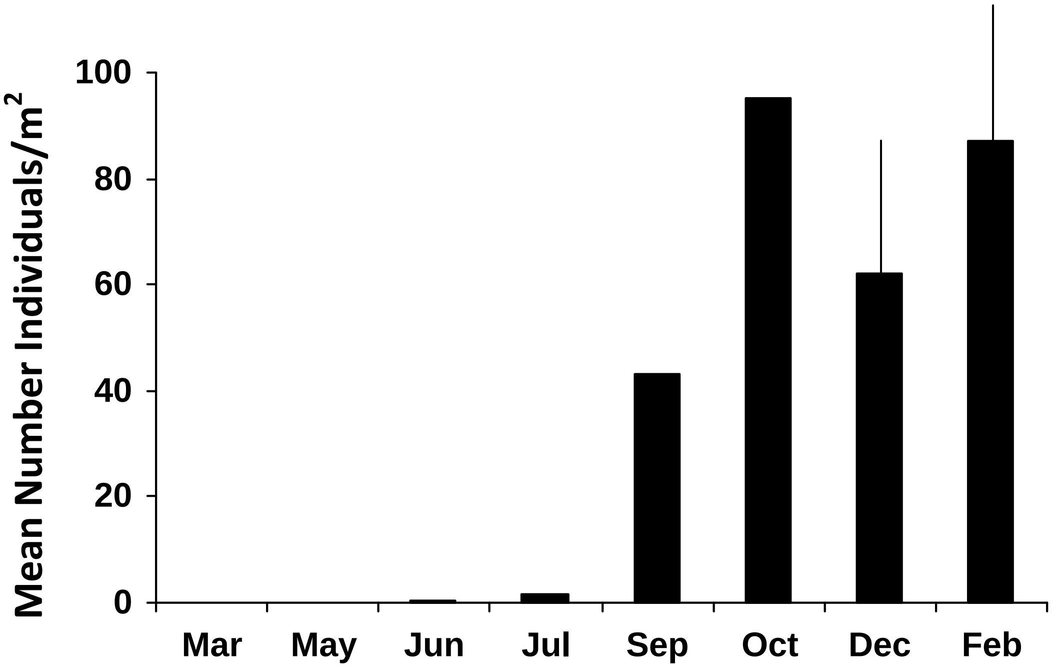


Figure 5-13. Percent Ephemeroptera-Plecoptera-Trichoptera during study year.

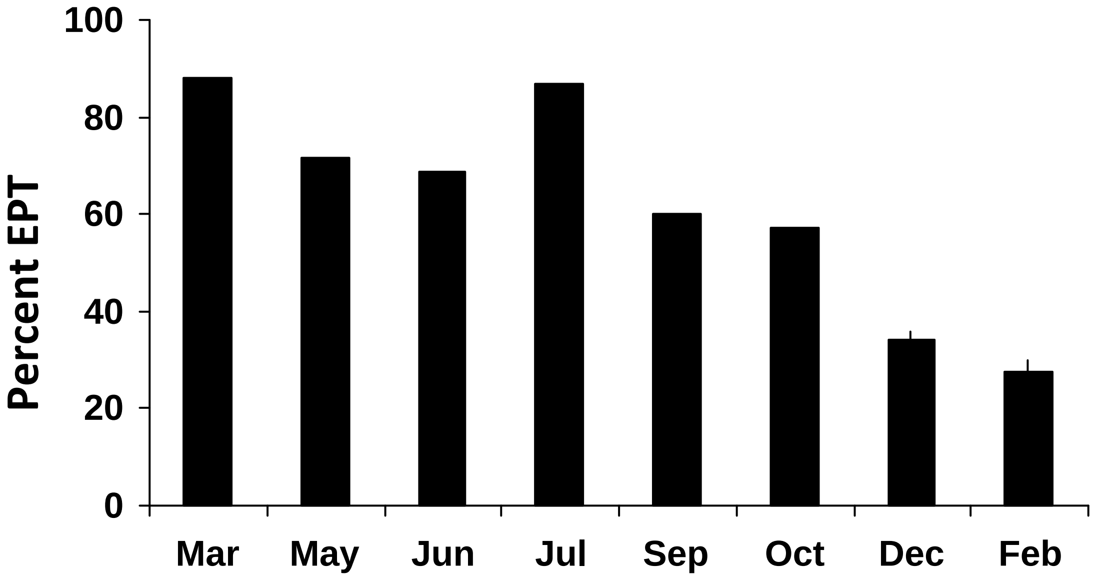


Figure 5-14. Percent Collector-Gatherers and Collector-Filterers during study year.

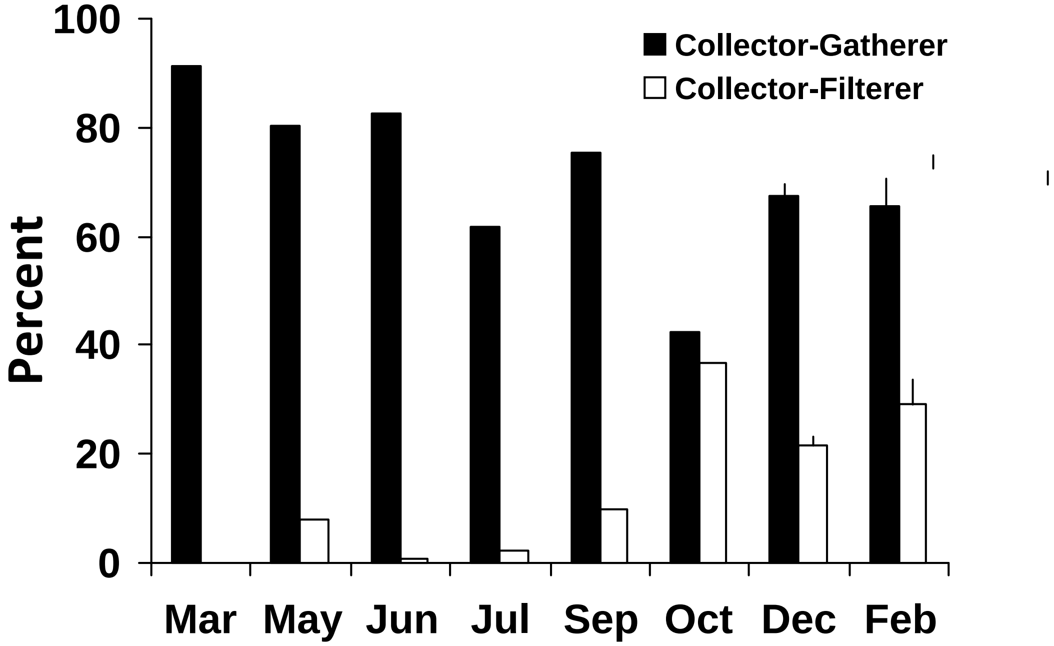


Figure 5-15. Hilsenhoff Biotic Index during study year.

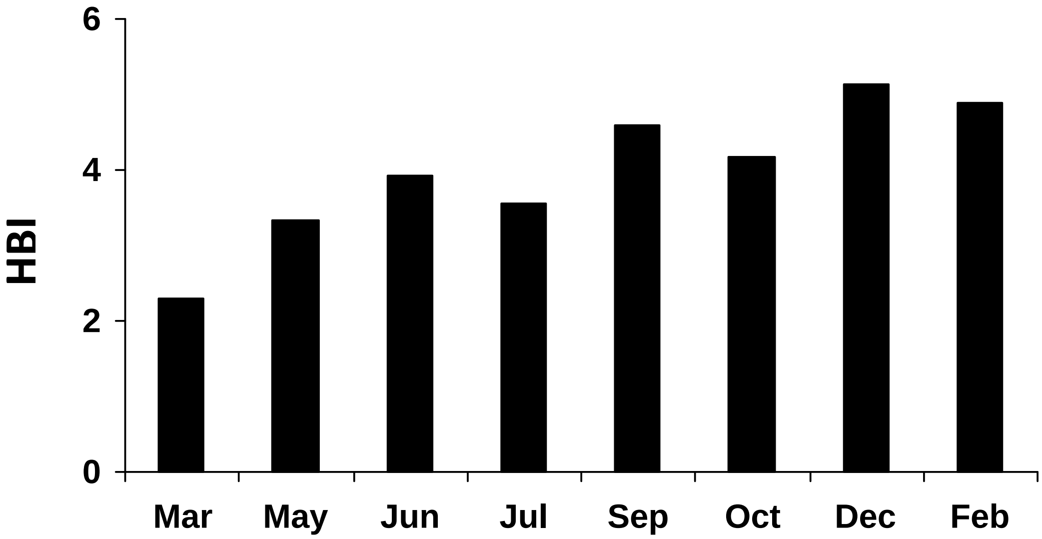
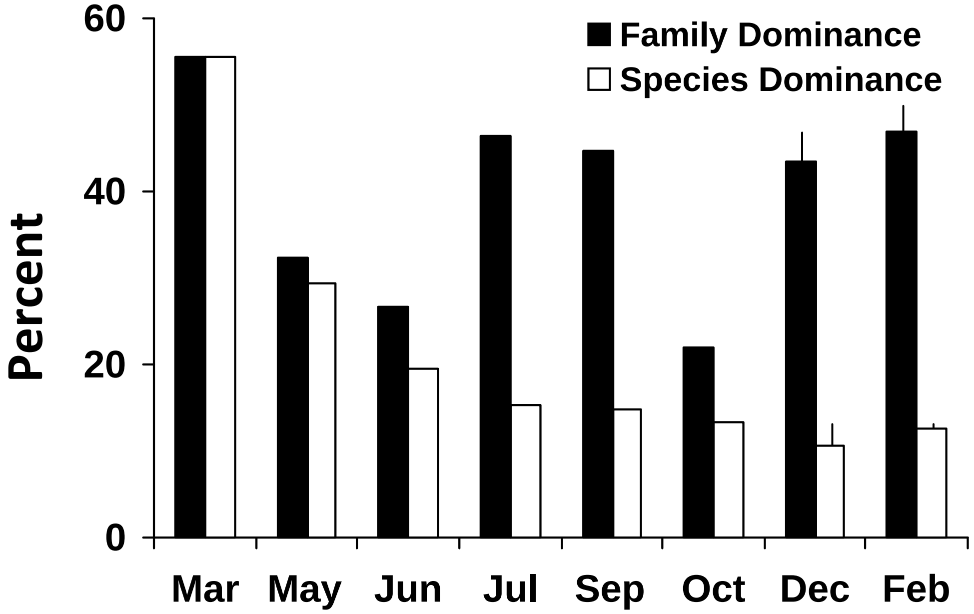


Figure 5-16. Percent Family and Species Dominance during study year.



5.3.2 Response to Experimental Releases

Habitat variables recorded in association with the two experimental floods were generally similar to those recorded during 2007-8 baseline data acquisition. Water depth (37.5 cm, SE= 3.10) and water temperature (mean= 7.00 ^{o}C, SE= 0.289) in summer 2008 were almost identical to baseline 2007-8 values (Table 5-2), whereas flow (mean= 57.0 cm/sec, SE= 5.28), stream width (mean= 25.6 m, SE= 2.06), and width:depth ratio (mean= 75.9, SE= 6.82) were somewhat higher during our release-associated sampling during summer of 2008. Mean water depth, water temperature, and flow were higher in summer 2009 than in summer 2008 (2009 means: 40.6 cm, SE= 2.13; 10.8 ^{o}C, SE= 0.56; 60.1 cm/sec, SE= 6.1, respectively). Mean conductivity, pH, and total dissolved solids were 10.1 μS/cm (SE= 0.38), 7.0 (SE= 0.020), and 4.9 ppm (SE= 0.20), respectively, for the summers of 2008 and 2009 combined; differences between years were minimal. Tree cover averaged only 5.1% (SE= 0.98). Mean algal dry mass was 5.12 gdm/m^2 (SE= 0.979).

In 2008, we collected 9,659 individual arthropods from 60 taxa representing 28 families and nine orders. Twenty-eight taxa collected in the 2007-8 baseline sampling were absent, but eighteen taxa that were absent that year were catalogued during the summer 2008 experiment. There was more total abundance in 2009: 13,547 individuals. There were, however, only 51 taxa collected in 2009; 71 different taxa were collected over both flood years. Total family richness in 2009 (29) was similar to that of 2008, as was order richness (9). We collected thirty-two families and ten orders across both years.

There were changes in the invertebrate assemblages that occurred in concert with the experimental floods, but these effects differed between 2008 and 2009 (Figs. 5-17 through 5-20). The 2008 flood changed an assemblage with relatively high dominance, apparent in the log normal distribution in the family and species rank-abundance plots before the event (Figs. 17, 18), to an assemblage with greater evenness, apparent in the broken stick distribution immediately after the release (Figs. 5-17, 5-18). Two months after the release, the family rank-abundance relationship was similar to that from before the event (Fig. 5-17), and the species rank-abundance plot showed less evenness still (Fig. 5-18). Immediately after the 2009 flood, family and species evenness was lower than before the release and lower still two months later, with three families demonstrating strong dominance (Figs. 5-19, 5-20).

Most assemblage-level metrics showed strong responses to the release (Table 5-8). Overall abundance fell in association with the releases and then rebounded. Overall abundances were higher in 2009 than in 2008. Family richness decreased in association with the releases, although after correcting for differing abundances (Margalef's correction) family richness increased after the 2008 release (Table 5-8). Margalef's family richness was higher in 2008 than in 2009. Species richness, with and without Margalef's correction, fell following the release and did not return to pre-release richness after two months. Margalef's species richness was also higher in 2008. Family dominance fell in response to the release and was still lower than pre-release levels after two months in 2008, whereas the opposite pattern obtained in 2009 (Table 5-8). Percent Ephemeroptera-Plecoptera-Trichoptera (%EPT) also showed opposing trends, increasing following the 08 release and decreasing after the 09 release (Table 5-8). Hilsenhoff's Biotic Index also showed differing response as a function of year. The 2008 flood caused a five-fold reduction in algal biomass, but there was about a 50% recovery in the two months that followed, whereas in 2009 there was little algal response (Table 5-6).

Figure 5-17. Rank-abundance by 2008 sampling event at the family level (log scale).

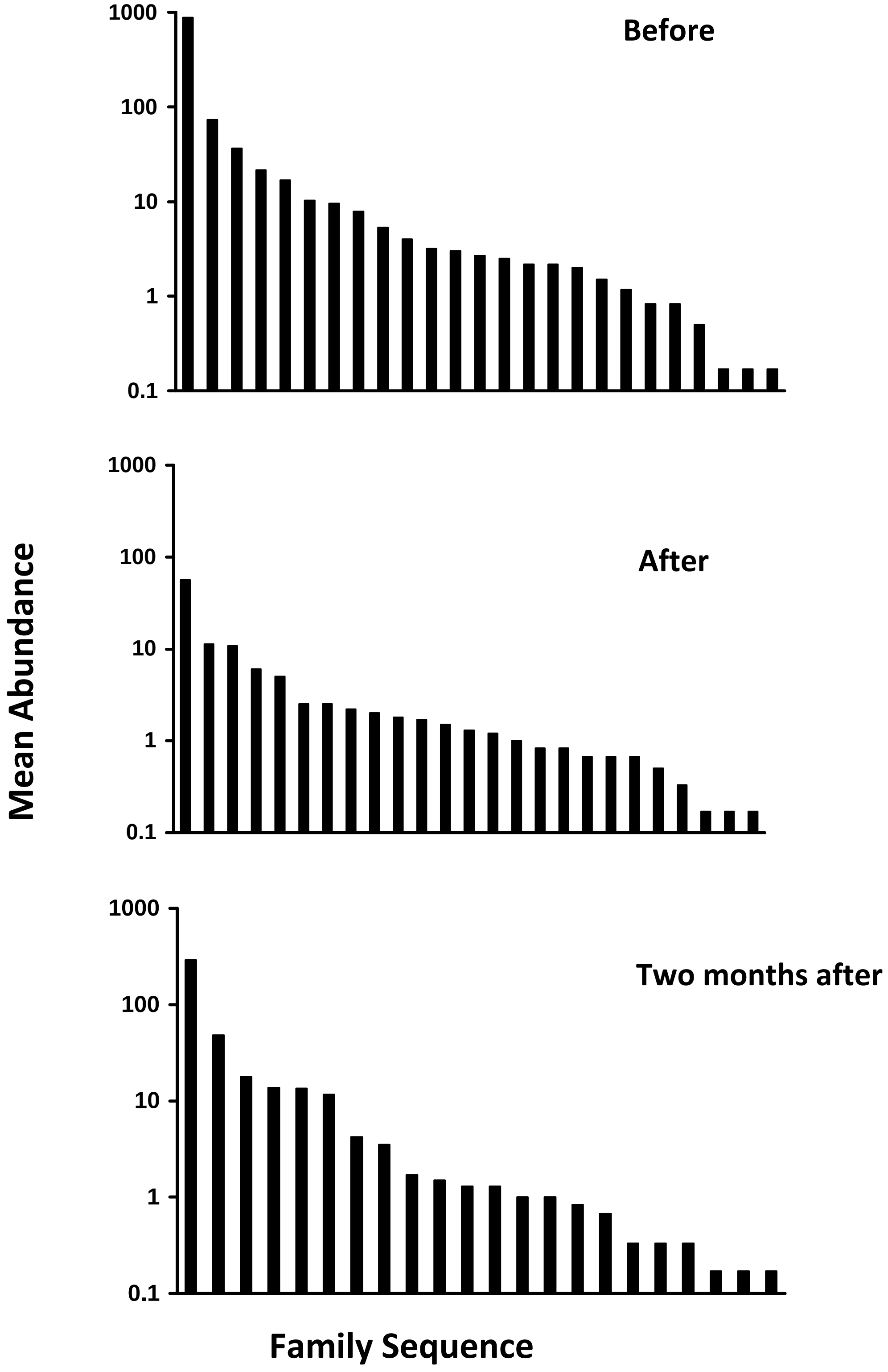


Figure 5-18. Rank-abundance by 2008 sampling event at the species level (log scale).

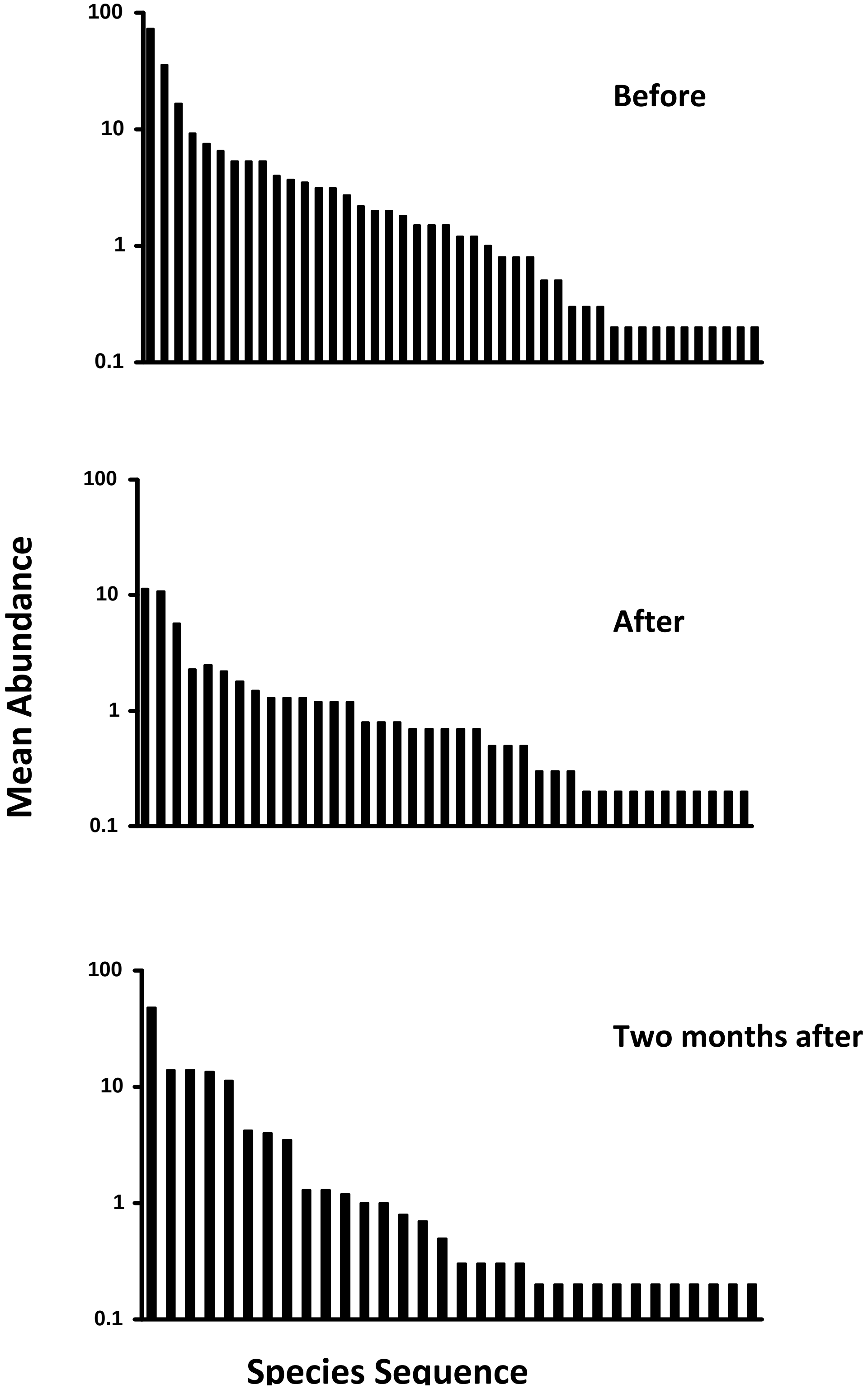


Figure 5-19. Rank-abundance by 2009 sampling event at the family level (log scale).

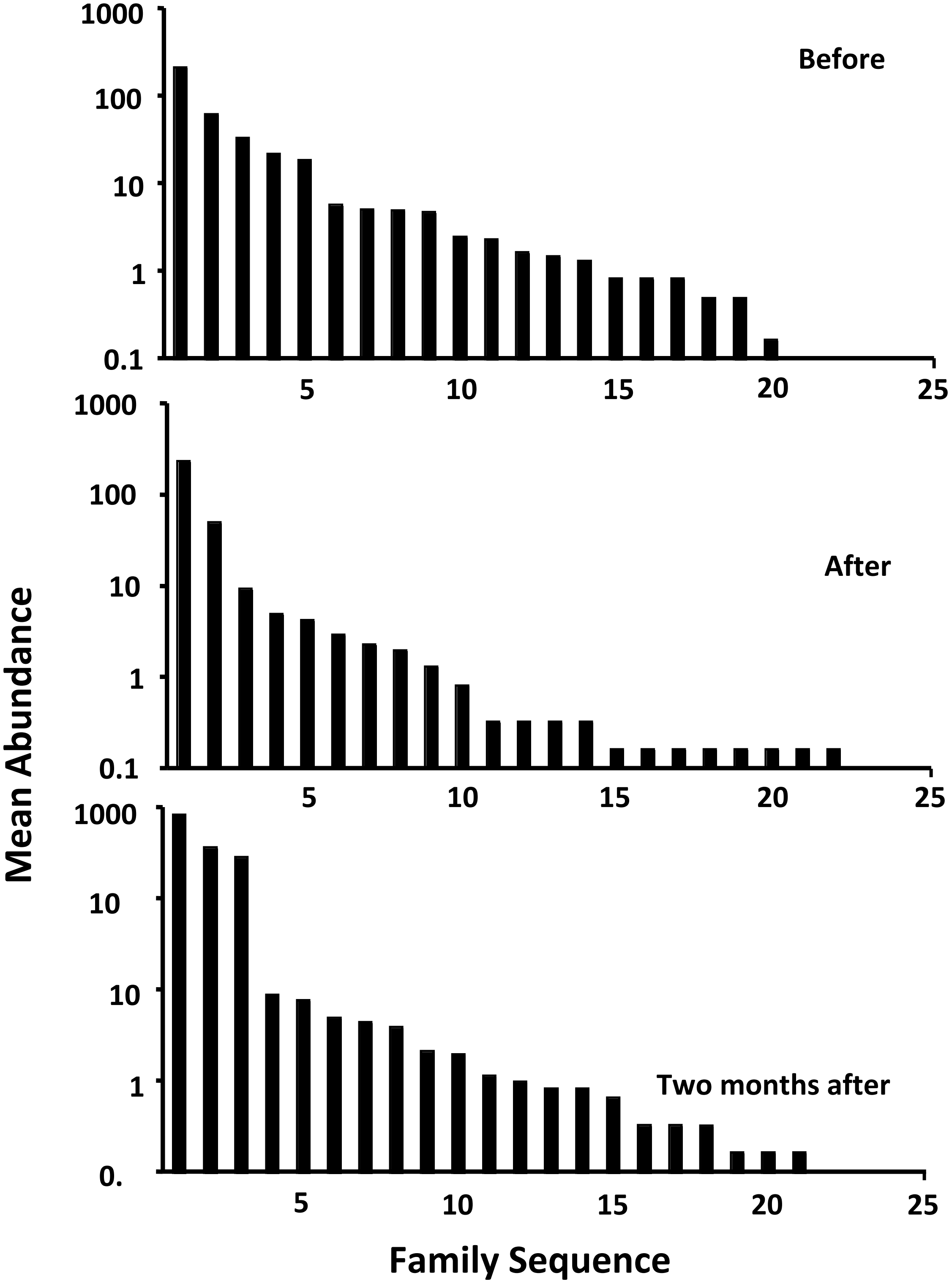
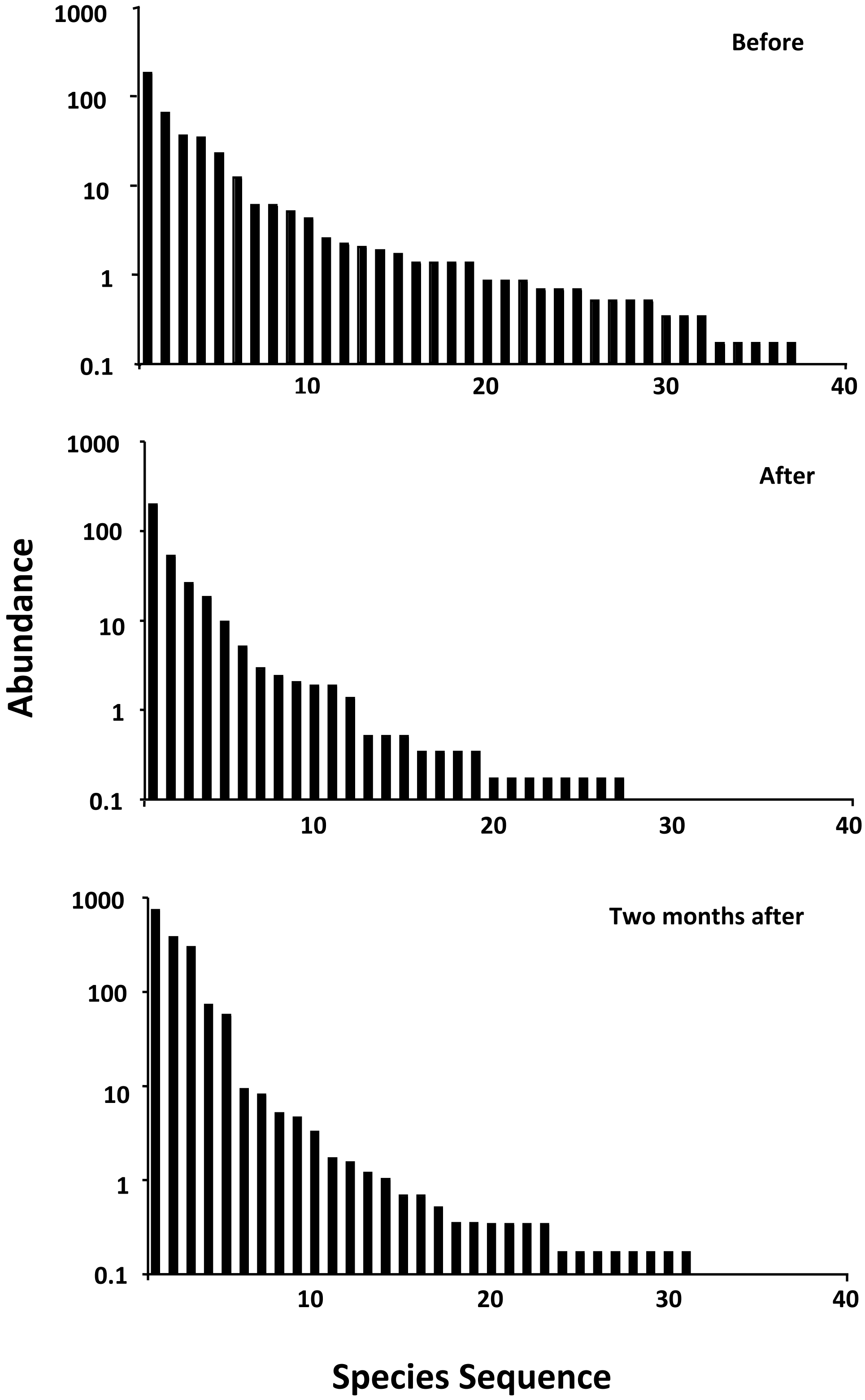


Figure 5-20. Rank-abundance by 2009 sampling event at the species level (log scale).



All orders decreased in abundance in association with the releases (Table 5-9), with the striking exception of Diptera in 2009. In contrast, Diptera in 2008 showed the greatest proportional and absolute flood-induced losses, falling from a mean of 892 to 61 individuals per square meter—a 93% loss. Prior to the release, Diptera dominated the assemblage at 82%; after the flood, Diptera was still the most abundant order, but this group represented only 54% of the total density. Less tolerant taxa lost density as well, but these losses were proportionally lower for Ephemeroptera, Plecoptera, and Trichoptera (Table 5-9). Less abundant taxa, such as Coleoptera, Acari, and Bivalvia all had reduced densities as well.

By two months after the releases, however, most taxa again increased in number, though most groups did not reach the densities seen before the release (Table 5-9). Ephemeroptera, Plecoptera, and Trichoptera had divergent recoveries in both 2008 and 2009. Ephemeroptera and Trichoptera recovered to a greater extent than Plecoptera, the former generally achieving abundances greater than before the floods. Ephemeroptera rebounded more strongly in 2009 than in 2008. Coleoptera had a similar response to Ephemeroptera, whereas Acari and Bivalvia showed no recovery, although both of these groups were relatively uncommon before the releases (Table 5-9). Following the two month recovery period, dipteran dominance was intact. Acari were more abundant in 2008, but the two most abundant orders, Diptera and Ephemeroptera, had their highest numbers in 2009.

Chironomid midges dominated the 2008 assemblage at the family level throughout all sampling periods despite the dramatic flood losses (Table 5-10). Nemourid stoneflies, particularly the genus *Malenka*, and baetid mayflies were also important in all phases of the study, although baetids became more dominant after the flood and nemourids less so. Leptophlebiid mayflies ranked third, fourth, and third among families at the three different 2008 sampling events (Table 5-10). One species of *Paraleptophlebia* dominated the family before and after the release, but a congeneric species dominated after two months. Ephemerellid mayflies were speciose and initially ranked fourth in family abundance, but were ranked fifth after the flood. Ephemerellids were almost absent two months after the 2008 experimental release and were represented entirely by *Serratella micheneri* (Table 5-10). Simuliid black flies were present in low numbers until two months after the release, at which time black flies reached 13.5 individuals per square meter and ranked fifth among all families.

A variety of other family-level responses to the 2008 release were observed. Twenty of the 28 families collected during the experiment were at their highest densities before the release (Table 5-10). Seven families were collected at their lowest densities after the release, but two families, Chloroperlidae (Plecoptera) and Lepidostomatidae (Trichoptera), were at their highest densities at this time. By two months after the 08 release, there were some notable increases and decreases. As indicated above, there were increases in baetids and simuliids, and polycentropodid and hydroptilid caddisflies were also at their highest levels at this time (Table 10). In contrast, there were striking reductions in abundances for a number of families between the second and third samplings. Among mayflies, heptageniids were reduced in number, ephemerellids were almost eliminated, and ameletids were completely absent. Perlid, perlodid, and nemourid stoneflies were all reduced in number as were hydropsychid and rhyacophilid caddisflies (Table 5-10). Mean California tolerance value (Table 5-5) for families that reached highs two months after the flood was 5.5 (SE= 0.50) but was 1.9 (SE= 0.55) for families that had reduced populations at this time.

Chironomids also dominated the 2009 assemblage but were not reduced in abundance after the flood and increased greatly in abundance by two months after the flood receded (847/m^2; Table 5-11). Baetids were again abundant throughout the study and again reached their highest numbers two months after the flood. As in 2008, simuliids were low in number until two months after the flood, but unlike in 2008 the 09 increase was dramatic, and simuliids were the second most abundant family at this time (371/m^2; Table 5-11). Leptophlebiids were the third most abundant family in 2009 and showed similar responses to flooding as in 2008. Nemourids also had a similar response but had lower absolute and proportional abundance than in 2008. Ephemerellids were again speciose and moderately abundant in 2009, and both richness and abundance dropped after the flood, but not as dramatically as in 2008 (Table 5-11).

In contrast to 2008, only one-third of the families had their highest abundances before the 2009 flood, and 11 or 29 families were most abundant two months after the flood (Table 5-11). Nine families were collected at their lowest densities after the 09 release, but four smaller families had highest abundances immediately after the flood. The latter did not include Chloroperlidae and Lepidostomatidae in 2009. Amelitid and heptageniid mayflies, perlodid stoneflies, limnephilid caddisflies, mites, and clams were all absent or almost absent two months after the 2009 flood (Table 5-11). Tolerance values were again in general higher for taxa that flourished two months after the flood than for those taxa that were greatly reduced in number.

Functional feeding groups were also apparently affected by the experimental releases. In 2008, the proportional contribution of collector-gatherers decreased, and all other groups increased, after the release (Table 5-11). The opposite relationship generally held in 2009. By two months after the 2008 release, proportion of collector-gatherers approximated pre-release levels, and most other groups fell in turn. Collector-filterers and piercer-herbivores, however, retained proportions similar to those observed after the flood (Table 5-11). In 2009, by two months after the flood, most feeding groups dropped in proportion, including collector gatherers, but collector-filterers increased from one percent to 28% of the assemblage. The proportions of scrapers, shredders, and piercer-herbivores were all higher in 2008 than in 2009.

Table 5-8. Response of mean (SE) macroinvertebrate assemblage-level variables and algal biomass to the 2008 and 2009 experimental release (all per-square-meter). %EPT= percent Ephemeroptera + Plecoptera + Trichoptera. "Sampling" references differences among the Before, After, and Two months after sampling periods. * represents p< 0.05; ** represents p< 0.01. Continues on next page

		Before		**After**		**2 mo after**		**ANOVA**		
	Year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	**Sampling**	**Year**	**Sampling * Year**
Total Individuals	08	1086	287	112	34	415	123	<0.0001**	0.0081**	0.0060**
	09	390	89.5	321	54.9	1547	231			
Family Richness	08	16.3	0.494	13.2	1.68	12.7	1.33	0.00081**	0.096	0.099
	09	12.8	1.42	8.83	0.980	11.5	0.922			
Margalef's Corrected Family Richness	08	2.25	0.0584	2.74	0.169	2.051	0.269	0.0037**	0.0067**	0.00038**
	09	2.01	0.183	1.37	0.158	1.44	0.109			
Species Richness	08	42.8	2.48	22.7	3.22	29.0	3.11	<0.0001**	0.052	0.11
	09	27.3	3.55	19.2	1.49	23.2	1.96			
Margalef's Corrected Species Richness	08	6.13	0.258	4.83	0.316	4.86	0.483	<0.0001**	0.0023**	0.70
	09	4.46	0.476	3.18	0.199	3.02	0.213			

% Family Dominance	08	77.6	3.61	47.8	5.51	61.1	8.00	0.34	0.82	0.0082**
	09	58.3	5.78	70.5	6.97	62.2	8.42			
% EPT	08	20.5	3.35	44.3	5.52	32.7	6.72	0.30	0.61	0.0038**
	09	39.3	6.55	26.8	6.72	22.4	4.86			
Hilsenhoff's Biotic index	08	5.47	0.0876	4.97	0.287	5.49	0.149	0.058	0.40	0.014*
	09	5.10	0.239	5.56	0.105	5.77	0.050			
Algal Biomass (gdm)	08	9.00	1.99	1.91	0.590	4.46	0.561	0.00077**	0.34	0.0027**
	09	3.79	0.395	3.83	1.020	2.93	0.760			

Table 5-9. Response of mean (SE) macroinvertebrate order densities per meter square to the 2008 and 2009 experimental release (all per-square-meter). %EPT= percent Ephemeroptera + Plecoptera + Trichoptera. "Sampling" references differences among the Before, After, and Two months after sampling periods. * represents p< 0.05; ** represents p< 0.01. Continues on next page

				Before		After			2 mo after	ANOVA
	Year	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	**Sampling**	**Year**	**Sampling * Year**
Ephemeroptera	08	90.8	14.6	25.2	7.76	67.7	17.1	<0.0001**	0.017*	0.035*
	09	122	33.4	56.8	12.7	299	57.4			
Plecoptera	08	86.2	25.9	15.7	5.48	16.8	4.62	0.0029**	0.21	0.051
	09	27.2	15.0	12.5	4.19	12.0	3.42			
Trichoptera	08	10.0	2.31	8.00	2.35	18.2	5.96	0.029*	0.14	0.72
	09	9.83	5.45	4.50	1.98	12.5	2.45			
Coleoptera	08	2.83	1.014	0.833	0.401	2.17	0.703	0.19	0.46	0.67
	09	2.33	1.94	0.833	0.477	2.33	1.58			
Diptera	08	892	260	61.0	21.2	310	112	0.00018**	0.0095**	0.00031**
	09	228	51.4	246	56.4	1221	213			

Acari	08	2.17	1.078	0.833	0.477	0.167	0.167	0.091	0.015*	0.39
	09	0.333	0.333	0.000	0.000	0.000	0.000			
Veneroidea (Bivalvia)	08	2.00	1.18	0.833	0.833	0.667	0.422	0.14	0.25	0.98
	09	1.33	1.33	0.000	0.000	0.000	0.000			

Table 5-10. Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release. Ephemeroptera and Plecoptera were all nymphs; Megaloptera, Trichoptera, and Diptera were larvae except for occasional pupae; Coleoptera were either larvae (l) or adults (a); and Acari and Bivalvia were adults.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Ephemeroptera	90.8	14.6	25.2	7.76	67.7	17.1
Ameletidae	5.33	2.96	0.667	0.667	0	0
Ameletus sp.	5.33	2.96	0.667	0.667	0	0
Baetidae	16.8	5.77	11.5	3.73	48.2	13.9
Baetis spp.	16.8	5.77	11.3	3.69	48.2	13.9
Unknown	0	0	0.167	0.167	0	0
Heptageniidae	10.3	4.86	2.00	0.775	1.50	0.563
Cinygmula sp.	2.67	1.02	0.167	0.167	1.17	0.601
Epeorus longimanus	3.67	1.98	0.500	0.342	0	0
Epeorus sp.	0.500	0.500	0.167	0.167	0	0
Ironodes sp.	3.50	2.63	1.17	0.543	0.333	0.21
Ephemerellidae	21.7	5.71	5.00	3.46	0.167	0.167
Caudatella hystrix	1.83	1.05	0.833	0.543	0	0
Ephemerella excrucians	5.33	1.61	1.33	1.151	0	0
Ephemerella dorothea infrequens	7.50	4.75	2.33	1.94	0	0

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		After		2 months after	
Mean	SE	Mean	SE	Mean	SE	
Ephemerella sp. A	0.500	0.500	0.500	0.500	0	0
Serratella teresa	6.50	0.719	0	0	0	0
Serratella micheneri	0	0	0	0	0.167	0.167
Leptophlebiidae	36.7	7.38	6.00	3.12	17.8	16.1
Paraleptophlebia sp. A	35.5	6.78	5.67	3.03	4.00	2.71
Paraleptophlebia sp. B	1.17	1.17	0.333	0.333	13.8	13.4
Plecoptera	86.2	25.9	15.7	5.48	16.8	4.62
Nemouridae	73.2	25.7	10.8	4.23	13.8	3.94
Malenka sp.	73.2	25.7	10.8	4.23	13.8	3.94
Perlidae	9.50	2.94	2.50	0.619	1.33	0.615
Calineuria californica	0.333	0.211	0.667	0.667	0.333	0.333
Hesperoperla pacifica	9.17	2.94	1.33	0.715	0.833	0.654
Hesperoperla sp.	0	0	0.500	0.342	0.167	0.167

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		After		2 months after	
Mean	SE	Mean	SE	Mean	SE	
Perlodidae	3.00	0.775	0.667	0.211	0.333	0.333
Osobenus yakimae	3.00	0.775	0.667	0.211	0	0
Skwalla americana	0	0	0	0	0.333	0.333
Chloroperlidae	0.500	0.342	1.67	1.31	1.33	1.33
Haploperla chilnualna	0.167	0.167	0.167	0.167	1.33	1.33
Plumiperla sp.	0.167	0.167	1.17	1.17	0	0
Paraperla sp.	0.167	0.167	0	0	0	0
Suwallia sp. A	0	0	0.333	0.333	0	0

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Megaloptera	0.167	0.167	0.167	0.167	0	0
Corydalidae	0.167	0.167	0.167	0.167	0	0
Orohermes crepusculus	0.167	0.167	0.167	0.167	0	0
Trichoptera	10.0	2.31	8.00	2.35	18.2	5.96
Philopotamidae	0	0	0	0	1.00	0.632
Dolophilodes sp.	0	0	0	0	1.00	0.632
Polycentropodidae	1.17	0.980	1.33	1.15	3.50	2.50
Polycentropus sp.	1.17	0.980	1.33	1.15	3.50	2.50
Hydropsychidae	3.17	2.07	2.17	1.33	0	0
Hydropsyche sp.	3.17	2.07	2.17	1.33	0	0
Rhyacophilidae	2.17	0.703	1.00	0.516	0.833	0.307
Rhyacophila sp. A	1.50	0.563	0.667	0.494	0.500	0.224
Rhyacophila sp. B	0.167	0.167	0.333	0.211	0.167	0.167
Rhyacophila sp. C	0.167	0.167	0	0	0	0
Rhyacophila sp. D	0.333	0.333	0	0	0.167	0.167

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Hydroptilidae	2.67	0.954	1.83	0.703	11.7	5.18
Hydroptila sp. A	1.00	0.817	0	0	11.3	5.28
Hydroptila sp. B	1.50	0.806	1.83	0.703	0.167	0.167
Hydroptila sp. pupa	0.167	0.167	0	0	0.167	0.167
Lepidostomatidae	0.833	0.401	1.50	1.02	1.00	0.632
Lepidostoma sp.	0.833	0.401	1.50	1.02	1.00	0.632
Limnephilidae	0	0	0.167	0.167	0	0
Psychoglypha sp.	0	0	0.167	0.167	0	0
Coleoptera	2.83	1.01	0.833	0.401	2.17	0.703
Haliplidae	0	0	0	0	0.167	0.167
Haliplus sp. (a)	0	0	0	0	0.167	0.167
Dytiscidae	0.167	0.167	0.167	0.167	0.333	0.211
Hygrotus sp. (l)	0.167	0.167	0	0	0	0
Laccophilus sp. (a)	0	0	0	0	0.167	0.167
Neoclypeodytes sp. (l)	0	0	0.167	0.167	0	0
Uvarus sp. (a)	0	0	0	0	0.167	0.167
Hydraenidae	0.167	0.167	0	0	0	0
Hydraena sp. (a)	0.167	0.167	0	0	0	0

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Elmidae	2.50	0.957	0.667	0.422	1.67	0.558
Ampumixis sp. (l)	0.167	0.167	0	0	0	0
Cleptelmis addenda (l)	0.667	0.333	0	0	0.333	0.333
Cleptelmis addenda (a)	0.167	0.167	0	0	0	0
Optioservus quadrimaculatus (l)	0.500	0.224	0.167	0.167	0	0
Optioservus quadrimaculatus (a)	1.00	0.683	0.500	0.342	1.33	0.333
Diptera	892	260	61.0	21.2	310	112
Chironomidae*	879	257	57.0	20.6	291	107
Tanypodinae	123	24.1	27.0	10.6	33.5	10.6
Chironominae: Tanytarsini	90.3	18.3	6.5	3.68	21.7	9.51
Other Chironomidae	666	241	23.5	9.79	236	97.9
Simuliidae	4.00	1.61	1.17	0.401	13.5	6.19
Simulium spp.	4.00	1.61	1.17	0.401	13.5	6.19
Tipulidae	0.833	0.543	0.333	0.211	0.333	0.211
Antocha sp.	0.833	0.543	0.167	0.167	0	0

Table 5-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2008 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Dicranota sp.	0	0	0	0	0.167	0.167
Hexatoma sp.	0	0	0.167	0.167	0	0
Limonia sp.	0	0	0	0	0.167	0.167
Empididae	7.83	4.43	2.50	0.847	4.17	2.02
Chelifera sp.	0.333	0.211	0.167	0.167	4.17	2.02
Clinocera sp.(l)	5.33	3.61	2.17	0.946	0	0
Clinocera sp. pupa	0.167	0.167	0	0	0	0
Hemerodromia sp.	2.00	1.00	0.167	0.167	0	0
Acari	2.17	1.08	0.833	0.477	0.167	0.167
Sperchontidae	2.17	1.08	0.833	0.477	0.167	0.167
Sperchon sp.	2.17	1.08	0.833	0.477	0.167	0.167
Bivalvia	2.00	1.18	0.833	0.833	0.667	0.422
Sphaeriidae	2.00	1.18	0.833	0.833	0.667	0.422
Sphaerium sp.	2.00	1.18	0.833	0.833	0.667	0.422
Total Individuals	**1086**	**287**	**112**	**33.6**	**415**	**123**

* Individual chironomid morphospecies were separated and counted but most were not identified.

Table 5-11. Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release. Ephemeroptera and Plecoptera were all nymphs; Megaloptera, Trichoptera, and Diptera were larvae except for occasional pupae; Coleoptera were either larvae (l) or adults (a); and Acari and Bivalvia were adults.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Collembola	0	0	0.167	0.167	0	0
Isotomidae	0	0	0.167	0.167	0	0
Ephemeroptera	122	33.4	56.8	12.7	299	57.4
Ameletidae	0.50	0.34	0	0	0	0
Ameletus sp.	0.50	0.34	0	0	0	0
Baetidae	63.3	16.5	51.2	15.2	290	59.8
Baetis spp.	63.3	16.5	51.2	15.2	290	59.8
Heptageniidae	4.83	3.52	0.333	0.211	0	0
Cinygmula sp.	1.33	0.803	0.333	0.211	0	0
Epeorus longimanus	2.17	1.45	0	0	0	0
Ironodes sp.	1.33	1.33	0	0	0	0
Ephemerellidae	19.0	9.20	0.333	0.333	0.833	0.307
Ephemerella excrucians	12.0	6.64	0	0	0	0
Ephemerella dorothea infrequens	5.83	2.81	0	0	0	0
Ephemerella sp. A	0.500	0.342	0	0	0.167	0.167
Drunella spinifera	0	0	0	0	0.167	0.167

Table 5-11 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Ephemerellidae (cont.)						
Serratella teresa	0.500	0.342	0.333	0.333	0	0
Serratella sp.	0.167	0.167	0	0	0.167	0.167
Unknown	0	0	0	0	0.333	0.333
Leptophlebiidae	33.9	20.1	5.00	4.61	7.83	5.06
Paraleptophlebia sp. A	33.7	20.2	5.00	4.61	7.83	5.06
Paraleptophlebia sp. B	0.167	0.167	0	0	0	0
Plecoptera	27.2	15.0	12.5	4.19	12.0	3.42
Pteronarcyidae	0	0	0.167	0.167	0	0
Pteronarcys sp.	0	0	0.167	0.167	0	0
Nemouridae	22.3	13.3	9.50	3.24	9.00	2.45
Malenka sp.	22.3	13.3	9.50	3.24	9.00	2.45
Perlidae	1.50	1.03	2.00	0.856	2.17	1.45
Calineuria californica	0.667	0.422	0.167	0.167	0.667	0.333
Hesperoperla pacifica	0.833	0.654	1.83	0.910	1.50	1.31
Perlodidae	0.833	0.654	0.333	0.333	0.167	0.167
Osobenus yakimae	0.833	0.654	0	0	0	0
Skwalla americana	0	0	0.333	0.333	0.167	0.167

Table 5-11 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Plecoptera (cont.)						
Chloroperlidae	2.50	1.77	0.500	0.500	0.833	0.654
Haploperla chilnualna	1.67	0.989	0.500	0.500	0.667	0.494
Paraperla sp.	0.167	0.167	0	0	0	0
Suwallia sp. A	0.667	0.667	0	0	0.167	0.167
Megaloptera	0	0	0.167	0.167	0	0
Corydalidae	0	0	0.167	0.167	0	0
Orohermes crepusculus	0	0	0.167	0.167	0	0
Trichoptera	9.83	5.45	4.50	1.98	12.5	2.45
Polycentropodidae	0.833	0.543	1.33	1.33	1.17	1.17
Polycentropus sp.	0.833	0.543	1.33	1.33	1.17	1.17
Hydropsychidae	0.167	0.167	0.333	0.333	4.50	2.98
Hydropsyche sp.	0.167	0.167	0.333	0.333	4.50	2.98
Rhyacophilidae	1.67	0.667	2.33	1.48	0.667	0.333
Rhyacophila sp. A	1.33	0.558	0	0	0	0
Rhyacophila sp. B	0	0	1.83	1.47	0.167	0.167
Rhyacophila sp. C	0	0	0	0	0.167	0.167

Table 5-11 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Rhyacophilidae (cont.)						
Rhyacophila sp. D	0.333	0.211	0.500	0.342	0.167	0.167
Unknown (pupa)	0	0	0	0	0.167	0.167
Brachycentridae	0	0	0	0	0.167	0.167
Micrasema sp.	0	0	0	0	0.167	0.167
Hydroptilidae	0.500	0.224	0.167	0.167	5.00	1.69
Hydroptila sp. A (l)	0	0	0.167	0.167	4.67	1.50
Hydroptila sp. A (pupa)	0	0	0	0	0.333	0.333
Hydroptila sp. B	0.500	0.224	0	0	0	0
Lepidostomatidae	5.83	3.55	0.167	0.167	1.00	0.516
Lepidostoma sp.	5.83	3.55	0.167	0.167	1.00	0.516
Limnephilidae	0.833	0.654	0.167	0.167	0	0
Psychoglypha sp.	0.667	0.667	0.167	0.167	0	0
Unknown	0.167	0.167	0	0	0	0
Coleoptera	2.33	1.94	0.833	0.477	2.33	1.59
Dytiscidae	0	0	0	0	0.333	0.211
Neoclypeodytes sp. (l)	0	0	0	0	0.333	0.211

Table 5-11 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Coleoptera (cont.)						
Elmidae	2.33	1.94	0.833	0.477	2.00	1.61
Cleptelmis addenda (l)	1.83	1.83	0.500	0.500	1.67	1.48
Heterlimnius sp.	0	0	0.167	0.167	0	0
Optioservus quadrimaculatus (l)	0	0	0	0	0.167	0.167
Optioservus quadrimaculatus (a)	0.500	0.224	0.167	0.167	0.167	0.167
Diptera	229	51.4	246	56.4	1221	213
Chironomidae*	218	52.0	238	56.1	847	253
Tanypodinae	4.17	4.17	25.5	15.1	55.0	16.4
Chironominae: Tanytarsini	35.0	12.3	18.0	12.7	71.0	23.2
Other Chironomidae	179	38.5	194	39.3	721	217
Simuliidae	5.17	1.76	3.00	1.03	371	146
Simulium spp. (l)	5.00	1.71	2.83	1.01	362	141
Simulium spp. (pupa)	0.167	0.167	0.167	0.167	9.33	7.07
Tipulidae	0	0	0.167	0.167	0.333	0.333
Dicranota sp.	0	0	0.167	0.167	0	0
Hexatoma sp.	0	0	0	0	0.333	0.333

Table 5-11 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 2009 experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
Diptera (contd.)						
Empididae	5.00	1.77	4.33	1.73	4.00	1.61
Chelifera sp. (l)	2.00	1.03	2.00	0.817	1.67	0.803
Chelifera sp. (pupa)	0.167	0.167	0	0	1.50	0.671
Clinocera sp.	2.50	0.957	2.33	1.20	0.333	0.211
Neoplasta sp.	0	0	0	0	0.500	0.342
Wiedemannia sp.	0.333	0.333	0	0	0	0
Acari	0.333	0.333	0	0	0	0
Limnesiidae	0.333	0.333	0	0	0	0
Bivalvia	1.33	1.33	0	0	0	0
Sphaeriidae	1.33	1.33	0	0	0	0
Sphaerium sp.	1.33	1.33	0	0	0	0
Total Individuals	**390**	**89.5**	**321**	**55.0**	**1547**	**231**

* Individual chironomid morphospecies were separated and counted but most were not identified.

Table 5-12. Response of functional feeding groups to the 2008 and 2009 experimental release (all per-square-meter). %EPT= percent Ephemeroptera + Plecoptera + Trichoptera. "Sampling" references differences among the Before, After, and Two months after sampling periods. * represents p< 0.05; ** represents p< 0.01.

	Year	**Before**		**After**		**2 mo after**		**ANOVA**		
		$\bar{x}$	**SE**	**$\bar{x}$**	**SE**	**$\bar{x}$**	**SE**	**Sampling**	**Year**	**Sampling * Year**
% Scrapers	08	1.90	0.640	2.54	0.946	0.546	0.182	0.012*	0.013*	0.16
	09	1.09	0.555	0.127	0.093	0.000	0.000			
% Predators	08	2.96	0.596	12.1	3.66	3.67	1.11	0.0024**	0.46	0.015*
	09	10.9	3.48	9.63	3.22	3.90	0.889			
% Collector-Gatherers	08	86.8	1.48	65.5	5.49	82.1	4.72	0.36	0.78	0.039*
	09	79.9	4.66	86.3	3.90	67.1	10.6			
% Shredders	08	7.57	1.09	11.1	2.73	5.86	1.89	0.0027**	0.021*	0.084
	09	6.15	2.65	2.83	0.850	0.672	0.183			
% Collector-Filterers	08	0.670	0.193	4.48	1.74	4.77	1.69	0.0013**	0.20	0.013*
	09	1.85	0.878	1.09	0.390	28.2	11.6			
%Piercer-Herbivores	08	0.354	0.155	3.61	2.39	3.28	1.31	0.13	0.0012**	0.25
	09	0.092	0.043	0.094	0.094	0.306	0.089			

5.4 Discussion

5.4.1 Assemblage Structure

We collected a diverse assemblage of macroinvertebrates that was generally similar in character to the assemblage in the riffle habitats in the upper Merced that were at approximately the same elevation and that had similar ecological characteristics (Stillwater Sciences 2007). Many of the families were common to both studies, including all mayfly families. Each stream had one beetle, one fly, and one stonefly that the other stream lacked. The Merced had four caddisfly families that were absent from the Tuolumne, and the Tuolumne had three caddisfly families that were absent from the Merced. The upper Merced comparison sites had four families of mites that we did not find in the upper Tuolumne, but the upper Tuolumne had one mite family that was absent from the Merced as well as bivalves. Sorensen's similarity coefficient was 0.68 for families and 0.59 for species. Like Stillwater Sciences (2007), we did not collect any New Zealand mudsnails, and it is likely that Yosemite National Park is free of these exotics at this time.

By way of further comparison, the reach of the upper San Joaquin River in Devils Postpile National Monument is a nearby river at about twice the elevation of the Poopenaut Valley (2300 versus 1100m) but with a fauna (Holmquist and Schmidt-Gengenbach 2005) that was not much more different from the upper Tuolumne than the upper Merced, despite the difference in elevation. Most of the families collected were shared by both the upper San Joaquin and upper Tuolumne. Although both streams again had the same families of mayflies, there were four families of caddisflies that were found in the Poopenaut that were not found in the Postpile, and vice versa. There were three families of Plecoptera and one dipteran and one hemipteran family that were found in the Postpile but not in the Poopenaut, but dobsonflies, bivalves, and one family of beetle were found in the Poopenaut but not in the Postpile. Sorensen's similarity coefficient was 0.68 for families, i.e., exactly the same as for the Tuolumne-Merced comparison, and species similarity (0.53) was only slightly lower than the Tuolumne-Merced similarity (0.59).

Rank-abundance plots retain much more information than diversity indices that, used alone, distill complex communities into single numbers with accompanying information loss, and rank-abundance plots are therefore useful components of initial assemblage descriptions (Stiling 2001; Magurran 2004; Underwood and Fisher 2006. The family and species rank abundance plots (log scale; Figs. 5-9, 5-11) fall between the log normal distribution and MacArthur's broken stick model. These curves indicate relatively high richness and evenness, minimal niche preemption, and relatively uniform division of resources (Magurran 2004, Schowalter 2006).

Collector-gatherers dominated the functional feeding groups at 70.9% of individuals and 31.8% of taxa. Collector-gatherers in combination with collector-filterers accounted for 84.4% of individuals, which exceeds the high 70% found in the upper Merced (Stillwater Sciences 2007). Such a high proportion of collector-gatherers, or a low collector-filterer:collector-gatherer ratio (which also obtained in the Poopenaut reach at 0.19), can suggest a relatively low ratio of suspended fine particulate matter to deposited fine particulate matter (Merritt and Cummins

1996, Merritt et al. 2008), which in turn can be related to reduction in transported particulates below deep release dams (Allan 1995). Predatory taxa accounted for 44.6% of species, but only 7.5% of individuals. The ratio of predators to all other feeding groups (0.75) was somewhat lower than the frequently encountered range of 0.10-0.20 (Merritt and Cummins 1996, Merritt et al. 2008). Scrapers were less important in our upper Tuolumne samples (2%) than in the upper Merced (21%; Stillwater Sciences 2007).

It is encouraging that there were so few tolerant fauna (see Methods) in the riffles below the dam. Our one tolerant taxon, the clam Sphaerium, accounted for only 1.4% of taxa and 0.26% of individuals. In contrast, tolerant taxa represented 14% of taxa in the riffles in the upper Merced. Hilsenhoff's Biotic Index (HBI), which weights tolerance by abundance, was relatively low at 4.01 across our samples. Percent Ephemeroptera-Plecoptera-Trichoptera (EPT) was in turn high at 78.8% of total individuals and 64% of taxa.

Although the detection of seasonal patterns was not a goal of this study, some patterns emerged, particularly when comparing spring-summer months with fall-winter months. There were significant increases in Diptera, collector-filterers, and HBI and a concomitant decrease in %EPT, in large part due to an increase in Simulium black flies. Somewhat surprisingly, there was also a decrease in Percent Species Dominance, which was largely a function of increased richness and abundance of Chironomidae (Diptera) during the fall and winter. Benthic invertebrate sampling is often done in the summer and/or fall, but clearly year-round sampling is desirable when possible because of the shifting nature of the assemblage.

The ancillary sampling of boulders and slabs indicated that these habitats have twice the faunal density of riffles in this reach, but also that this density if highly variable. These large rock substrata had a strikingly different assemblage structure than the riffles in some cases. For instance the mean of 276 elmid beetles/m^2 was 64 times greater than the mean for riffles.

Habitat assessments indicated that in general this river reach should provide good habitat for fauna (overall score of 155 was at the low end of the Optimal range; Table 5-3). The mean habitat quality score fell into the lower range of scores for the nearby upper Merced River (Stillwater Sciences 2007). RMC Water & Environment and McBain & Trush (2006) identify reduction of magnitude and duration of snowmelt flows and reduced winter peak flood magnitude as likely consequences of flow regulation below Hetch Hetchy with potential effects on geomorphology, riparian vegetation, and fauna (see also Chapter 2 of this report). Reduced flow variability can lead to reduced habitat heterogeneity and increased algal cover and sediment deposition (Allan 1995). Carter and Fend (2001) found several of these factors to be important in structuring the BMI assemblage in the upper Merced. There was a lack of woody debris at our sites, and there was generally a substantial cover of filamentous green algae (Figs 5-2 through 5-4). There were, however, plentiful green algae in the river above the reservoir as well (pers. obs.). There was clear evidence of sediment deposition at some sites, though the mean for this parameter fell just within the Optimal range, and this parameter was a significant predictor of baetid mayfly abundance at our sites.

Stream width, depth, and flow in the study reach of the Tuolumne River (Table 5-2) were generally similar in riffle habitats in the upper Merced River (Stillwater Sciences 2007). Temperatures from the Poopenaut reach of the Tuolumne, however, appear to have been substantially lower than those from the upper Merced: 7.81^{o}C (mean from our 2007 September and October samples) versus 13.3^{o}C (our calculated mean for the upper Merced based on fall 2006 data in Stillwater Sciences 2007). The much more extensive data from temperature recorders above and below the reservoir and on the upper Merced (National Park Service, 2009) confirm this observation. Deep-release dams typically reduce daily and annual temperature fluctuations and lower mean annual temperatures (Ward and Stanford 1979). These changes often lead to negative impacts on BMI diversity because of disruption of thermal cues for reproduction and development, reduction of degree days for completion of life cycles, and slowing of metabolic rates (Hayden and Clifford 1974, Lemkuhl 1974, Allan 1995), and Hawkins et al. (1997) found temperature to be a key factor in structuring BMI. RMC Water & Environment and McBain & Trush (2006) note that fauna are likely to be similarly affected by disrupted thermal regimes below Hetch Hetchy. Although diversity is often reduced in response to increased temperatures, overall production can be increased (Wohl et al. 2007). Water temperatures below the dam are clearly lower than above-reservoir and Merced River temperatures (National Park Service, 2009), but our first year of study did not include an above-reservoir comparison group, precluding conclusions about temperature regime and the influence of the dam and reservoir on downstream BMI along this isolated reach. We did not find increases in BMI diversity or decreases in tolerance with increasing distance downstream from the dam, suggesting that temperature effects may not be as pronounced as seen below some other cold-water dams (Ward and Stanford 1979, Allan 1995). The 5km study reach, however, may have been insufficient in length to have allowed appreciable warming before the discharged water left the study area.

This first year of study was designed to be an initial characterization of the BMI assemblage in riffle habitats that could be used as baseline data. Year to year variability can be substantial (Leland et al. 1986, Holmquist and Schmidt-Gengenbach 2005), and we advocate continued monitoring of this reach, including additional habitats, in order to establish a longer-term baseline and to detect effects due to changes in dam operations, climate, and other factors.

The Year 1 assemblage characterization yielded some results suggesting some level of impact due to dam operations, whereas other results provide an initial indication of little if any negative effect, but this first year of study was not designed to be an assessment of effects of stream regulation. Comparison of below-dam, above-reservoir, and unregulated reaches can be a powerful tool to discriminate potential effects of dam operations, with the caveat that these reaches can also differ as a function of geomorphological or other covariates (Holmquist et al. 1998, Greathouse et al. 2006a,b). Such comparisons would be an important complement to the ongoing Looking Downstream efforts.

5.4.2 Response to Experimental Releases

The 2008 and 2009 releases were very different in character, and although these differences make the two releases imperfect replicates, the two floods capture many different variables and influences on the benthic macroinvertebrate assemblage. Before-After assemblage differences in 2008 were clearly attributable to the experimental flood, as this release was essentially a one-day event, and we sampled the day before and the day after the release. Confounding seasonal effects were absent. The 2008 release occurred in late May. In contrast the 2009 flood started earlier, in late April, and ended later, in mid-July. This longer flood much more closely approximated a natural spring pulse, but was also long enough that seasonal dynamics in the invertebrate assemblage, apparent from our year-long 2007-2088 sampling, likely overlie results attributable to flood effects. Further, the After-Two-Months sampling occurred in September of 2009, versus July of 2008, so the last 2009 sampling interval was almost certainly affected by seasonal dynamics as well. Such a seasonal overlay is likely to be particularly significant in an area such as Hetch Hetchy with strong seasonality, particularly in the temperature regime. The long duration of the falling hydrographic limb probably allowed recovery of populations during the period in which flows were low enough that scour was reduced but still high enough to preclude sampling. Thus, three of the five most important hydrological factors that regulate the ecology of streams (magnitude, frequency, duration, timing, and rate of change of flow; Richter et al. 1996, Poff et al. 1997, Cortes et al. 1998) differed between the two years; magnitude and frequency of flooding were similar in 2008 and 2009. In addition, the 2008 flood was likely to have created some persisting effects that carried over to the 2009 pre-flood assemblage, i.e., some populations may not have recovered in the ensuing year. Lastly, it appeared that in 09 there was more sand and silt deposited in slower sections of riffles just downstream of catchments than was present in 08. The increased presence of fines in 2009 may have been an important influence on some taxa. These many differences between the two floods probably account for many of the divergent invertebrate changes associated with the 2008 and 2009 floods. The two releases were good complements: effects of the 2008 release were more easily interpreted, whereas the 2009 release approximated a natural spring flood.

The 2008 release had major immediate effects on the ecology of the river, and some of these effects would be generally viewed as positive changes. Total abundance and all order abundances fell in 2008, but dominance decreased and evenness increased. Robinson et al. (2003) observed similar shifts in an assemblage following a series of experimental releases. Losses of Chironomidae were striking, perhaps because of a known proclivity for drift, i.e., leaving the substrate either actively or passively to enter the water column, as a response to floods (Perry and Perry 1986, Wallace 1990, Imbert and Perry 2000, Jakob et al. 2003) and perhaps also due to association with filamentous green algae, much of which was removed by the 08 release. Proportions of taxa indicative of lotic system health increased, e.g. Ephemeroptera-Plecoptera-Trichoptera, predators, and intolerant taxa as indicated by Hilsenhoff's Biotic Index. Jakob et al. (2003) found no significant response of Ephemeroptera and Plecoptera to a series of experimental releases and attributed the lack of response to morphological and behavioral adaptations to torrential flow (see also Holomuzki and Biggs 2000). Although %EPT increased in our study, there were losses of all of these taxa in response to the flood—but at a lower rate than was found for other groups. There were significant but mixed effects on richness measures in our Tuolumne system; effects on richness were generally negative. Overall declines in macroinvertebrate abundance and richness have also been noted in response to similar release experiments (Jakob et al. 2003, Robinson et al. 2003).

Assemblage dynamics were different in 2009, probably due in large part to the later post-flood sampling and recovery of some populations during the falling hydrographic limb. Total individuals decreased only minimally after the flood and increased dramatically by two months after the flood. Abundances of all orders except Diptera did fall in response to the 2009 release, as in 2008, but dominance increased instead of decreasing. This opposite response was proximately due to the slight increase in Diptera and probably ultimately due to late summer increases in chironomids and simuliids which were apparently sufficient to compensate for losses due to scour and active drift. Actual increases in simuliids may have been even greater than our results suggest, because simuliids can be difficult to dislodge by kick netting (Armitage 1976). Proportion of EPT decreased, instead of increasing as in 2008, probably for the same reasons. As in 2008, there was a general downward trend for richness and diversity metrics after the flood.

Green algal biomass was greatly reduced in 08, and such reductions have been found in association with other experimental releases (Jakob et al. 2003). Algal reductions in response to releases have been found to be less severe close to dams (Jakob et al. 2003) as a result of lack of scouring material (Shannon et al. 2001). In our study, there were not longitudinal differences along the studied river reach, despite our study area being longer in length than that used by Jakob et al. (2003). Before-flood algal biomass in 2009 was half that of before-flood 2008, possibly due to lack of recovery from the previous year, though green algae grows quickly and proliferates in the constant low flow often found below dams (Cortes et al. 1998). Most notably, there were no apparent algal losses associated with the 2009 flood, probably because of recovery from the initial scouring during the long falling hydrographic limb.

The food web was clearly modified by the 2008 release. The proportion of collector-gatherers was reduced by the flood in the short term, and the collector-filterer:collector-gatherer ratio increased from a very low 0.0077 to 0.068 immediately after the flood. More importantly, this ratio was still higher than pre-flood levels two months later (0.058). The persistence of the increase in collector-filterers may have been the result of an increased ratio of suspended fine particulate matter to deposited fine particulate matter (Merritt and Cummins 1996, Merritt et al. 2008). Such a shift in this particulate ratio was probably not a result of increased suspended particulates over the two month period after the release, unlikely below a deep release dam (Allan 1995), but was more likely a result of removal of deposited fines (Eustis and Hillen 1954, Johnson et al. 1995, Henson et al. 2007) by the flood. Silt deposition favors many collector-gatherers, for instance Tanytarsini (Chironomidae; Armitage 1977). Although suspended particulates likely only increased during and immediately after the release (Jakob et al. 2003), reduction of these particulates is common below dams without surface discharge (Allan 1995). Much of this material is allochthonous in nature, and dams can disrupt the hydrological connectivity with upstream reaches and uplands (Allan 1995, Pringle 2006). In 2009, the collector:filterer ratio was initially low (0.023) and remained so (0.013) immediately after the release, but rose to a very high 0.42 two months after the release due to the rapid increase in simuliids in the early fall. Prior to the 2008 release, the proportion of predators (0.030; Table 11) was lower than in our 2007-8 baseline sampling (0.075; Table 6), which in turn was lower than the more frequently encountered range of 0.10-0.20 (Merritt and Cummins 1996, Merritt et al. 2008). Immediately after the release, the proportion of predators rose into the 0.10- 0.20 range (0.12) but fell again by two months after the release (0.037). In 2009, the proportion of predators was 0.11, but this proportion was reduced by about two-thirds after the release and stayed at approximately that level into the fall. The proportion of predators was apparently lowered by the large number of baetids, chironomids, and simuliids.

Many of the apparent responses to the flood lessened in the months immediately following the release, as has been found in analogous studies (Jakob et al. 2003, Robinson et al. 2003). This response was particularly notable in 2008 but was present in 2009 as well. After two months many metrics had levels between those observed immediately before and immediately after the flood. Chironomids recovered much of their abundance in the two months following the flood (greatly exceeding initial abundances in 2008), and we observed increases in Baetidae and Simuliidae as was also reported by Robinson et al. (2003), although we did not observe the broad increase in Plecoptera that these authors recorded. All three of these groups have adaptations that allow rapid colonization of denuded substrata (Robinson and Minshall 1986, Robinson et al. 2003). It is encouraging that some of the positive effects of the release persisted for at least two months; much of this change is likely due to provision of bare substrata lacking sediment and algal cover (Ward 1976, 1984). The releases were valuable experiments that provided a first indication of how river health might respond to an intact disturbance regime.

Although some effects of the release may be transitory, others are likely to persist for some time. Both periphyton and sediments are mobilized rapidly by artificial floods (Jakob et al. 2003). But, as algae recolonize substrata, faunal metrics related to algal growth (Armitage 1976) would be expected to return over a period of months to levels seen before the release. In contrast, faunal metrics driven by sedimentation would be expected to remain changed for years, because sediment would take some time to reaccumulate to pre-release levels (Ward 1984).

In general, river health will benefit over the long term from river regulation that mimics the natural pattern of flooding as closely as possible (Morehardt 1986, Bayley 1991, Jobin 1998), in part because spring flooding is a key natural disturbance (Resh et al. 1988, Townsend et al. 1997, Vinson 2001). Robinson et al. (2003) caution that responses to new release programs continue to develop over a period of years, rather than months, as the assemblage adjusts to a new and more variable habitat configuration. These authors argue that release programs and associated benthic sampling should be sustained if managers desire a more natural macroinvertebrate assemblage.

There are several additional lines of investigation that would help inform management of the Tuolumne River. As outlined in the previous Discussion section, an observational study that includes not only the below-dam reach, but also above-reservoir and unregulated reaches would be a key element in developing context for current river condition. It would also be useful to compare the assemblage below Lake Eleanor, with annual spring discharge (B. McGurk pers. comm.), with the assemblage below the Hetch Hetchy reservoir. Drift of benthic macroinvertebrates is important in structuring stream assemblages (Wallace 1990). Both reductions and increases in flow can enhance drift (Waters 1972, Scullion and Sinton 1983, Perry and Perry 1986), and altered drift patterns can therefore occur below dams and in other regulated systems (Irvine and Henriques 1984, Imbert and Perry 2000, Greathouse et al. 2006b). For instance, loss of taxa below dams may occur, because drift losses are not replenished by drifting individuals from upstream reaches—often entrapped by the reservoir. In turn, drift from the reach immediately below a dam may not be carried very far downstream because of reduced flows. We recommend investigation of drift in the Tuolumne system. Lastly, the seasonal wetlands perched above the river were historically inundated seasonally and almost certainly contributed significant macroinvertebrate biodiversity to the river corridor. Ponds, marshes, and wet meadows harbor large and diverse aquatic faunas (Wiggins et al. 1980, Law and Morton 1993, Williams 2006) that change throughout the dry-wet-dry progression in the Sierra, at least in higher elevation systems, further enhancing diversity (Holmquist and Schmidt-Gengenbach 2006, Holmquist et al. in press, submitted) and food resources available to vertebrates (Batzer and Wissinger 1996). Examining these wetland macroinvertebrate assemblages during experimental floods would be an important addition to the Looking Downstream initiative.

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