Yosemite National Park

Division of Resources
Management and Science

Looking Downstream
2008 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 2008 field season, in particular the physical and ecological responses to an experimental "pulse flow event" from O'Shaughnessy Dam. This three day event (May 27-29, 2008) culminated in a peak discharge of 6,800 cubic feet per second (cfs), which we calculate to be a "normal" (~1 year return interval) spring runoff river discharge under unimpaired, or pre-dam, conditions. Thus, the pulse flow event of 2008 simulated the approximate timing and magnitude (but not duration) of a typical spring runoff event.

Our hydrologic research verifies that relatively small increases in river stage immediately downstream of O'Shaughnessy Dam cause relatively large changes in river stage in Poopenaut Valley. The peak flow of 6,800 cfs was more than adequate to fill a large seasonal pond on the north side of Poopenaut Valley and inundate most wetland areas in the valley. Once full, the seasonal pond took about 6 weeks to drain via subsurface flow and evaporation, recharging the groundwater in the adjacent meadows. Groundwater conditions in the meadows and wetlands of Poopenaut Valley appear to be driven primarily by the level of the Tuolumne River, rather than adjacent hillslope hydrology.

Wetland maintenance provides one avenue for making quantitative recommendations for the magnitude of discharges from O'Shaughnessy Dam. Vegetation work in 2007 and 2008 reveal 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 magnitude required to maintain wetlands in Poopenaut Valley. We took initial steps in 2008 to address the timing of future water releases, primarily by initiating a riparian (willow and cottonwood) seed dispersal study.

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. The available habitat in Poopenaut Valley provides structural integrity beneficial to a wide diversity of birds. Timing and duration of water releases probably has a direct effect on the nesting success of riparian focal species understory nesters such as Song Sparrow, Yellow-breasted Chat, and Wilson's Warbler.

The pulse flow event created striking changes in the macroinvertebrate assemblage in the Tuolumne River. The flood changed an assemblage with relatively high dominance to an assemblage with greater evenness and greater proportional biodiversity. The flood caused a five-fold reduction in algal biomass, but there was about a 50% recovery in the two months that followed. All macroinvertebrate orders and most families decreased in abundance. By two months after the release, however, most taxa had increased in abundance, though most groups did not reach the densities seen before the release. The pulse flow event had major immediate

effects on the macroinvertebrate ecology of the river, and many of these effects would be generally viewed as positive changes.

Chapter 1. Introduction

The primary goals of the Looking Downstream project are 1) to address 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 the river's overall hydrological and ecological condition. An important overarching goal of these studies is to provide science-based information to the San Francisco Public Utilities Commission (SFPUC) that can be used to design environmental water releases from O'Shaughnessy Dam 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, appears to be 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 (2007 Looking Downstream report). For these reasons, we have focused our research efforts primarily in Poopenaut Valley, specifically on the meadow and riparian ecosystems found there.

In late May of 2008, scientists from the National Park Service, SFPUC, and McBain & Trush, Inc. collaborated on designing a 36-hour-long experimental pulse flow release of water from O'Shaughnessy Dam. The goals of this pulse flow event and our 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 for purposes of determining the time necessary to fully saturate the meadow,
- Determine the timing of riparian seed dispersal as it relates to peak river discharge, and
- Determine impacts to wildlife, primarily benthic macroinvertebrates within the Tuolumne River and bird species within the adjacent riparian vegetation.

As such, our 2008 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 and the 2008 Pulse Flow Event

2.1 Introduction

Hydrological monitoring of Poopenaut Valley river-stage and groundwater continued in 2008 and focused primarily on a 36-hour duration experimental “pulse flow event” occurring May 27-29, 2008. We report here on the pulse flow event and subsequent releases covering a 6-week period ending in early July 2008. A primary goal of the Looking Downstream project is to maintain and enhance aquatic and wetland habitat in Poopenaut Valley. As such, objectives for the pulse flow were to:

- Determine flow magnitudes necessary to inundate meadows and fill the seasonal pond on the north side of Poopenaut Valley,
- Determine meadow soil transmissivity for purposes of determining the time necessary to fully saturate the meadow, and
- Determine the length of time that the seasonal pond north of the river could retain open water following dry antecedent conditions.

The spring of 2008 was the second driest on record (1930-present) for the Hetch Hetchy area, with rainfall totaling just 2.65 inches from March through May. Snow pack was slightly above normal (112%) on April first as averaged among snow course data from within the Hetch Hetchy watershed. The onset of spring runoff was April 10th 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 spring runoff, the date at which half of the annual flow has passed the USGS gage, was May 17th. The seasonal pond in Poopenaut Valley remained dry (since spring 2007) through the winter and spring until filled by the pulse flow event.

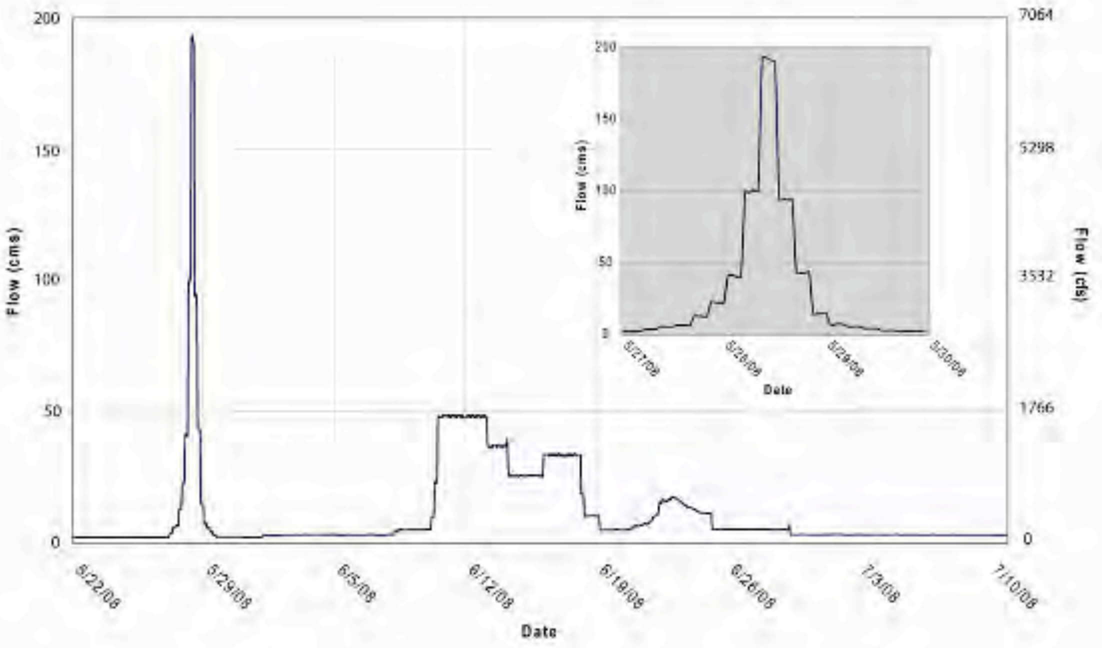
2.2 Methods

Monitoring groundwater and surface water conditions continued in 2008 using the same monitoring array installed in 2007 (Figure 2-1). Installation procedures, well logs, and surveyed elevations are detailed in the 2007 Looking Downstream Report (National Park Service, 2007). We used dataloggers (Solinst Leveloggers and Onset Hobo U20 water level loggers) to collect hourly water level and temperature data throughout the winter and spring of 2007-2008 at 10 wells, 2 river stage recorders, 1 pond stage recorder, and 4 tributary stage recorders. Additionally, we collected air temperature and relative humidity using an Onset Hobo Temperature/RH sensor and logger mounted 2 meters above the ground on the northeast side of a ponderosa pine at the edge of the southwest meadow. Prior to the pulse flow event, we checked all dataloggers and reset them to 15 minute logging intervals.

Figure 2-1. Site map showing well and stage recorder locations.

The pulse flow event consisted of a symmetrical hydrograph of 60 hours duration that began on May 27th, peaked at 6,800 cubic feet per second (cfs) or 193 cubic meters per second (cms) near midday on May 28th and ended in the early hours of May 29th. The total water released during the event was 6,500 acre-feet (8 million cubic meters). Subsequent releases were longer in duration and peaked at 1,700 cfs (Figure 2-2).

Figure 2-2. Tuolumne River Flow below Hetch Hetchy Reservoir (USGS Gage 11276500) May 22 – July 9, 2008. Inset shows details of the experimental flood pulse.



In addition to the installations noted above, we recorded the passage of the floodwave in Poopenaut Valley by mapping the extent of inundation, reshooting photopoints, and hand-measuring groundwater wells where possible. We mapped the extent of inundation using a Trimble ProXT Global Position System unit, visual observation, and photographs.

2.3 Results

Figures 2-3a and b show river stage and groundwater well responses to the pulse flow along Transects 1 and 2. There was a delay of about 4.75 hours between flow changes at the dam and when these changes were observed in Poopenaut Valley. During the pulse flow, surface water generally inundated groundwater wells before the surrounding soils were saturated from groundwater migration (i.e. surface water poured down into the wells), so well data does not reflect the true water table. Subsequent high flows in June did not inundate the wells, and their response is likely more reflective of groundwater conditions. Wells 4, 5, 9, and 10 remained dry throughout the study period. Well 6 recorded 5 cm of water at the bottom of the well close to the peak discharge of the pulse flow event.

Figure 2-3. a) Transect 1 groundwater levels and river stage.

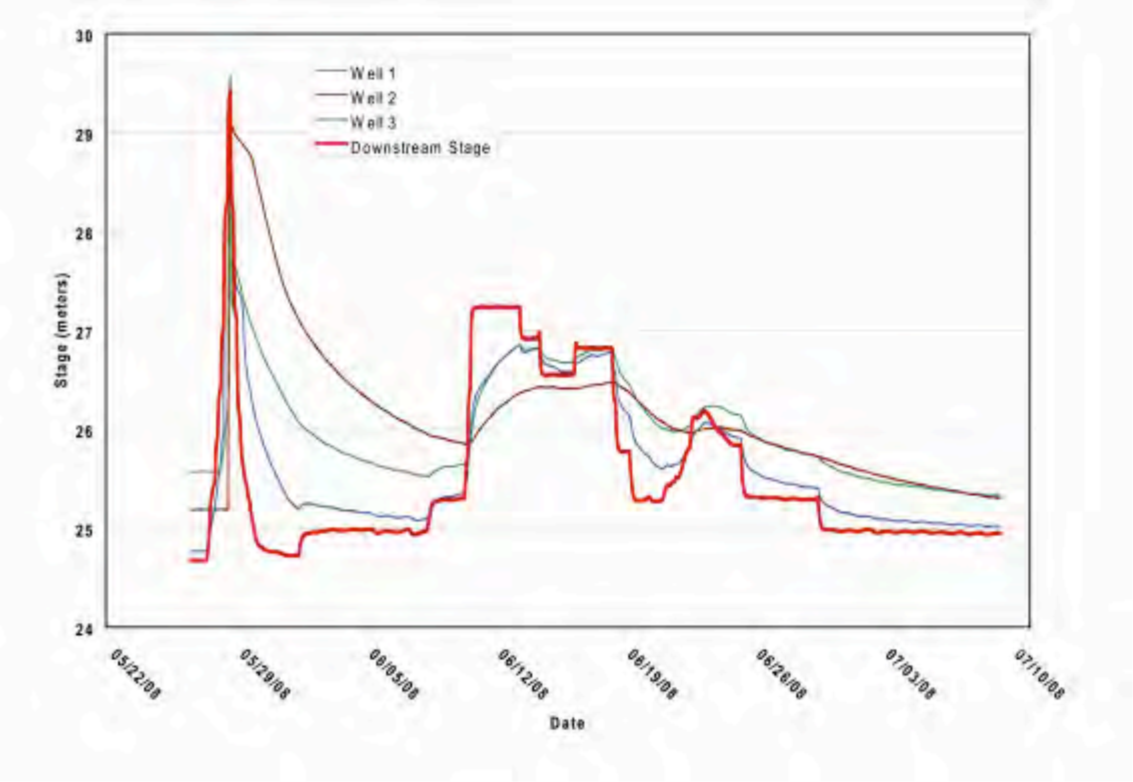


Figure 2-3. b) Transect 2 groundwater levels plus Well 8 and river stage. Well 8 data is truncated where water level fell below the level of the sensor and bottom of the well.

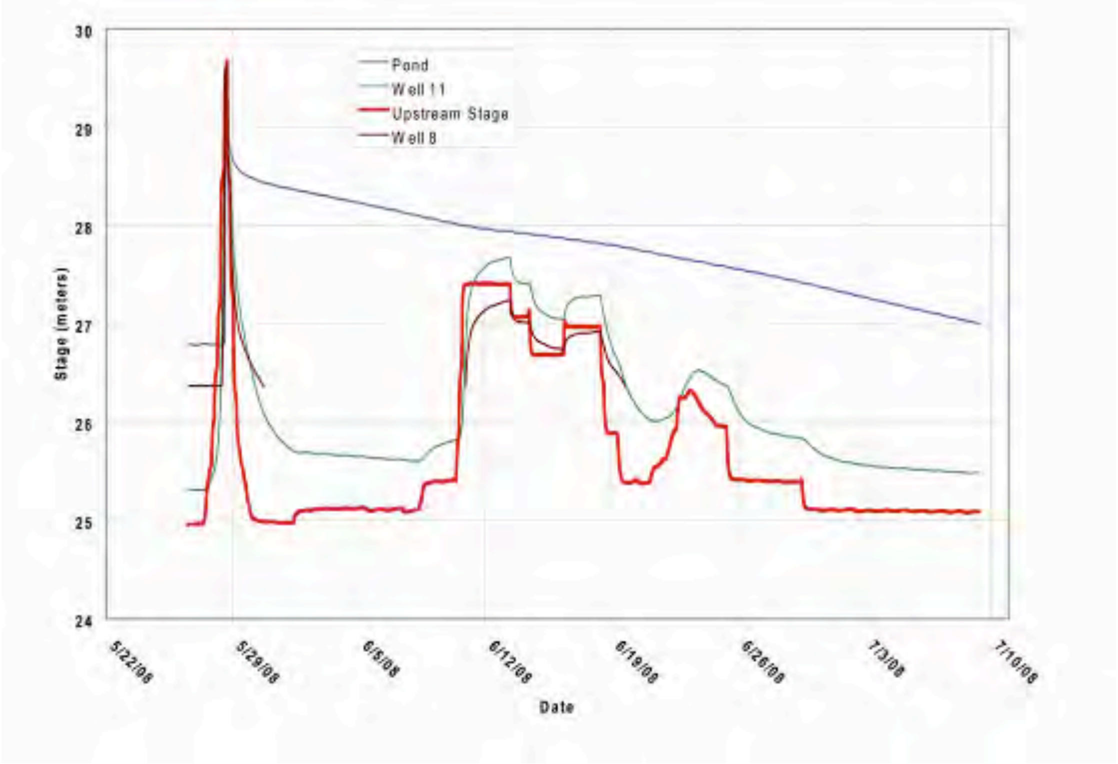


Figure 2-4 depicts areas of inundation at 3,600 and 6,800 cfs. Flow magnitudes are estimated to be approximately the same as those measured at the USGS gaging site below O'Shaughnessy Dam. Tributary contributions were less than 10 cfs at the time of the pulse flow, based on visual estimates of flow on the three main tributaries to Poopenaut Valley. Dashed lines indicate approximate inundation line based on ground photography. River stage at 6,800 cfs was sufficient to inundate approximately 60% (3.1 hectares) of the south meadow west of the southwest tributary and fill the seasonal pond in the north part of the area through a spillway on it's southwestern side (Figure 2-5). River stage at 3,600 cfs was sufficient to inundate low lying meadow areas immediately adjacent to the river (1.2 hectares of the southwest meadow area) and the downstream southern tributary as well as the large sandbar in the east-central part of the study area (Figures 2-5 and 2-6). Maximum flow inundation was mapped from 1625 Pacific Daylight Time (PDT) to 1726 PDT, a period when the upstream stage was between 29.606 and 29.671 meters, the latter being the peak recorded stage. Although the maximum flow peak lasted a little more than two hours, the extent of inundation observed is likely only slightly less than the potential maximum inundation at 6,800 cfs.

Figure 2-4. Inundation extent at 3,600 cfs (red) and 6,800 cfs (yellow). Dotted lines indicate approximate inundation lines determined from photographs. Red dots are groundwater well locations.

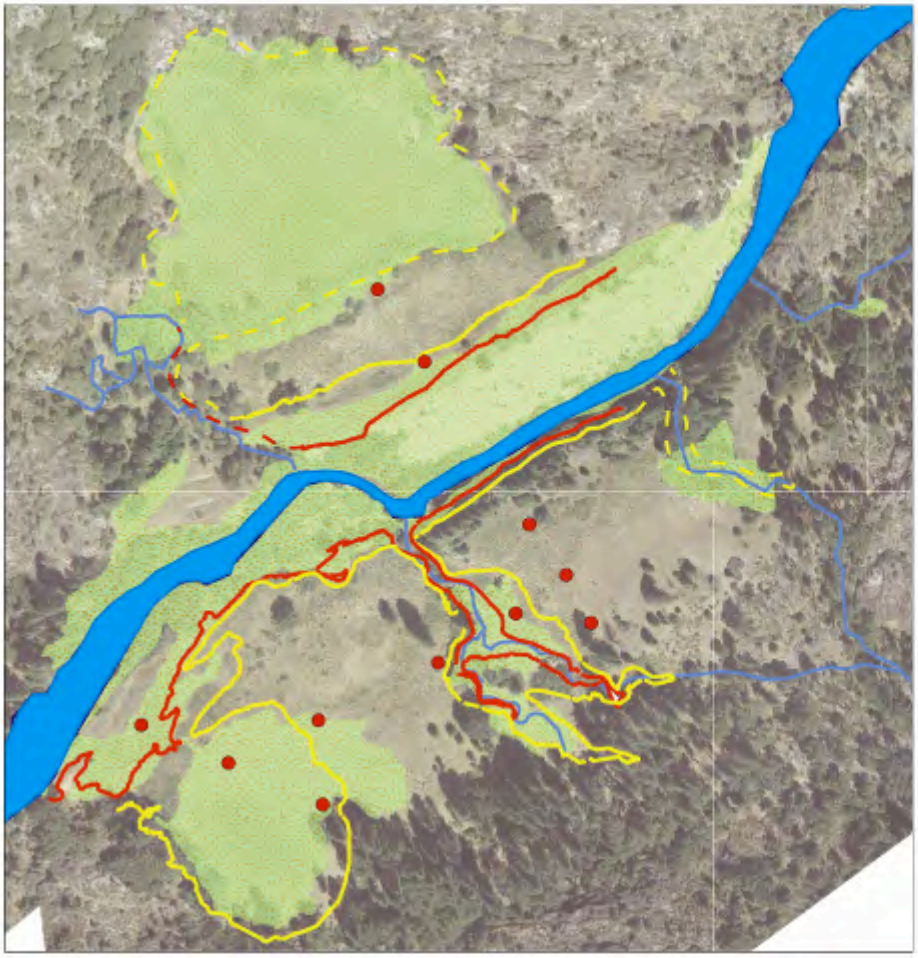


Figure 2-5. View to the southwest with the seasonal pond in the foreground. Photos were taken on May 28th at flows of approximately a) 1,400, b) 3,600, and c) 6,800 cfs.

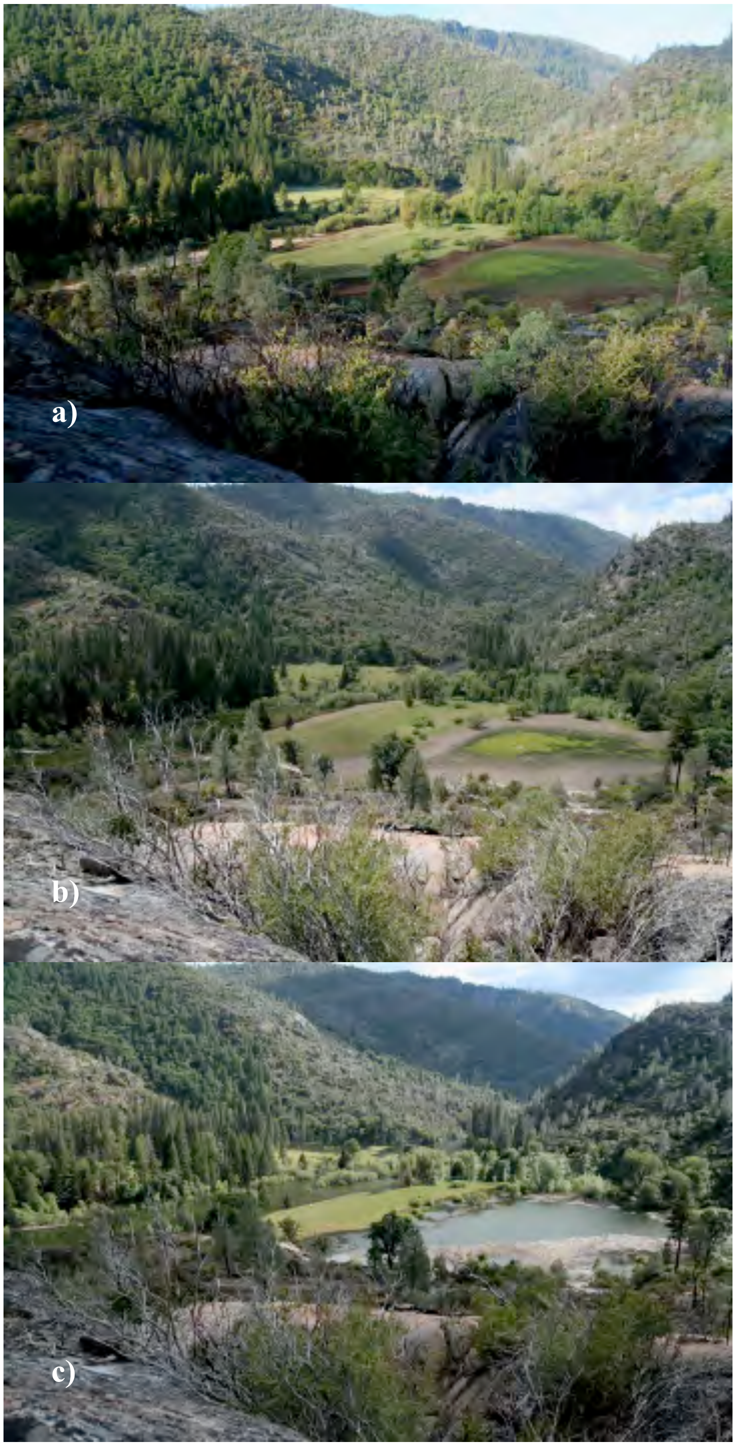
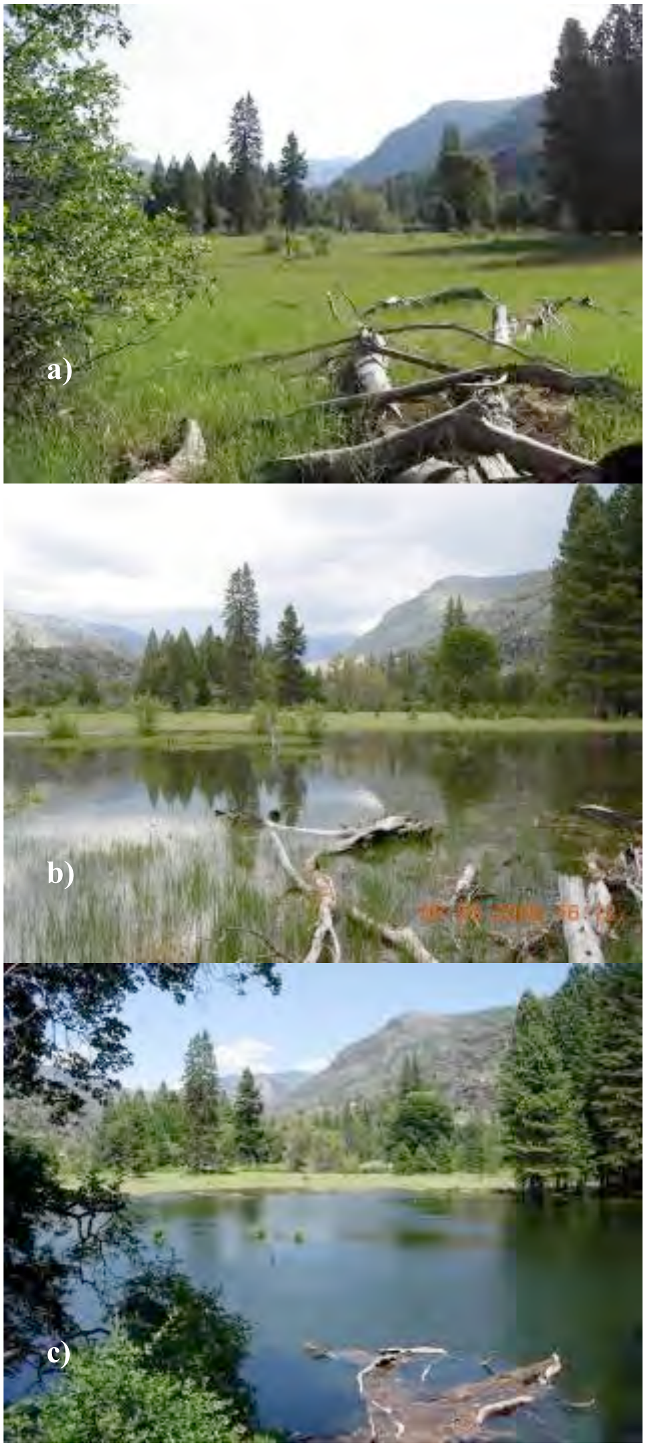


Figure 2-6. Photos of south meadow in a) 2006 (8,400 cfs), b) 2007 (3,000 cfs), and c) 2008 (6,800 cfs) during peak flows. Note inundation of encroaching conifers at the highest flow in 2006.



Tributary flows were very low (estimated to be less than 10 cfs) during spring 2008 due to little snow in their headwater regions. As a result, we were unable to detect clear relationships between flow timing on the tributaries and flows on the Tuolumne River during this first year of monitoring. Monitoring of tributary flows will continue in 2009.

2.4 Discussion

The pulse flow peak was similar in magnitude to a typical pre-dam spring runoff flood, with a return interval of approximately 1.1 years under an unimpaired flow regime. The fact that the pulse flow event was sufficient to inundate most of the mapped wetlands (Figure 2-4) is compelling evidence that development of this wetland was driven primarily by unimpaired river discharge. Groundwater levels remained very low throughout the meadows during the fall of 2007, and winter and spring of 2008, generally more than 2 meters (6.5 ft) below the ground surface. As such, it appears that hillslope contributions to groundwater are insufficient to raise groundwater levels to the point where they could be used by most meadow plants. This hypothesis will have to be tested during wetter years.

One of the more interesting results of the pulse flow event was the filling of the seasonal pond and its subsequent drainage over the following six weeks (Figure 2-3b); note that the pond had been dry prior to the experimental flood. Except for the initial spillage during the flood recession limb and ignoring evaporation/evapotranspiration , the pond drains by subsurface seepage, and thus maintain high groundwater levels in the surrounding meadow (see Well 11 record in Figure 2-3b). The ability of the pond to retain water and essentially ‘water’ the surrounding landscape over relatively long periods has important implications for the lifecycles of plants and animals that may depend on the pond resources. More critically, filling the pond with a pulse flow event at the right time of year may prove essential for the survival of some species such as tree frogs, western pond turtles, or garter snakes.

We have hypothesized that asynchronous flood peaks on the tributaries and the main stem have contributed to the observed incision of the tributary channels, up to approximately 2 m below the meadow surfaces near the Tuolumne River channel. While this remains to be fully tested given the very dry conditions in 2008, we did observe a potential second mechanism driving incision: rapid drainage of the flooded tributaries on the steep recession limb of a flood on the main stem. In the southwest portion of Poopenaut Valley, flow depth and flow velocity out of the meadow during pulse flow drawdown appeared to have been sufficient to rapidly scour meadow soils had they not been vegetated. Mitigating this potential impact could be accomplished simply by reducing the rate of flood recession. If future studies confirm that rapid downramping is causing erosion and/or incision in these tributaries, or failure of the banks adjacent to these tributaries, the NPS and SFPUC should work to identify ramping rates that avoid or reduce this impact.

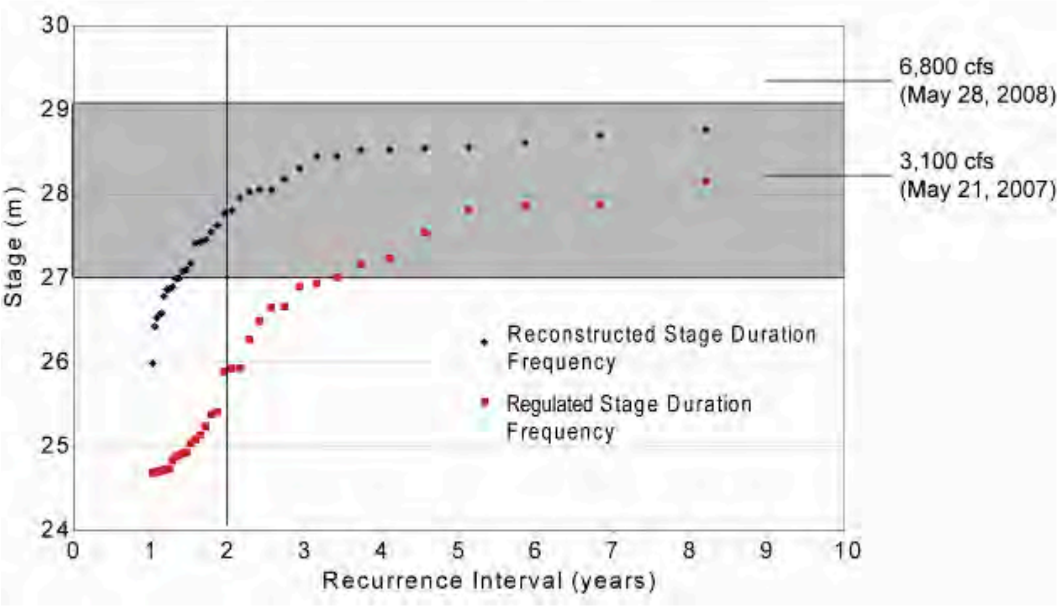
Quantitative determination of meadow soil transmissivity (the rate at which water is transmitted through a unit width of aquifer under a unit hydraulic gradient) was not possible during this experimental flow due to the surface infiltration of many wells by flood waters, as well as the short duration of the flood. Future pulse flows could address this by allowing the river discharge to increase gradually allowing substantial lateral infiltration of the meadow prior to inundation.

2.5 Wetland maintenance: Potential steps toward developing flood criteria for ecological benefit

One of the primary purposes of the Looking Downstream project is to identify flow conditions supportive of proper functioning ecological processes downstream of O'Shaughnessy Dam. Here we outline one such approach using wetland maintenance as an example. Ultimately, we may have several such flow recommendations to simulate the wide natural variability that the system once experienced.

For soil saturation to impact vegetation, it must occur within a major portion of the root zone, usually within 30 cm (12 inches) of the surface (Environmental Laboratory 1987). Based on studies in other Sierra Nevada meadows, hydrophytic vegetation, which is adapted to periods of inundation, occurs where the watertable is 0–40 cm below the surface, and more mesic vegetation, which is not typically adapted to periods of inundation, exists where the water-table is 20–80 cm below the surface (Allen-Diaz 1991). For purposes of recommending flows on the Tuolumne River, we consider that wetlands require soils to be saturated to within 40 cm of the ground surface (D. Cooper, pers. comm.) for 12.5 percent of the growing season, or frost-free period for 5 out of every 10 year period (USACOE). We calculate the number of frost-free days in Poopenaut Valley to be 208, so 26 days of soil saturation is necessary to maintain a wetland condition. Because groundwater levels appear to be driven primarily by river stage, this suggests that river stage must exceed levels sufficient to raise groundwater levels in wetland soils to within 40 cm of the ground surface for a period of 26 days on a 2-year return interval. By combining this high-flow criterion with wetland elevation and river stage-discharge relationships, we can develop a stage-duration-frequency relationship for Poopenaut Valley under impaired (present-day) and unimpaired (pre-dam) conditions (Figure 2-7).

Figure 2-7. Stage-Duration-Frequency relationship for a 26-day high flow duration in Poopenaut Valley. The gray shading represents the range of elevations (local datum) in the lower meadow along Transect 1. Reconstructed stage is derived from discharge data from the USGS Pohono Bridge gage on the Merced River scaled by basin size and a stage-discharge relationship developed for Poopenaut Valley.



We observe in Figure 2-7 that the reconstructed two-year high flow return interval falls in the middle of the range of meadow (and wetland) elevations along Transect 1, while the regulated stage falls about one meter (3.3 ft) below the wetlands. Regulated flows achieve similar stage durations at a 5-7 year return interval. While this may be sufficient to maintain the lower-lying wetlands, the evidence of drying wetlands suggests that it is insufficient to maintain most of the wetland areas. This notion is supported by Table 2-1, which shows whether wetland conditions were satisfied during the past 10 years at wells 1-3. Under reconstructed flows, all three locations satisfied the wetland criteria. Under regulated flows only well 3 met the criteria.

Table 2-1. Number of years during the period 1998-2007 that a 26-day river-stage duration exceeded levels (local datum) necessary to maintain wetland conditions at wells 1-3. Yellow cells indicate that soils adjacent to wells 1 and 2 likely received inadequate saturation to maintain wetland conditions.

Well Number	Ground Surface Elevation (m)	Minimum Groundwater elevation (m)	Number of times exceeded in past 10 years	Number of times exceeded (reconstructed flows)
1	29.13	28.73	1	5
2	28.79	28.39	3	9
3	27.25	26.85	5	10

2.6 Conclusions and Future Work

The 2008 pulse flow event revealed the following:

1) Relatively modest flows are sufficient to inundate large areas of Poopenaut Valley,

2) The peak flow of 6,800 cfs was more than adequate to fill the seasonal pond and inundate most wetland area in the valley,
3) Groundwater conditions in the meadows and wetlands of Poopenaut Valley appears to be driven primarily by river stage rather than adjacent hillslope hydrology, and
4) Once full, the seasonal pond took about 6 weeks to drain via subsurface flow and evaporation.

In order to move from these observations to potential flow prescriptions now requires an examination of flow timing, magnitude, and duration. Flow timing must be informed by floral and faunal phenology, particularly wetland and riparian vegetation as well as plants and animals dependent on pond resources. For magnitude and duration for purposes of maintaining wetlands, we need to understand the evolution of groundwater levels and soil moisture during the flood hydrograph. Specific questions include:

1) How long does it take for soil saturation to occur spatially within wetland polygons?
2) Once saturated, how does soil moisture evolve on the recession limb of the river hydrograph?
3) What are the relative efficiencies of lateral and vertical infiltration of wetland soils and can these differences be exploited to shape the pulse flow wave to optimize the use available water?

In 2009, we intend to address the groundwater questions through a cooperative agreement with the University of California at Santa Cruz. This will facilitate the completion of a groundwater model of the valley based on a 2009 experimental flood that can be used to model the effects of various flows, transient and static, on wetland soil moisture. This model could then be tested in subsequent years under different flow scenarios.

Chapter 3. 2008 Vegetation Surveys in Poopenaut Valley

3.1 Introduction

The wetland delineation and description of existing vegetation types in Poopenaut Valley, completed in 2007 and detailed in the 2007 Looking Downstream report, provide a preliminary baseline of the composition and spatial distribution of plant communities. In order to refine these assessments and to establish monitoring for detection of any change over time, vegetation work continued throughout the 2008 season. These efforts include a seed dispersal study, vegetation monitoring (transects and quadrats), and invasive species survey and removal.

3.2 Seed Dispersal Study

Riparian vegetation in Poopenaut Valley provides critical habitat for wildlife, particularly birds (see Chapter 4), and requires further investigation to determine current conditions and establish the relationship to the hydrologic regime. The reproduction of 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 to determine the timing of seed production and dispersal as related to flow conditions on the Tuolumne River. We hung seed traps consisting of $8^{1/2}$ x 11" pieces of plywood with a Vaseline coated piece of paper (the trap) in trees in late April 2008 and collected them weekly throughout the growing season (early August). Seeds were later counted and graphed to depict the beginning, peak and end of the seed dispersal period.

Seed dispersal timing varied between species, with arroyo willow (*Salix lasiolepis*) producing seed in late April to early May, shiny willow (*Salix lasiandra ssp. lucida*) and red willow (*Salix laegivata*) primarily producing seed throughout June and dusky willow (*Salix melanopsis*) and narrow-leaved willow (*Salix exigua*) producing seed from late June into early August (see Figures 3-1 a and b). Dusky willow showed the longest duration of seed production and arroyo willow the shortest period. Black cottonwood produced catkins in April but either a hard freeze in late April or drought conditions caused the trees to drop the catkins and no seed production occurred. HOBO data loggers located in the forested edge of the meadows recorded air temperature readings of near freezing (0.5 degrees C) for two nights in early May but these temperatures do not seem sufficient to cause leaf damage. The location of the data loggers in the forest also may not capture actual temperatures in the more open areas, where frost was observed.

Figure 3-1 Shiny and Dusky/Narrowleaf Willow seed count

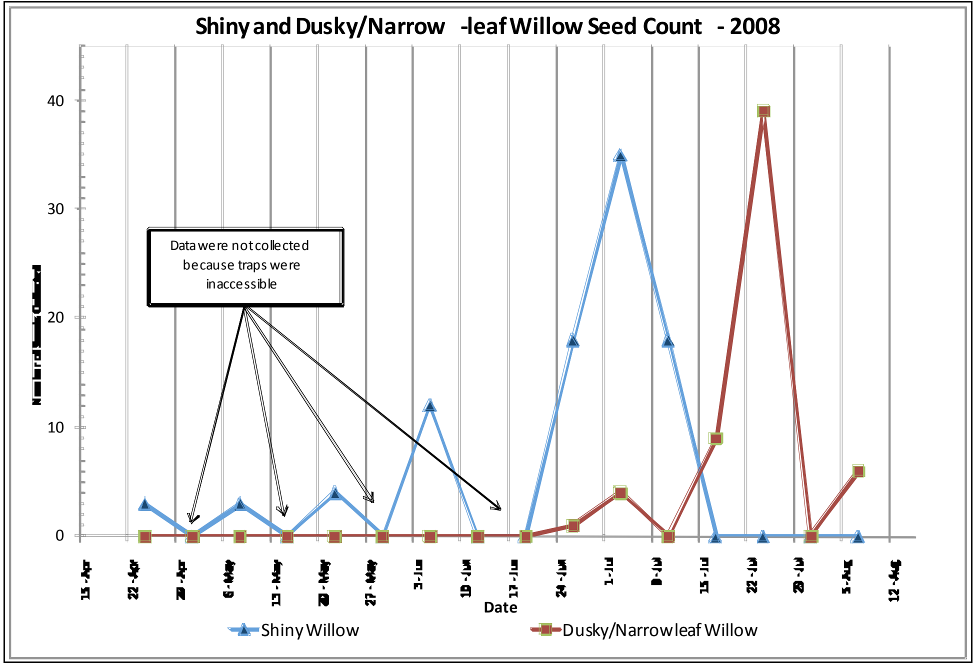


Figure 3-2 Arryo and Red Willow seed count

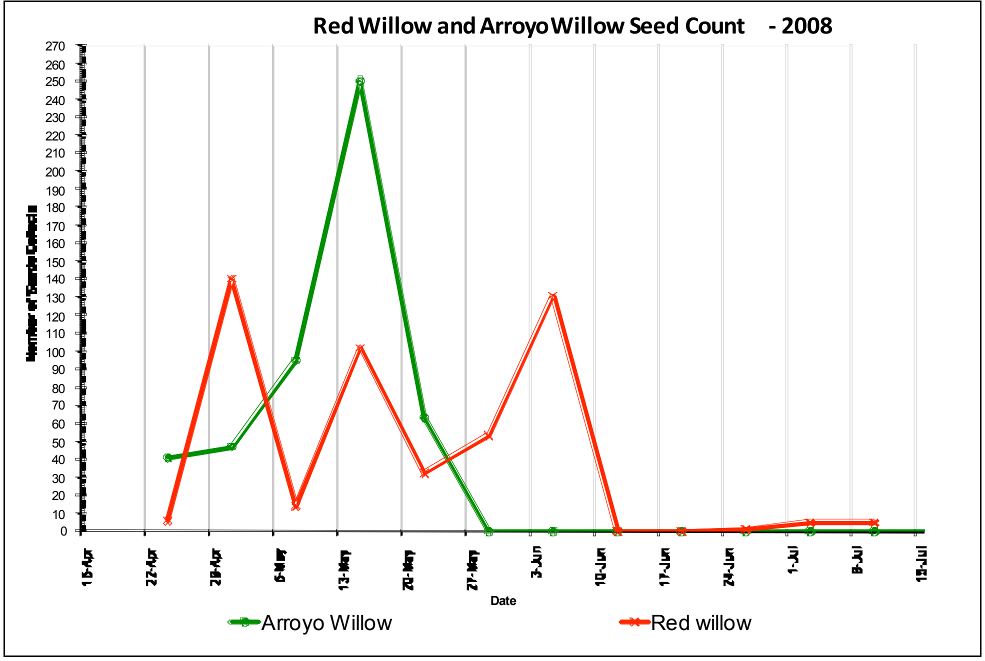


Figure 3-3. a) Willow seed trap in red willow b) Female willow catkin

Figure 3-4. a) Seed trap above water (circle) b) Willows in the channel May 28, 2008

Several issues influenced the data collection and quality of data for this study. The experimental flood on May 28 and a second, smaller release from June 11-17 influenced the study because many of the willows lie within the flooded area at these water levels. During the pulse flow event, we removed the majority of the traps for the duration of the event and replaced them once water levels decreased. However, we underestimated the river stage and four traps were submerged. We were unable to move traps prior to the subsequent high flows in early June and 11 traps were submerged for several days. Fortunately, the traps were recovered once water levels decreased. Although we recovered and replaced all seed traps, data for those periods of time were lost (Note the lack of data on the graphs). Inability to access the traps located on the north side of the river also prevented data collection during this time. High temperatures in Poopenaut Valley, frequently exceeding 100ºF, caused the Vaseline to melt and fail to “trap” the seeds. This likely decreased the amount of seed captured and seed production rates may be underestimated. These experiences are part of establishing a technique in a new area, and will help subsequent work in 2009 to proceed more smoothly. Documentation of the life cycle stage of the willow (i.e. percent of the canopy with flowering catkins) was also recorded so qualitative information on the timing of flowering and seed production timing when traps were not set up is available.

Of particular interest is the long duration of seed production by dusky willow and narrow-leaved willow, species that lie within the bed and banks of the Tuolumne River and experience inundation at relatively low flows (1000 cfs). Catkin development began in early June, just after the experimental release. Seed production increased and began to taper off by the middle of

June. The second increase in water levels occurred June 11-17 and subsequently, new catkins developed and seed production continued well into early August. It appears that willows respond rapidly to water availability but further data collection and a comparison with the same willow species located on the Merced River in 2009 may clarify this relationship. Subsequent conversations with willow expert John Bair also indicate that two reproductive cycles for these willow species is not so unusual.

3.3 Vegetation Monitoring

Observations in Poopenaut Valley and in other montane meadows indicate that non-native plants, both perennial (e.g., Kentucky bluegrass) and annual (e.g., cheatgrass) grasses are less likely to dominate in wetter areas. Perennial grasses historically sown for forage for domestic animal grazing typically do not occur in wetlands dominated by sedges. Based on the Yosemite Floristic Classification, these vegetation types (i.e. Kentucky bluegrass dominated) may in fact be degraded sedge dominated plant communities. In drier conditions, non-native perennial grasses are able to out-compete more hydrophytic plants and, subsequently, increase in dominance.

The dominance of annual nonnative grasses in Poopenaut Valley indicate past or contemporary disturbance. Based on historic stream gage data downstream of O'Shaughnessy Dam, rising and falling limbs of peak flow hydrographs are typically very short (compared to the much more gradual rising and falling limbs observed in free-flowing rivers such as the Merced River during spring runoff). This flashiness of water moving through the system could contribute to the soil disturbance in those areas that lack the anchoring roots of perennial plants, thereby perpetuating annual non-native plant communities.

It is important to establish monitoring to detect any changes in plant communities responding to annual variations in temperature and available water. In order to assess this, we established nine transects along and perpendicular to the five established cross sections, covering 600 meters of point intercept and associated nested frequency quadrats. These data can help determine current species composition, frequency, spatial extent and cover. These data can then be associated with existing and potential hydrologic conditions in relation to the elevations along those cross sections. These data may indicate any changes in the spatial extent of particular plant communities over time. We will complete these analyses in the fall of 2009 after additional modeling information and data are available. Additional work in Poopenaut Valley included more plant species identification (166 species) and refinement of wetland delineation and vegetation type boundaries.

3.4 Invasive Plant Removal and Survey

We continued efforts to improve the survey for invasive species and control existing populations in Poopenaut Valley. High priority invasive species for the park including bull thistle, Himalayan blackberry, Klamath weed and wooly mullein were targeted. Surveys around Poopenaut Valley revealed that some populations were more extensive than previously observed while others are more manageable. We mowed approximately 0.25 hectares of Himalayan blackberry and removed several hundred individual wooly mullein, Klamath weed and bull thistle plants. Himalayan blackberry also occurs upstream of Poopenaut Valley along the river corridor and there is a very large patch of Himalayan blackberry established just below the dam and eradication of these populations is necessary to eliminate upstream seed sources.

We will continue eradication of other high priority species including bull thistle, wooly mullein and Klamath weed in 2009. A more detailed survey of these areas will help determine the spatial distribution and extent of existing Himalayan blackberry populations and guide eradication efforts.

3.5 Future work

In 2009, we plan to expand the seed dispersal study to include areas along the Merced River and assess the rate and timing of seed dispersal as related to unimpaired flow regimes. Vegetation monitoring will continue and expand to include focused study of the riparian plant community, conifer encroachment and the relationship of vegetation types to the soil moisture gradient.

Chapter 4. 2008 Passerine Bird Surveys in Poopenaut Valley

4.1 Introduction

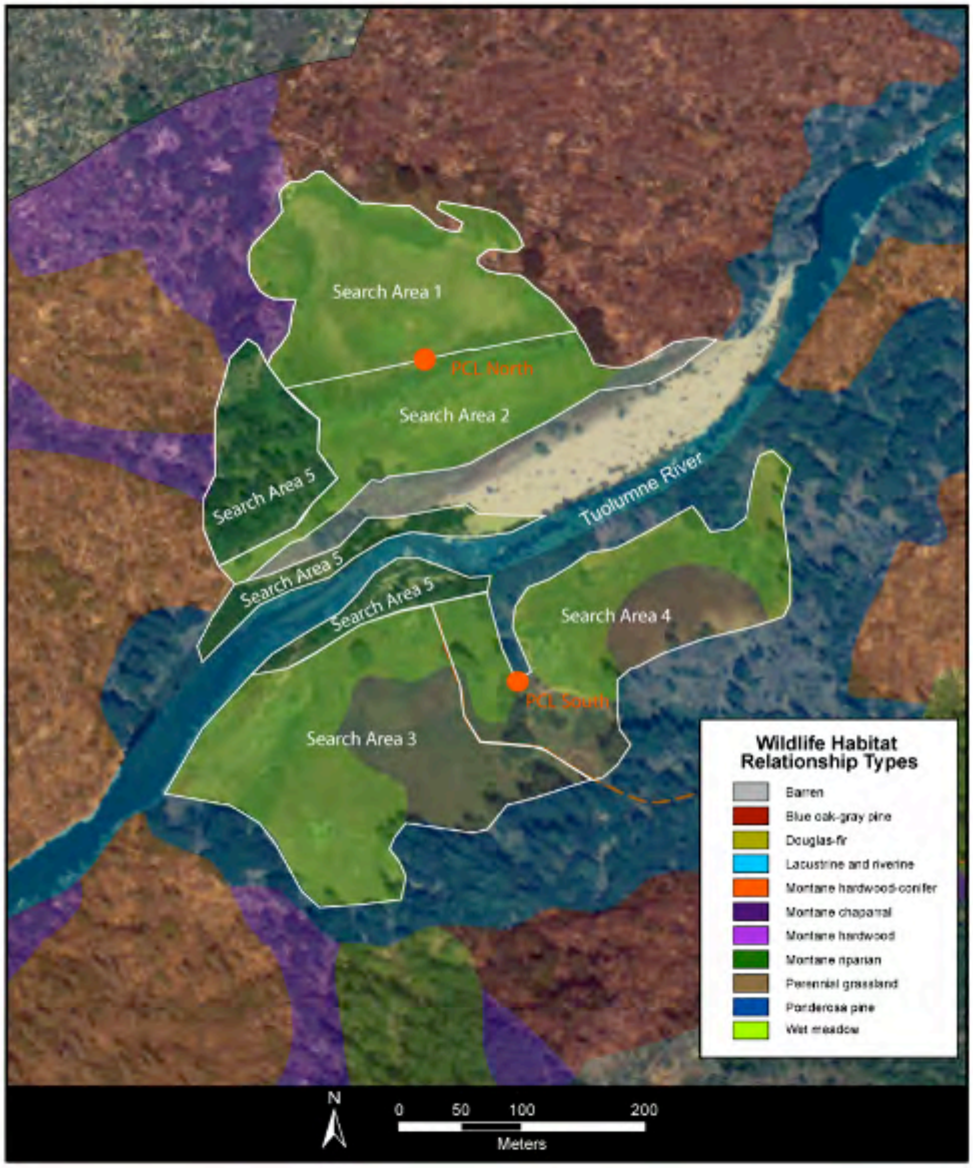
The sensitivity of bird populations to changes in the ecosystem makes them an important indicator of overall habitat quality (Marzluff and Sallabanks 1998). Long-term monitoring of birds, particularly during the breeding season, can be used to effectively assess habitat health (Ralph et al. 1993). Bird 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 the scientific 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. In our 2007 Looking Downstream report, we modeled predicted occurrence of vertebrate species between O’Shaughnessy Dam and the park boundary and in Poopenaut Valley using California Wildlife Habitat Relationships (WHR) system models and validation tools. Since 2007, we have been characterizing the bird community in Poopenaut Valley and assessing the Poopenaut Valley riparian habitat in relation to bird riparian focal species breeding in Poopenaut Valley.

4.2 Methods

We conducted the second year of standardized area search surveys and the first 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 3 hectares (see 2007 Report 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, and evenness.

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 second consecutive year of area search surveys in Poopenaut Valley were conducted during summer 2008 and comprised three separate visits (5/8/2008, 5/23/2008, and 6/24/2008). During the third visit, the north side of the river (Areas 1, 2, and partially 5) were inaccessible due to high water, thus introducing potential bias by reduced effort in these Areas. For area searches, a total of 233 individuals of 35 species were observed in Poopenaut Valley (Table 4-1). To account for possible duplicate observations among visits, we estimated relative abundance to be 169 individuals (Table 4-1). The most frequently encountered species were Red-winged Blackbird (*Agelaius phoeniceus)* (23 individuals), Bullock's Oriole (*Icterus bullockii)* (19 individuals), and Black-headed Grosbeak (*Pheucticus melanocephalus)* (12 individuals). In 2007-2008 combined, we detected 48 total species, comprising 21 probable and 4 confirmed locally breeding species, 6 riparian focal species (Black-headed Grosbeak, Song Sparrow (*Melospiza melodia)*, Warbling Vireo (*Vireo gilvus)*, Wilson's Warbler (*Wilsonia pusilla)*, Yellow-breasted Chat (*Icteria virens)*, and Yellow Warbler (*Dendroica petechia)* (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 species, Brown-headed Cowbird (*Molothrus ater)*.

Consistent with 2007 results, bird indices from the montane riparian habitat in Search Area 5 had the highest number of species richness (24 species), area search detections (41 individuals), diversity index (*H* = 3.02) and relatively high evenness (*J* = 0.95). The wet meadow areas averaged 34 individual detections of 18 species (Table 4-2). Search Area 1 stood out as having among the lowest values for almost all avian variables measured (Table 4-2).

Table 4-1. Bird species detected from area searches and their relative abundance in Poopenaut Valley, Yosemite National Park, in May – June 2008.

		Areas					
Common Name	**Status**	**1**	**2**	**3**	**4**	**5**	**Total**
American Robin			2	2	4		8
Brown-headed Cowbird		2	2	1	1	2	8
Black-headed Grosbeak	RFS	2	3	2	3	2	12
Black Phoebe						1	1
Brewer's Blackbird				4			4
Brown Creeper				1		1	2
Black-throated Gray Warbler				1	1	1	3
Bullock's Oriole		2	5	4	2	6	19
Bushtit			2			1	3
Cassin's Vireo		1	1		1	1	4
Chipping Sparrow			2	1	1	2	6
Dark-eyed Junco					1		1
Dusky Flycatcher			1			1	2
Hairy Woodpecker						1	1
House Wren		1				1	2
Lazuli Bunting						2	2
Lesser Goldfinch				3			3
Mallard		8		3			11
Mourning Dove				1			1
Nashville Warbler					1		1
Northern Flicker						1	1
Northern Rough-winged Swallow		1					1
Nuttall's Woodpecker						1	1
Pacific-slope Flycatcher			1	1			2
Red-winged Blackbird		15	6			2	23
Song Sparrow	RFS			1		2	3
Spotted Towhee			2	1	3	2	8
Steller's Jay					4		4
Violet-green Swallow				1		1	2
Warbling Vireo	RFS		1	1	2	3	7
Western Scrub-Jay		2	1		1		4
Western Tanager				1	2	1	4
Western Wood-Pewee		2	1		2	2	7
Yellow-rumped Warbler						1	1
Yellow Warbler	CSC, SSC, RFS		3	1		3	7
Total		**36**	**33**	**30**	**29**	**41**	**169**

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

Table 4-2. Species richness (number of species), abundance, bird diversity, and evenness from area searches, by study area in Poopenaut Valley, May – June 2008.

Search Area	*Species Richness*	*Abundance Estimate**	*Species Diversity Index**	*Evenness**
Search Area 1 Wet Meadow	10	36	1.80	0.78
Search Area 2 Wet Meadow	15	33	2.52	0.93
Search Area 3 Wet Meadow	18	30	2.72	0.94
Search Area 4 Wet Meadow	15	29	2.57	0.95
Search Area 5 Montane Riparian	24	41	3.02	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 using the Bray-Curtis Dissimilarity Measure revealed that Areas 2 and 3 differed the most in community assemblage (I_{BC} = 0.143, Table 4-3), whereas Areas 4 and 5 shared the highest degree of community similarity (I_{BC} = 0.500, Table 4-3).

Table 4-3. Bray-Curtis Dissimilarity Matrix for bird assemblages by study area in Poopenaut Valley, May – June 2008. Numbers in bold type indicate the least and most similar sites.

	Area 1	*Area 2*	*Area 3*	*Area 4*	*Area 5*
Area 1	0				
Area 2	0.333	0			
Area 3	0.333	**0.143**	0		
Area 4	0.375	0.273	0.263	0	
Area 5	0.25	0.182	0.263	**0.5**	0

4.3.2 Point Counts

The first year of point count surveys in Poopenaut Valley were conducted during summer 2008 and comprised three separate visits (5/8/2008, 5/23/2008, and 6/24/2008). Results from point count surveys were similar north and south of the river. Because the river was too high to cross during Visit 3, we were only able to conduct two sets of surveys on the north side. Results were averaged per visit to account for differences in effort. At North Poopenaut, an average of 23.5 individual birds of 8 species were detected per visit and at South Poopenaut, an average of 21.33 individuals of 8 species were detected per visit. Point count surveys detected five species not previously recorded during area searches: Wrentit (*Chamaea fasciata)*, Oak Titmouse (*Baeolophus inornatus)*, Mountain Quail (*Oreortyx pictus)*, Red-breasted Nuthatch (*Sitta Canadensis)*, and White-breasted Nuthatch (*Sitta carolinensis)*.

Table 4-4. Average bird species relative abundance and species richness, total number of individuals, and species relative abundance by point using 2008 point count data. Data include all detections, excluding flyovers.

Point	**North Poopenaut**		**South Poopenaut**	
Visits	**2**	**Average**	**3**	**Average**
Total Individuals	**47**	**23.50**	**64**	**21.33**
Species Richness	**16**	**8**	**24**	**8**
Acorn Woodpecker	1	0.50	3	1.00
American Robin		0.00	3	1.00
Anna's Hummingbird	1	0.50		0.00
Black-headed Grosbeak	5	2.50	8	2.67
Black Phoebe		0.00	1	0.33
Bullock's Oriole	8	4.00	1	0.33
Cassin's Vireo	2	1.00	2	0.67
Chipping Sparrow	3	1.50	3	1.00
Dusky Flycatcher	1	0.50		0.00
Lesser Goldfinch		0.00	3	1.00
MacGillivray's Warbler		0.00	1	0.33
Mountain Quail	1	0.50		0.00
Northern Flicker	1	0.50	1	0.33
Oak Titmouse		0.00	1	0.33
Red-breasted Nuthatch		0.00	1	0.33
Red-winged Blackbird	9	4.50	3	1.00
Song Sparrow		0.00	1	0.33
Spotted Towhee		0.00	5	1.67
Steller's Jay	2	1.00	8	2.67
Warbling Vireo	3	1.50	2	0.67
Western Scrub-Jay	1	0.50	2	0.67
Western Tanager		0.00	1	0.33
Western Wood-Pewee	3	1.50	4	1.33
White-breasted Nuthatch		0.00	1	0.33
Wrentit		0.00	2	0.67
Yellow-rumped Warbler	2	1.00	2	0.67
Yellow Warbler	4	2.00	5	1.67

4.3.3 Breeding Birds

Out of 53 species detected during 2007 and 2008 area searches and 2008 point counts, we identified four confirmed breeding species, 21 probable breeding species, and 28 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 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 - 2008.

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
Black Phoebe	X	S		AS, PC
Brewer's Blackbird	X			AS
Brown-headed Cowbird	X	S, P		AS
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
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			AS
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
Wrentit	X			PC
Yellow-breasted Chat	**X**			AS
Yellow-rumped Warbler	X			AS, PC
Yellow Warbler	**X**	**S, T**		AS, PC

Breeding status for each species is reported as possible, probable, and confirmed breeders (see text from 2007 Report for description) at Poopenaut Valley, summer 2007 and 2008. 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 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 affect on these species nesting success.

4.5 Future work

Further research is needed to gain a greater understanding of potential downstream effects of O'Shaugnessy 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. For example, investigating nesting success of understory nesting Song Sparrows and Wilson's Warblers in relation to water releases from O'Shaughnessy Dam would indicate if the timing and duration of flood events impacted their nesting success.

This spring 2009, we will conduct the third consecutive year of area searches and second consecutive year of point counts. In addition, we will 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 the 2008 Pulse Flow Event

5.1 Introduction

Macroinvertebrates are excellent integrators of physical, chemical, and biological processes and are highly valued as indicators of river health (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 benthic macroinvertebrate study (2007), our 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. These data are presented in the 2007 Looking Downstream report. The second year of study (2008) assessed the effects of an experimental spring pulse flow on the benthic macroinvertebrate assemblage. This chapter summarizes those results; detailed methods and results are provided in Appendix 2.

5.2 Assemblage Structure

For the 2007-8 assemblage description, we sampled macroinvertebrates in the riffles of the Poopenaut Valley reach at approximately six-week intervals for one year. This sampling produced baseline data on assemblage structure, trophic groups, the level of "tolerance" to degraded conditions exhibited by the fauna (low tolerance generally indicates healthy stream conditions), the physical environment, and overall habitat quality.

We sampled with kick nets as per US Environmental Protection Agency rapid bioassessment protocols and calculated metrics emphasized richness, dominance, trophic roles, and tolerance. Key physical measurements included flow, depth, temperature, and stream width, and we also completed EPA habitat assessments at each site.

We collected 69 taxa representing 25 families and eight orders. Ephemeroptera were found in every sample, and this order was dominated by Baetidae, Ephemerellidae, and Leptophlebiidae. Plecoptera were lower in abundance but were still found in every sample. Trichoptera were similar to Plecoptera in abundance, and the most common caddisfly families were Hydropsychidae, Hydroptilidae, and Philopotamidae. Coleoptera were relatively uncommon, and Elmidae and Hydrophilidae were the only families collected. Diptera was the most abundant order, and in turn Chironomidae and Simuliidae were the most common dipterans.

The majority of species were either predators or collector-gatherers, but collector-gatherers accounted for 71% of total individuals, whereas predators only represented 7.5% of individuals. Tolerance values ranged from 0 to 8, but there were 36 intolerant taxa and only one intolerant taxon. This one tolerant taxon, a clam, represented 1.4% of taxa and only 0.26% of individuals. Diptera increased three-fold during the fall and winter, and in turn overall tolerance of the assemblage increased from low to moderate levels during this time.

A high proportion of collector-gatherers, or a low collector-filterer:collector-gatherer ratio (which also obtained in the Poopenaut reach), can suggest a relatively low ratio of suspended fine particulate matter to deposited fine particulate matter. It is encouraging that there were so few tolerant fauna in the riffles below the dam.

Habitat condition had mean scores that fell in the Optimal range for eight of the ten parameters, and the overall score (155) also fell just within the Optimal range. There was a lack of woody debris at our sites, and there was generally substantial coverage by filamentous green algae.

As discussed in the 2007 Looking Downstream report, the water in Tuolumne River in Poopenaut Valley is colder than in analogous reaches in the upper Merced River, but we did not find increases in benthic macroinvertebrate diversity or decreases in tolerance with increasing distance downstream from the dam, although the 5km study reach may have been of insufficient length to have allowed appreciable warming before the discharged water left the study area.

Year to year variability in stream macroinvertebrate fauna can be substantial, 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. Our first year of sampling raised some questions regarding effects of river regulation on the benthic macroinvertebrate assemblage, and comparison of below-dam, above-reservoir, and unregulated reaches would be an important complement to the ongoing Looking Downstream efforts.

5.3 Benthic Macroinvertebrate response to Pulse Flow Event

We sampled the below-dam reach one day before, one day after, and two months after the experimental release using the method outline above. We sampled fauna with kick nets, and we also added several metrics to our assessment, most importantly algal biomass. Most analysis was via 1x3 repeated measures ANOVAs.

The experimental release created striking changes in the macroinvertebrate assemblage that were apparent in all of our analyses. The flood changed an assemblage with relatively high dominance to an assemblage with greater evenness and greater proportional biodiversity. Most assemblage-level metrics showed strong responses to the release. The flood caused a five-fold reduction in algal biomass, but there was about a 50% recovery in the two months that followed. All macroinvertebrate orders decreased in abundance in association with the release as did most of the 28 families. By two months after the release, however, most taxa had again increased in number, though most groups did not reach the densities seen before the release. Chironomid midges dominated the assemblage at the family level throughout all sampling periods despite dramatic flood losses, but the proportion of the fauna represented by these larval midges decreased in favor of more desirable taxa such as mayflies, stoneflies, and caddisflies.

The proportional contribution of collector-gatherers decreased, and all other groups increased, after the release. The strongest positive responses were demonstrated by predators, collector-filterers, and piercer-herbivores.

The release had major immediate effects on the ecology of the river, and many of these effects would be generally viewed as positive changes. The food web was clearly modified by the 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.

Most of the responses to the flood did lessen in the months immediately following the release, and after two months many metrics had levels between those observed immediately before and immediately after the flood. It is nonetheless 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.

As algae recolonize substrata, faunal metrics related to algal growth 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.

It is probable that both initial effects of the release and the duration of these effects would be greater in response to a release of longer duration. In general, river health would benefit from releasing flows to mimic the natural pattern of flooding as closely as possible. Yosemite National Park and SFPUC are working together to plan a second pulse flow event of longer duration and with more gradual rising and falling hydrographic limbs. Such a release would provide a much better understanding of invertebrate-flow-habitat relationships.

5.4 Future work

There are several additional lines of investigation that would help inform management of the Tuolumne River. As noted above, comparison of below-dam, above-reservoir, and unregulated reaches should be a component of the ecological assessment of the river. Drift of benthic macroinvertebrates, in which fauna leave the substrate either actively or passively and enter the water column, is important in structuring stream assemblages and is in turn influenced by dam operations. 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. Examining these wetland macroinvertebrate assemblages would be an important addition to the Looking Downstream initiative.

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Pg. _____ of _____

Appendix 1. Looking Downstream Variable Circular Plot (VCP) Point Count Data Form

State	Region	Station	Month	Day	Year	Visit

First Name	Last Name	Address	Telephone	Email

Point #		Time				Species				≤ 10	10-20	20-30	30-40	40-50	50-75	75-100	> 100	Fly-overs	Breeding Obs

Breeding Obs Codes: CO=copulation, MC=material carry, FC=food carry, NF=nest found, FL=fledglings, FS=fecal sac carry, DD=distraction display, PA=pair, DI=display

Weather Information: Please estimate temperature, cloud cover (% of sky covered by clouds), and approximate wind speed.

______˚ F or C (circle one) ______% ______ mph, knots, or kmph (circle one)

Appendix 2. Benthic Macroinvertebrate Research Methods and Results

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 a simulated spring flood event.

Methods

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 A2-1, Figs. A2-1 though A2-5). We sampled benthic macroinvertebrates, took a variety of physical measurements, and made habitat assessments at each of these stations.

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 $0.25m^2$ 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 (Fig. A2-2 through A2-4). 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 1988), 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 □$(n_i a_i/N)$, 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).

Response to Experimental Release

We sampled the below-dam reach one day before, one day after, and two months after the experimental release described in Chapter 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. A2-1, A2-2 through A2-6, A2-8 through A2-9) 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 Year 2, 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^o 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^o C), Orion perpHect buffer 7, (ph 7.00 +/-0.01 at 25^o 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 1x3 repeated measures ANOVAs. 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. We examined multiple comparisons with one-tailed paired t-tests. Although all tests were *a priori* orthogonal contrasts, we desired relatively tight control of type-I error rate. We used the sequential Bonferroni adjustment (Holm 1979, Shaffer 1995, Jaccard and Guilamo-Ramos 2002), which has greater power than the standard Bonferroni adjustment (Rice 1989), to correct probability values to familywise error rates. Corrections were done in MacBonferroni (Watkins 2002).

Results

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 A2-2), 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 A2-2).

Habitat condition had mean scores that fell in the Optimal range for eight of the ten parameters (Table A2-3). 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. A2-6, A2-7). There was more evenness at the family level (Figs. A2-8, A2-9) 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 A2-4). Species level rank-abundance showed a similar distribution (Figs. A2-10, A2-11) 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 A2-4).

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 A2-5). 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 A2-5). *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 A2-5). 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, Claassenia sabulosa,* and *Suwallia* sp. A had the highest frequency of occurrence at 0.625 (Table A2-5).

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 A2-5).

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 A2-5). 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.

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 A2-5). 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 A2-5).

We also collected dobsonflies (Megaloptera), water mites, and clams, all in small numbers (Table A2-5). *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 A2-5). 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 A2-6) instead of relative to numbers of taxa. Collector-gatherers accounted for 70.9% of total individuals - a function of several abundant mayfly species (Table A2-5). Although predators accounted for a majority of taxa, due in large part to the speciose stoneflies (Table A2-5), predators only represented 7.47% of individuals (Table A2-6). In contrast, the four collector filterer taxa represented 13.5% of total individuals (Table A2-6), a function of abundant black flies (Table A2-5). Percent scrapers was notably low at only 1.98% (Table A2-6).

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 A2-5). 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 A2-5). 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 A2-3) for chironomids (midges), and lack of sediment deposition (Table A2-3) for baetid mayflies.

Some seasonal trends were apparent, particularly when spring-summer and fall-winter months were compared (Table A2-7). Diptera increased three-fold during the fall and winter (from a mean of 66.9 to 196 individuals/m^2; Table A2-7). 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 A2-7, Fig. A2-12). 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 A2-7). In turn, %EPT decreased (from over 80% to 30%; Table A2-7, Fig. A2-13), and %Collector-Filterers, the simuliid functional feeding group, increased (from zero to above 20%; Table A2-7, Fig. A2-14). The dominant functional feeding group, collector-gatherers, decreased from 91% to about 60% during this time (Fig. A2-14), 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 A2-5), and Hilsenhoff's Biotic Index increased steadily from 2.29 to ~5.0 from spring to winter (Fig. A2-15, Table A2-7). Percent Species Dominance, however, decreased from 56% to ~15% during this time period (Fig. A2-16, Table A2-7), whereas % Family Dominance did not show as steady a decline (Fig. A2-16).

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).

Response to Experimental Release

Habitat variables recorded across all three sampling periods were generally similar to those recorded during the previous year. Water depth (37.5 cm, SE= 3.10) and water temperature (mean= 7.00 ^{o}C, SE= 0.289) were almost identical to 2007-8 values (Table A2-2), whereas flow (mean= 57.0, SE= 5.28), stream width (mean= 25.6, 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 conductivity, pH, and total dissolved solids were 8.9 μS/cm (SE= 0.59), 6.9 (SE= 0.021), and 4.4 ppm (SE= 0.31), respectively. Tree cover averaged only 5.1% (SE= 0.98). Mean algal dry mass was 5.12 gdm/m^2 (SE= 0.979). Habitat condition determined via EPA Habitat Assessment protocols during the summer 2008 experiment (158) was similar to that observed during the 2007-8 initial assemblage description (155; Table A2-3).

In this second phase of the study, 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.

The experimental release created striking changes in the macroinvertebrate assemblage that were apparent in all of our analyses. The 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. A2-17, A2-18), to an assemblage with greater evenness, apparent in the broken stick distribution immediately after the release (Fig. A2-17, A2-18). Two months after the release, the family rank-abundance relationship was similar to that from before the event (Fig. A2-17), and the species rank-abundance plot showed less evenness still (Fig. A2-18).

Most assemblage-level metrics showed strong responses to the release (Table A2-8). Overall abundance fell ten-fold from over 1000 individuals per square meter to just over 100 individuals per square meter. There was little change in family richness, but after correcting for differing abundances (Margalef's correction), family diversity peaked after the release and then fell again by two months after the release (Table A2-8). In contrast, species richness, with and without Margalef's correction fell following the release and did not return to pre-release richness after two months. Family dominance fell in response to the release and was still lower than pre-release levels after two months (Table A2-8). Percent Ephemeroptera-Plecoptera-Trichoptera (%EPT) doubled following the release and decreased but did not fall to pre-release levels (Table

A2-8). A trend of decreasing, followed by increasing, Hilsenhoff's Biotic Index was observed, but these effects were non-significant by a small margin. The flood caused a five-fold reduction in algal biomass, but there was about a 50% recovery in the two months that followed.

All orders decreased in abundance in association with the release (Table A2-9). Diptera showed the greatest flood-induced losses, falling from a mean of 892 to 61 individuals per square meter—a 93% loss. Less tolerant taxa lost density as well, but these losses were proportionally lower: 72%, 82%, and 20% for Ephemeroptera, Plecoptera, and Trichoptera (Table A2-9). Less abundant taxa, such as Coleoptera, Acari, and Bivalvia all had reduced densities as well. 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.

By two months after the release, however, most taxa had again increased in number, though most groups did not reach the densities seen before the release (Table A2-9). Diptera rebounded to 310 individuals per square meter, or 35% of previous densities. Ephemeroptera, Plecoptera, and Trichoptera had divergent recoveries. Ephemeroptera recovered to 75% of pre-flood densities, whereas Plecoptera increased to only 19% of pre-flood densities (Table A2-9). In contrast, Trichoptera increased to 182% of pre-flood densities. Coleoptera had a similar response to Ephemeroptera, whereas Acari and Bivalvia densities fell still further in the two months following the release, although both of these groups were relatively uncommon before the release (Table A2-9). Following this two month recovery period, dipteran dominance was 75%, i.e., close to pre-flood levels. These shifts in order-level dominance parallel overall family dominance (Table A2-8).

Chironomid midges dominated the assemblage at the family level throughout all sampling periods despite the dramatic flood losses (Table A2-10). 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 sampling events (Table A2-10). 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 experimental release and were represented entirely by *Serratella micheneri* (Table A2-10). 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 release were observed. Twenty of the 28 families collected during the experiment were at their highest densities before the release (Table A2-10). 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 release, there were some striking increases and decreases. As noted above, there were increases in baetids and simuliids, and polycentropodid and hydroptilid caddisflies were also at their highest levels at this time (Table A2-10). 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 A2-10). Mean California tolerance value (Table A2-6) 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.

Functional feeding groups were also affected by the experimental release. The proportional contribution of collector-gatherers decreased, and all other groups increased, after the release (Table A2-11). The strongest positive responses were demonstrated by predators, collector-filterers, and piercer-herbivores, increasing by a factor of four, six, and ten, respectively, although the before-after contrast was not significant for piercer herbivores due to high variance. By two months after the 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 A2-11).

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. The family and species rank abundance plots (log scale; Figs. A2-9, A2-11) 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 1988, 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 A2-3). 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 A2-2 through A2-4). 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 A2-2) 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°C (mean from our 2007 September and October samples) versus 13.3°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 (2007 Looking Downstream Report) 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 (2007 Looking Downstream report), 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.

Response to Experimental Release

The release had major immediate effects on the ecology of the river, and many of these effects would be generally viewed as positive changes. Total abundance and all order abundances fell, 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 (Wallace 1990, Imbert and Perry 2000, Jakob 2003) and perhaps also due to association with filamentous green algae. Proportions of taxa indicative of lotic system heath 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. 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).

Green algal biomass was greatly reduced, 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).

The food web was clearly modified by the 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). Prior to the 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 (0.37).

Most of the responses to the flood lessened in the months immediately following the release, as has been found in analogous studies (Jakob et al. 2003, Robinson 2003). 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, and we observed increases in Baetidae and Simuliidae as was also observed by Robinson et al. (2003), although we did not observe a 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 release was a highly valuable experiment that provided a first indication of how river health might respond to an intact disturbance regime.

The differences between the Before and After samples were clearly due to the experimental flood, as sampling was done the day before and the day after the release. It is possible that some of the changes that we observed two months after the flood were due to seasonal changes or interactions with seasonal changes. The benthic macroinvertebrate assemblage did show some seasonal trends in 2007-8, although there were not major seasonal effects observed between May and July (Table A2-7; Figs A2-16 through A2-20). The slight increase in black fly (simuliid) abundance during the summer could have contributed to the higher proportion of black flies apparent two months after the release (Fig. A2-16). Similarly, increased family dominance in late summer could have contributed to the apparent increase in dominance two months post-release (Fig. A2-20). Although it seems unlikely that there were major confounding effects due to seasonality, in the absence of a control system such effects cannot be completely dismissed.

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 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).

It is probable that both initial effects of the release and the duration of these effects would be greater in response to a release of longer duration. In general, river health will benefit 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). Yosemite National Park and SFPUC are working together to plan a second controlled release for spring of 2009. The proposed goal is a release of longer duration and with more gradual rising and falling hydrographic limbs. Such a release would provide a much better understanding of invertebrate-flow-habitat relationships, and we would sample such a release using the sampling design that we implemented for the 2008 release. 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 very 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, 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 2005, 2006, 2008, Pierotti et al. 2008). Examining these wetland macroinvertebrate assemblages would be an important addition to the Looking Downstream initiative.

Table A2-1. 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

Table A2-2. Means and standard errors for physical parameters.

Metric	Mean	SE
Water depth (cm)	38.0	4.01
Water temperature (^{o}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

Table A2-3. 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.
8. Bank Stability (Left)	8.71	0.360	**Optimal** Banks stable; evidence of erosion or bank failure absent or minimal; little potential for future problems. <5% of bank affected.
(Right)	9.14	0.404	
9. Vegetative Protection (Left)	8.43	0.429	**Optimal** More than 90% of the streambank surfaces and immediate riparian zone covered by native 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.
(Right)	8.71	0.421	
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 A2-4. 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

Table A2-5. 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^oFFG**	**2^oFFG**	**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 A2-5, 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				
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
Zapada cinctipes	1.69	1.69	0.125	sh		2
Unknown	0.375	0.375	0.125	sh	cg	2
	Abundance		**Frequency**	**1^oFFG**	**2^oFFG**	**CTV**
	Mean	SE				
Plecoptera, cont.						
Perlidae	8.38	3.74	0.875			
Claassenia sabulosa	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

Table A2-5, 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.

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
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

	Abundance		**Frequency**	**1^oFFG**	**2^oFFG**	**CTV**
	Mean	SE				
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
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

Table A5, 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				
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
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
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

Table A2-5, 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).

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
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

	Abundance		**Frequency**	**1°FFG**	**2°FFG**	**CTV**
	Mean	SE				
Mollusca, Bivalvia						
Veneroida0.875	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 A2-6. 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

Table A2-7. 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

Table A2-8. Response of mean (SE) macroinvertebrate assemblage-level variables and algal biomass to experimental release (all per-square-meter). %EPT= percent Ephemeroptera + Plecoptera + Trichoptera. The ANOVA column contains p-values for 1x3 repeated measures ANOVAs. The three columns representing the three possible multiple comparisons contain p-values resulting from one-tailed t-tests. Asterisks represent significance at two different error rates: * represents p< 0.05 at the per contrast error rate; ** represents p< 0.05 after correction to family-wise error rate via the sequential Bonferroni inequality.

	Before		**After**		**2 mo after**		**ANOVA**	**Before-After**	**After-2 mo after**	**Before-2 mo after**
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE				
Total Individuals	1086	287	112	34	415	123	0.0037	0.0036**	0.038**	0.024**
Family Richness	16.3	0.494	13.2	1.68	12.7	1.33	0.063	0.064	0.33	0.031*
Margalef's Corrected Family Richness	2.25	0.0584	2.74	0.169	2.051	0.269	0.015	0.0036**	0.0090**	0.15
Species Richness	42.8	2.48	22.7	3.22	29.0	3.11	0.0036	0.0042**	0.069	0.016**
Margalef's Corrected Species Richness	6.13	0.258	4.83	0.316	4.86	0.483	0.033	0.0033**	0.44	0.030*
% Family Dominance	77.6	3.61	47.8	5.51	61.1	8.00	0.018	0.0025**	0.14	0.045*
% EPT	20.5	3.35	44.3	5.52	32.7	6.72	0.018	0.0013**	0.11	0.075
Hilsenhoff's Biotic index	5.47	0.0876	4.97	0.287	5.49	0.149	0.098	0.055	0.077	0.48
Algal Biomass (gdm)	9.00	1.99	1.91	0.590	4.46	0.561	0.00029	0.0011**	0.00085**	0.035**

Table A2-9. Response of mean (SE) macroinvertebrate order densities per meter square to experimental release. The ANOVA column contains p-values for 1x3 repeated measures ANOVAs. The three columns representing the three possible multiple comparisons contain p-values resulting from one-tailed t-tests. Asterisks represent significance at two different error rates: * represents p< 0.05 at the per contrast error rate; ** represents p< 0.05 after correction to family-wise error rate via the sequential Bonferroni inequality.

	Before		**After**		**2 mo after**		**ANOVA**	**Before-After**	**After-2 mo after**	**Before-2 mo after**
	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**				
Ephemeroptera	90.8	14.6	25.2	7.76	67.7	17.1	0.0063	0.0087**	0.021**	0.11
Plecoptera	86.2	25.9	15.7	5.48	16.8	4.62	0.012	0.017*	0.18	0.028*
Trichoptera	10.0	2.31	8.00	2.35	18.2	5.96	0.13	0.22	0.066	0.058
Coleoptera	2.83	1.014	0.833	0.401	2.17	0.703	0.11	0.023*	0.045*	0.37
Diptera	892	260	61.0	21.2	310	112	0.0028	0.0022**	0.038**	0.025**
Acari	2.17	1.078	0.833	0.477	0.167	0.167	0.19	0.20	0.15	0.053
Veneroidea (Bivalvia)	2.00	1.18	0.833	0.833	0.667	0.422	0.34	0.079	0.39	0.19

Table A2-10. Response of mean (SE) macroinvertebrate densities per meter square to 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
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

Table A2-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to experimental release.

	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
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
Claassenia sabulosa	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
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 A2-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 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 A2-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 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 A2-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to 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
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
	Before		**After**		**2 months after**	
	Mean	SE	Mean	SE	Mean	SE
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

Table A2-10 (cont.). Response of mean (SE) macroinvertebrate densities per meter square to experimental release.

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 A2-11. Response of functional feeding groups to experimental release. The ANOVA column contains p-values for 1x3 repeated measures ANOVAs. The three columns representing the three possible multiple comparisons contain p-values resulting from one-tailed t-tests. Asterisks represent significance at two different error rates: * represents p< 0.05 at the per contrast error rate; ** represents p< 0.05 after correction to family-level error rate via the sequential Bonferroni inequality.

	Before		**After**		**2 mo after**		**ANOVA**	**Before-After**	**After-2 mo after**	**Before-2 mo after**
	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**				
% Scrapers	1.90	0.640	2.54	0.946	0.546	0.182	0.061	0.26	0.039*	0.036*
% Predators	2.96	0.596	12.1	3.66	3.67	1.11	0.0061	0.011**	0.015**	0.29
% Collector-Gatherers	86.8	1.48	65.5	5.49	82.1	4.72	0.026	0.010**	0.061	0.16
% Shredders	7.57	1.09	11.1	2.73	5.86	1.89	0.057	0.081	0.023*	0.13
% Collector-Filterers	0.670	0.193	4.48	1.74	4.77	1.69	0.11	0.037*	0.47	0.017*
%Piercer-Herbivores	0.354	0.155	3.61	2.39	3.28	1.31	0.21	0.076	0.44	0.041*

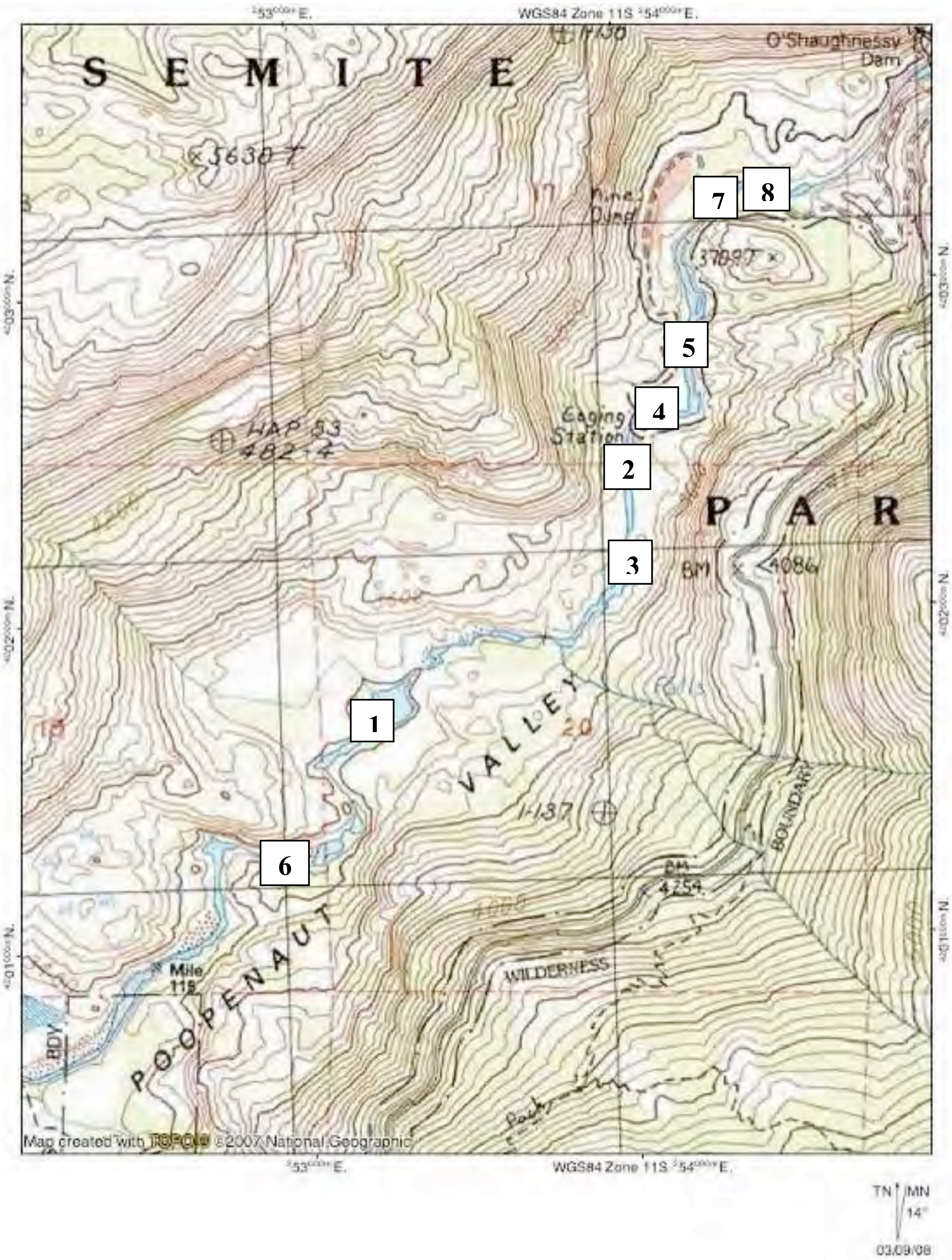

Figure A2-1. Location of benthic macroinvertebrate sampling sites.

Figure A2-2. Sites 1 (top) and 2 (bottom).

Figure A2-3. Sites 3 (top) and 4 (bottom).

Figure A2-4. Sites 5 (top) and 6 (bottom).

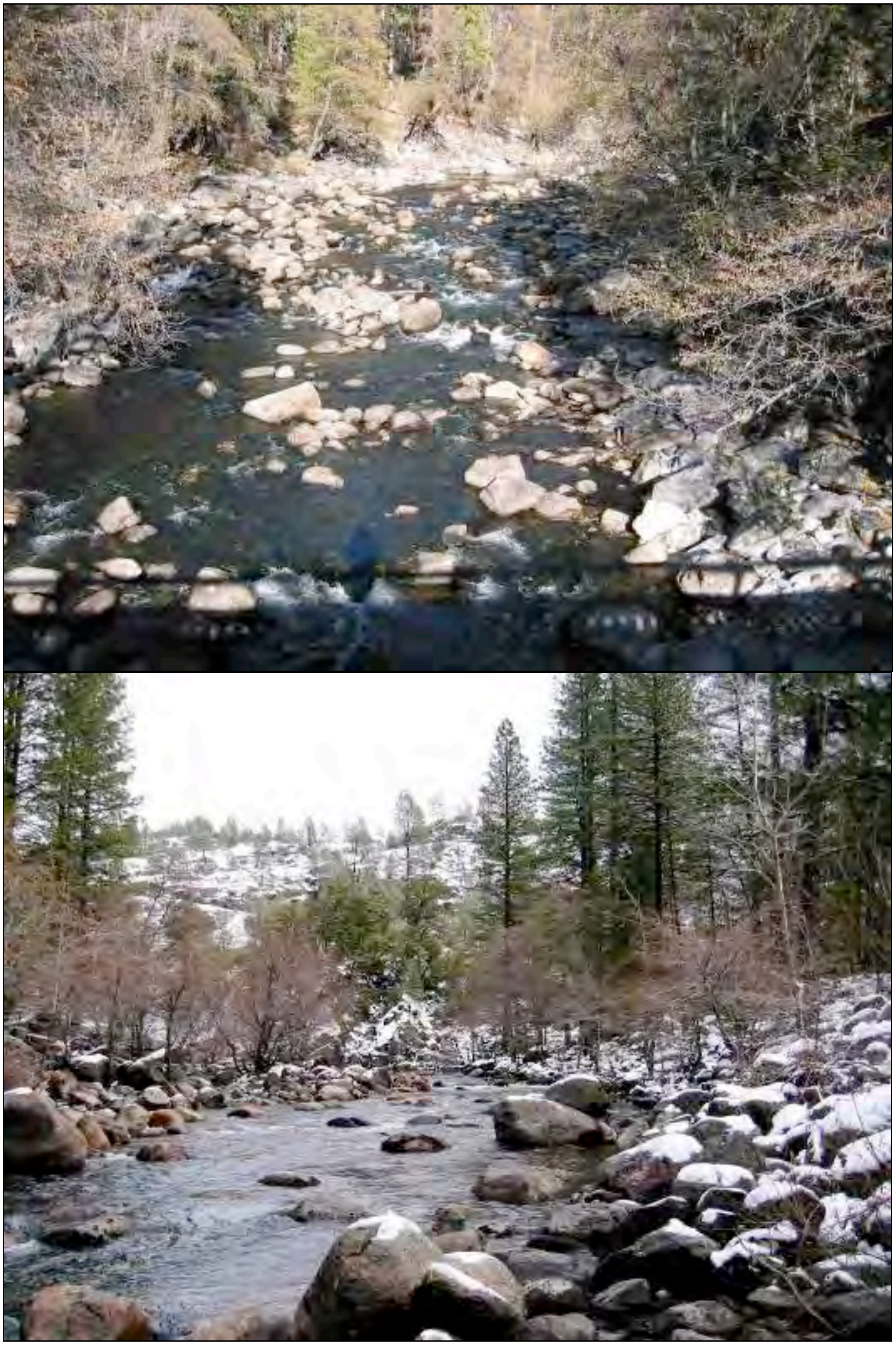

Figure A2-5. Sites 7 (top) and 8 (bottom).

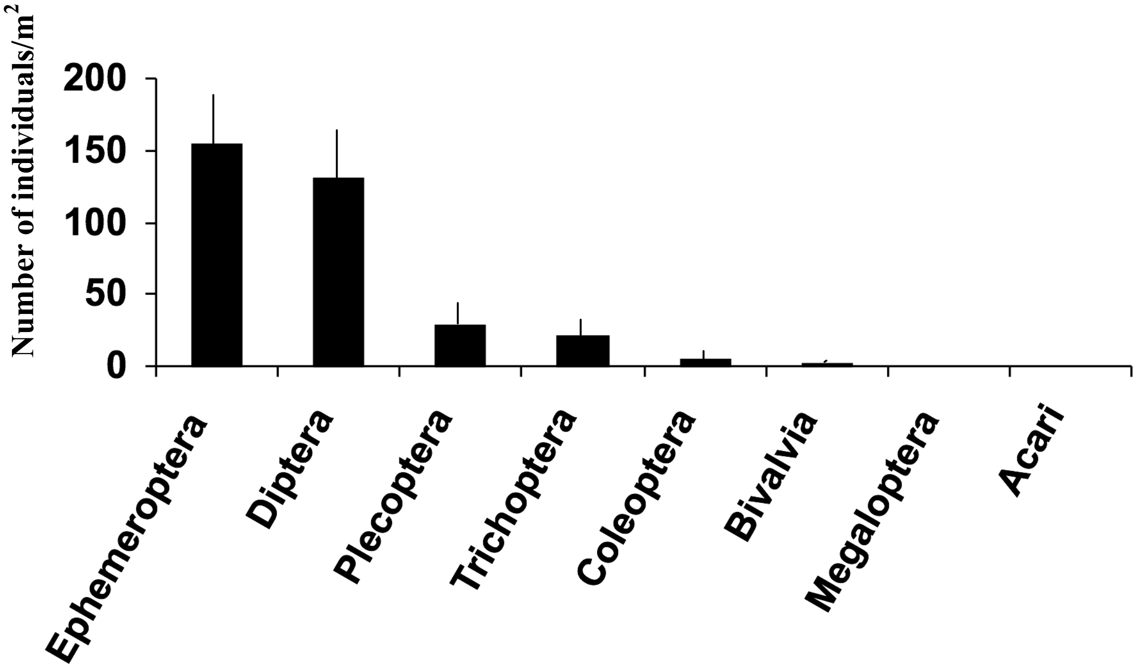

Figure A2-6. Rank-abundance by order, plus Class Bivalvia (linear scale).

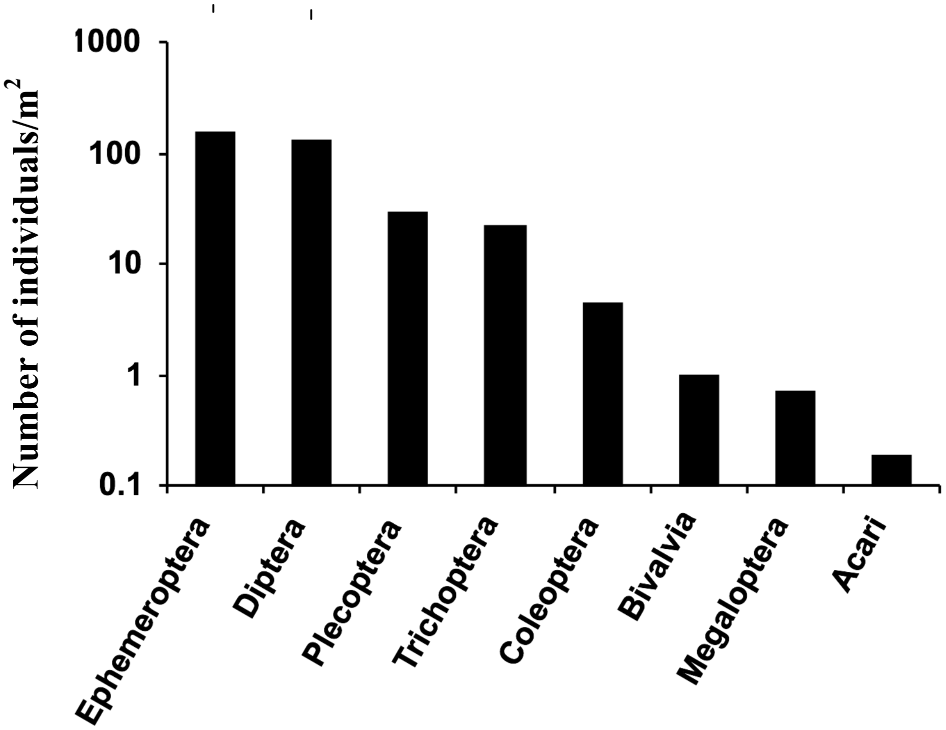

Figure A2-7. Rank-abundance by order, plus Class Bivalvia (log scale).

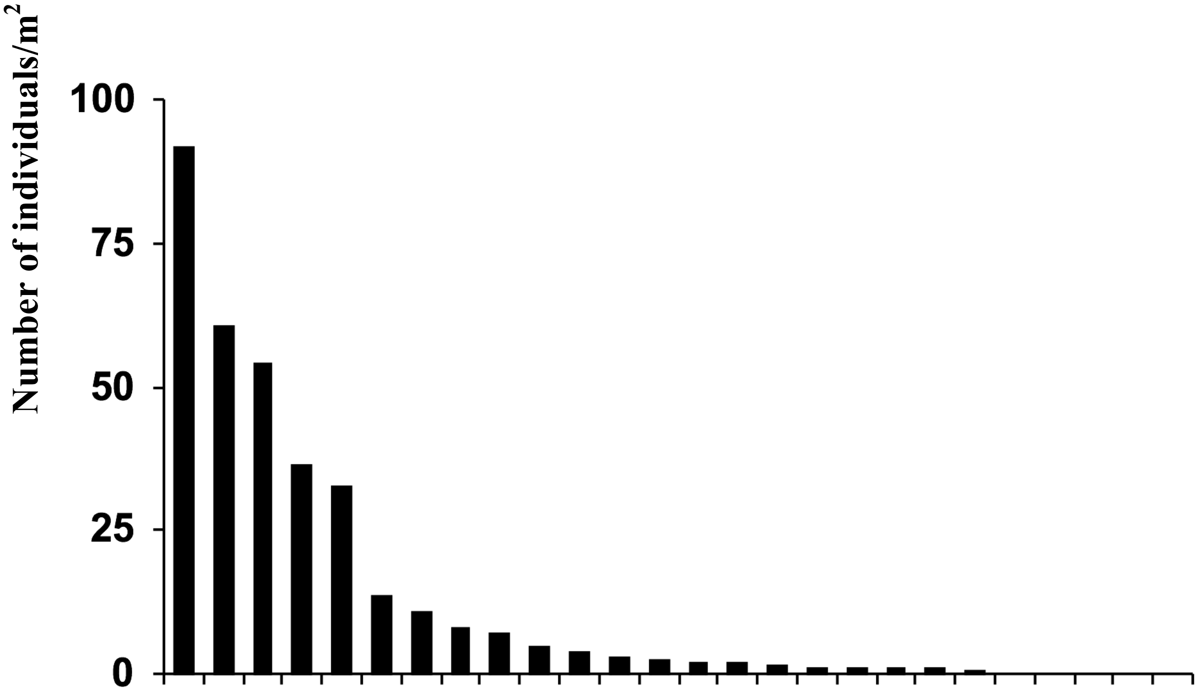

Figure A2-8. Rank-abundance by family (linear scale).

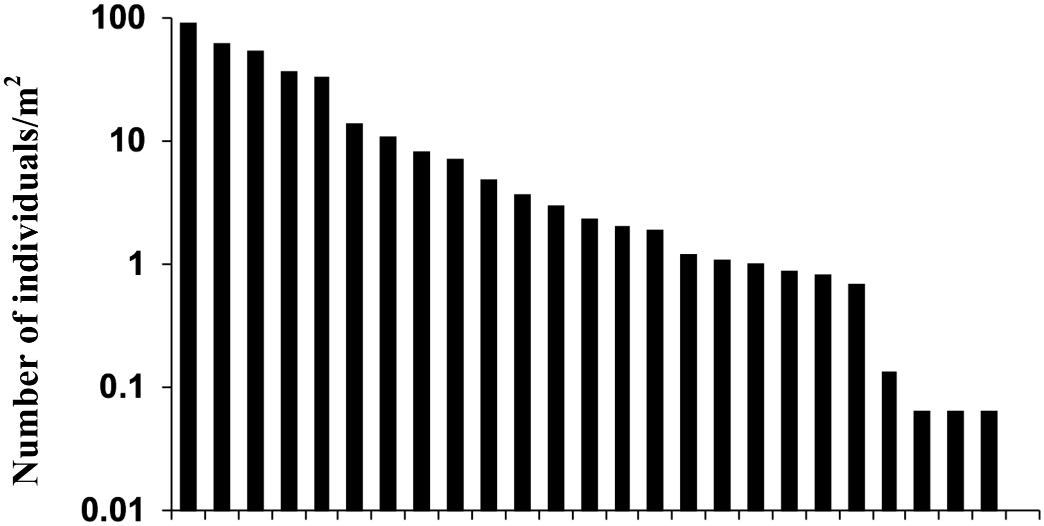

Figure A2-9. Rank-abundance by family (log scale).

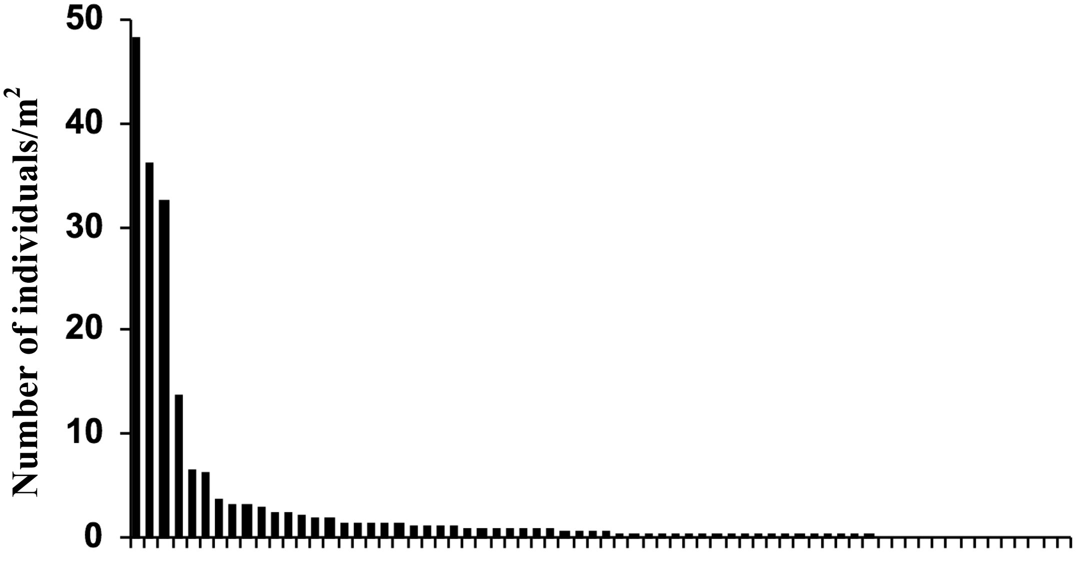

Figure A2-10. Rank-abundance at the species level (linear scale).

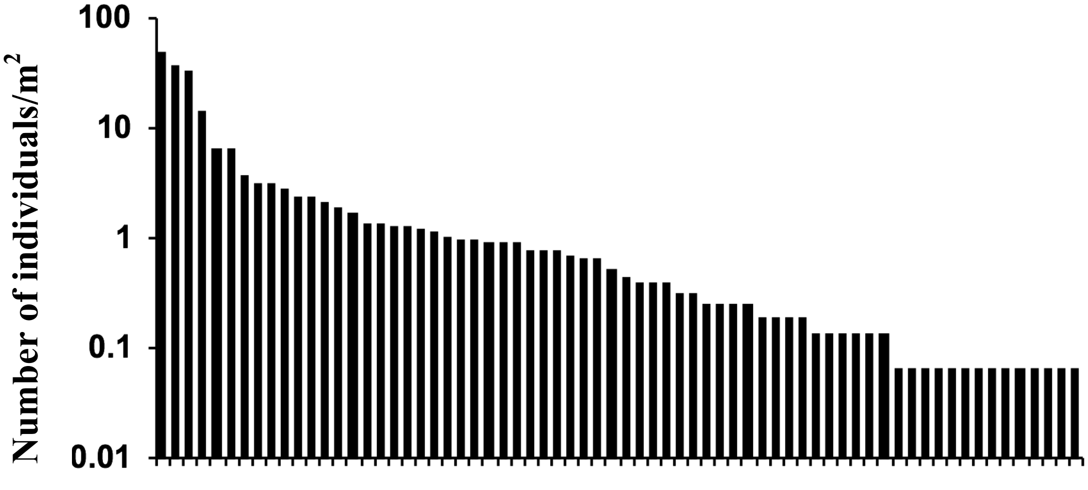

Figure A2-11. Rank-abundance at the species level (log scale).

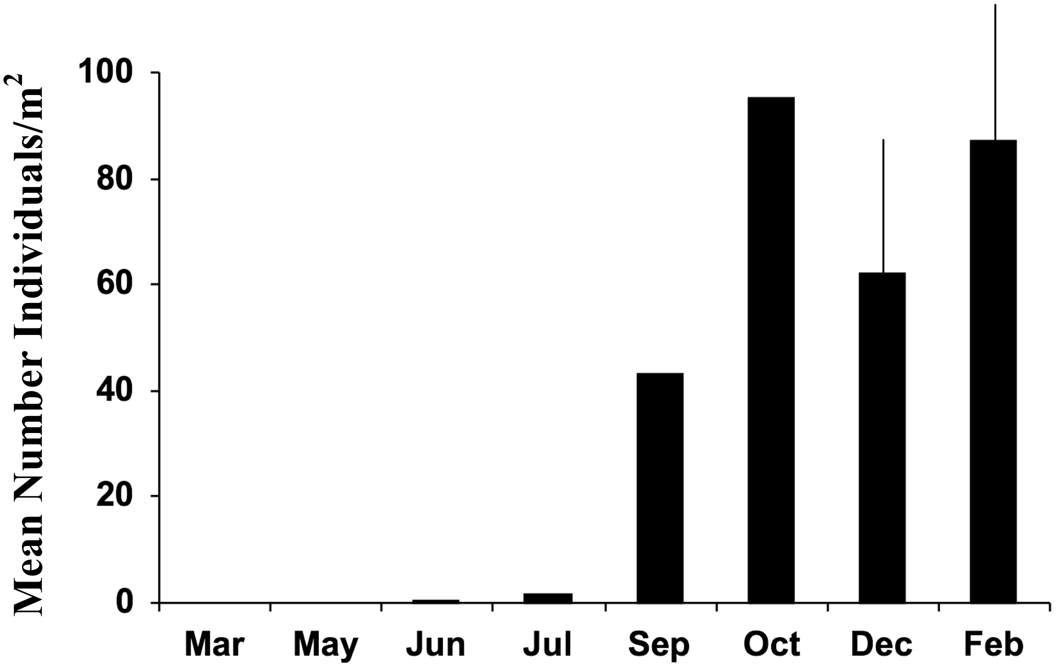

Figure A2-12. *Simulium* (black flies; Diptera: Simuliidae) densities during study year.

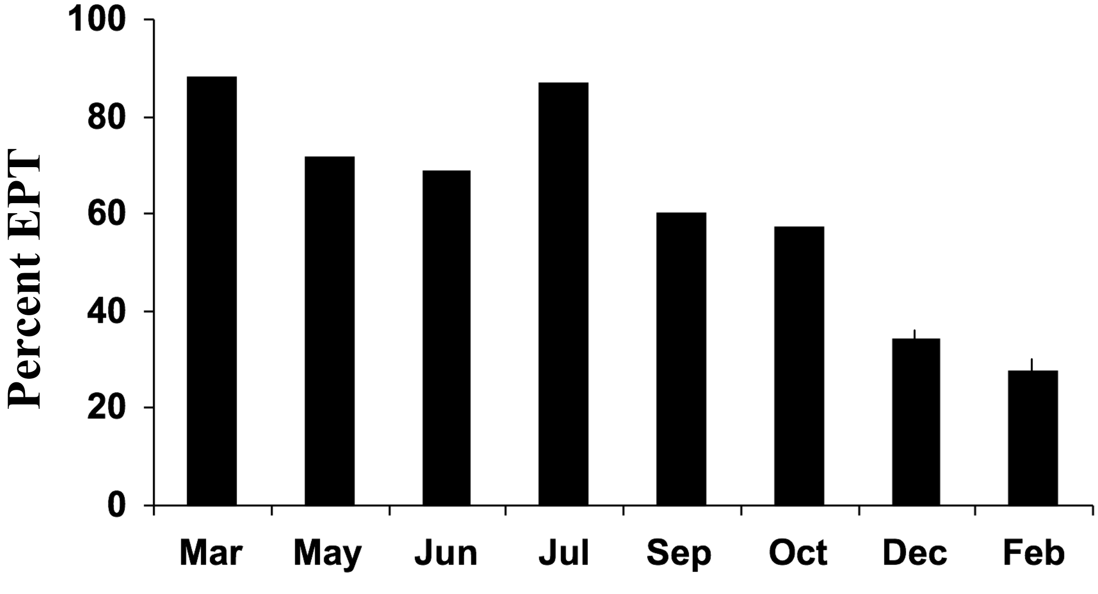

Figure A2-13. Percent Ephemeroptera-Plecoptera-Trichoptera during study year.

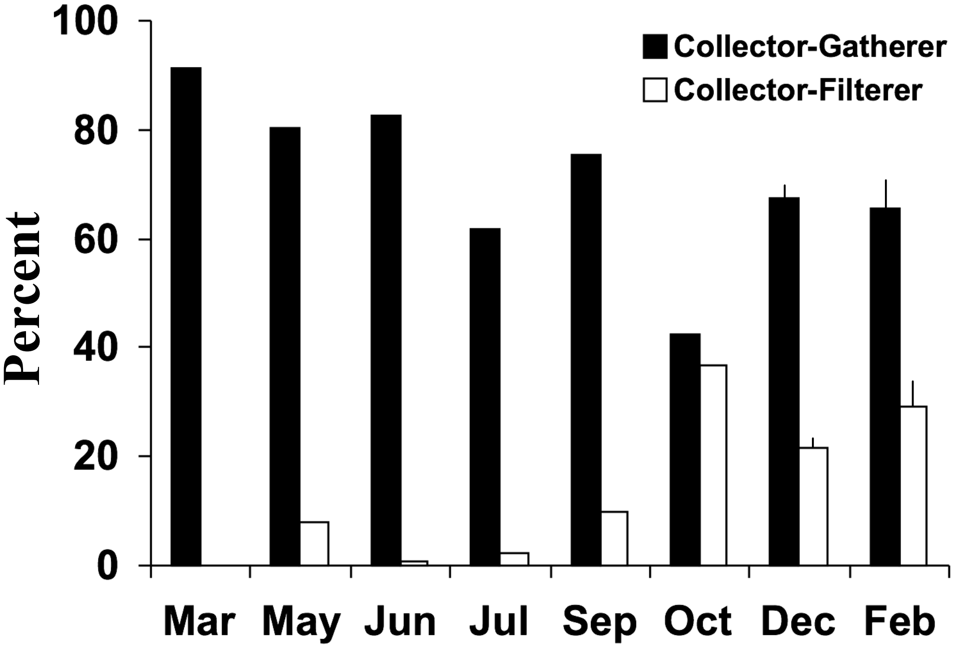

Figure A2-14. Percent Collector-Gatherers and Collector-Filterers during study year.

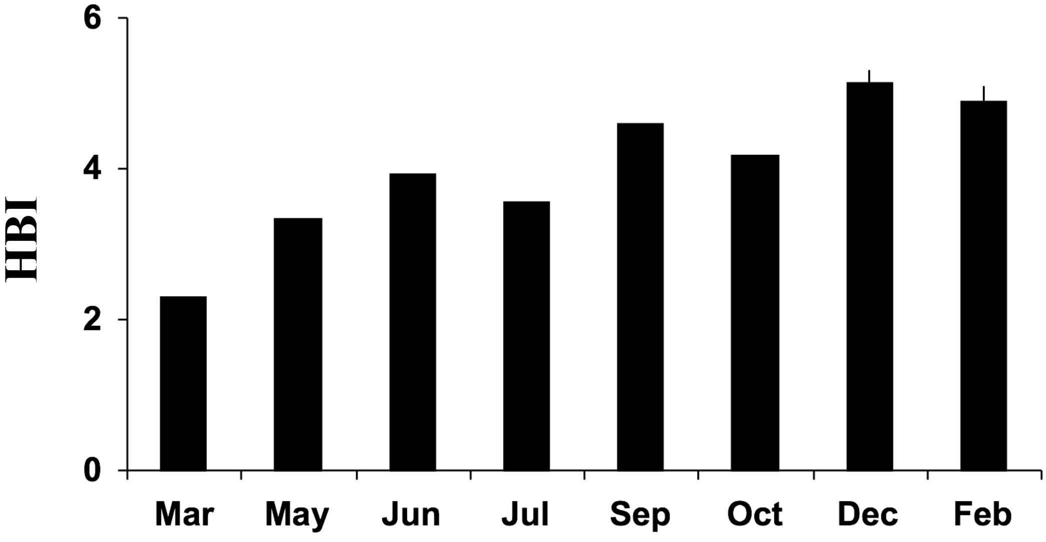

Figure A2-15. Hilsenhoff Biotic Index during study year.

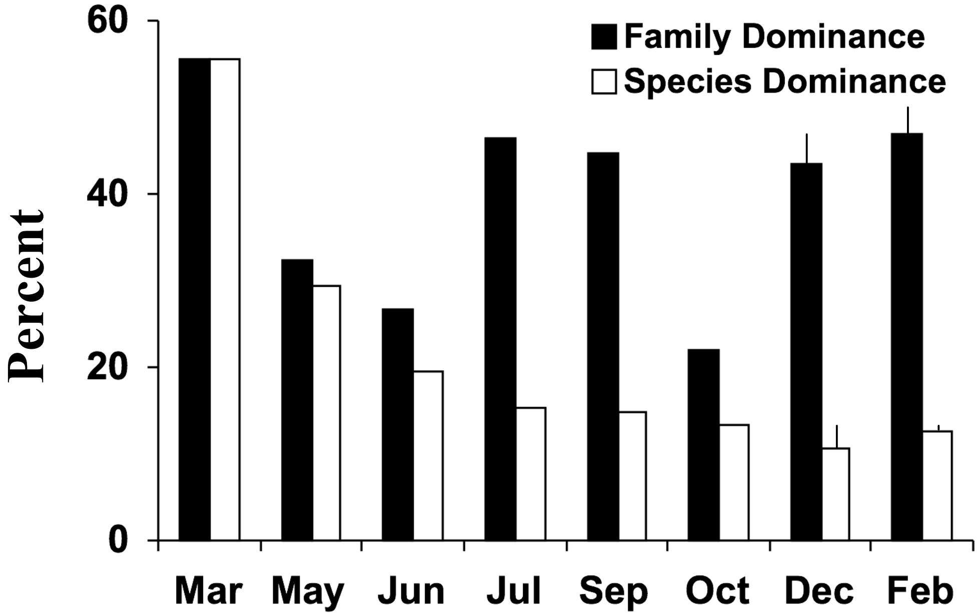

Figure A2-16. Percent Family and Species Dominance during study year.

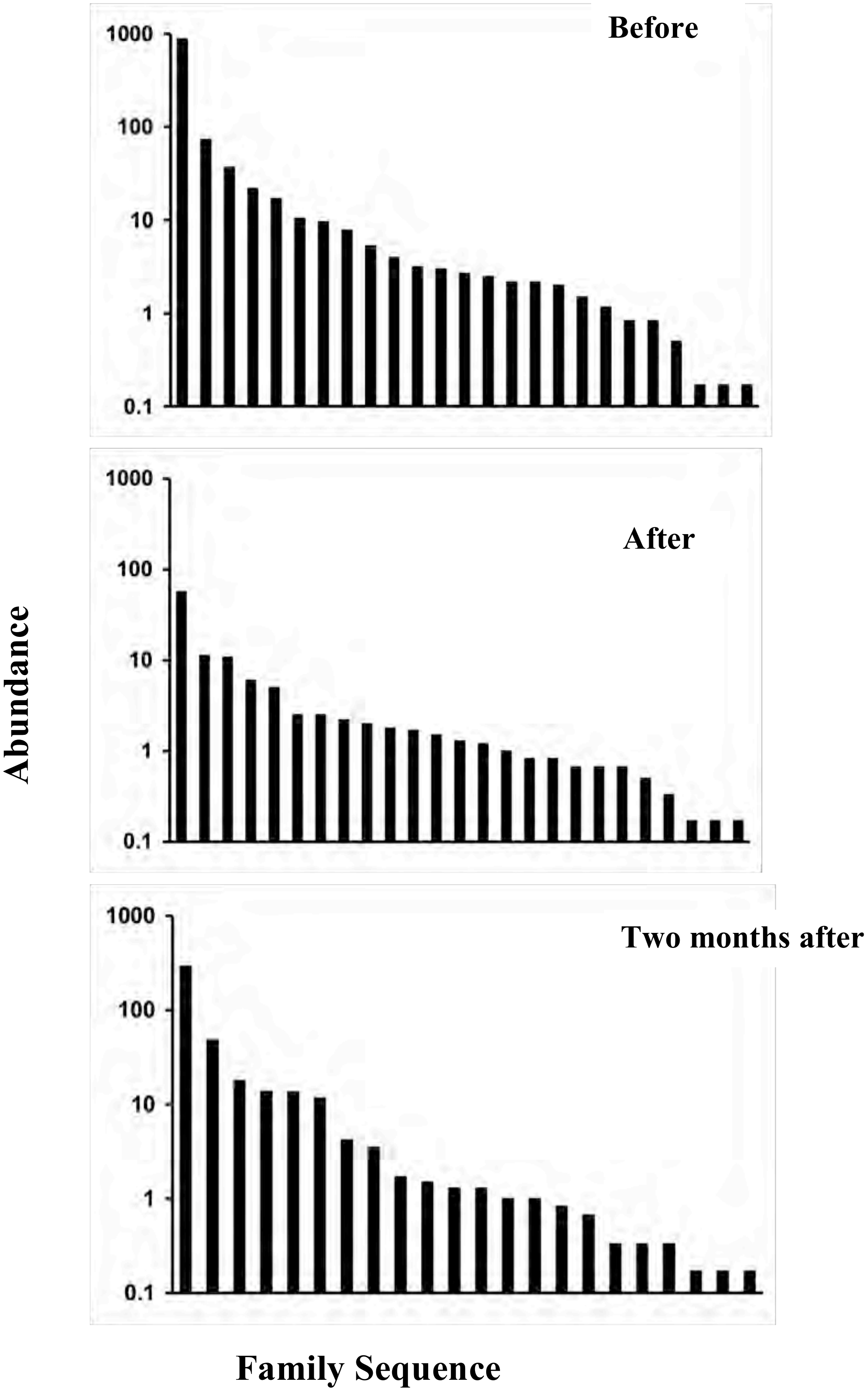

Figure A2-17. Rank-abundance by sampling event at the family level (log scale).

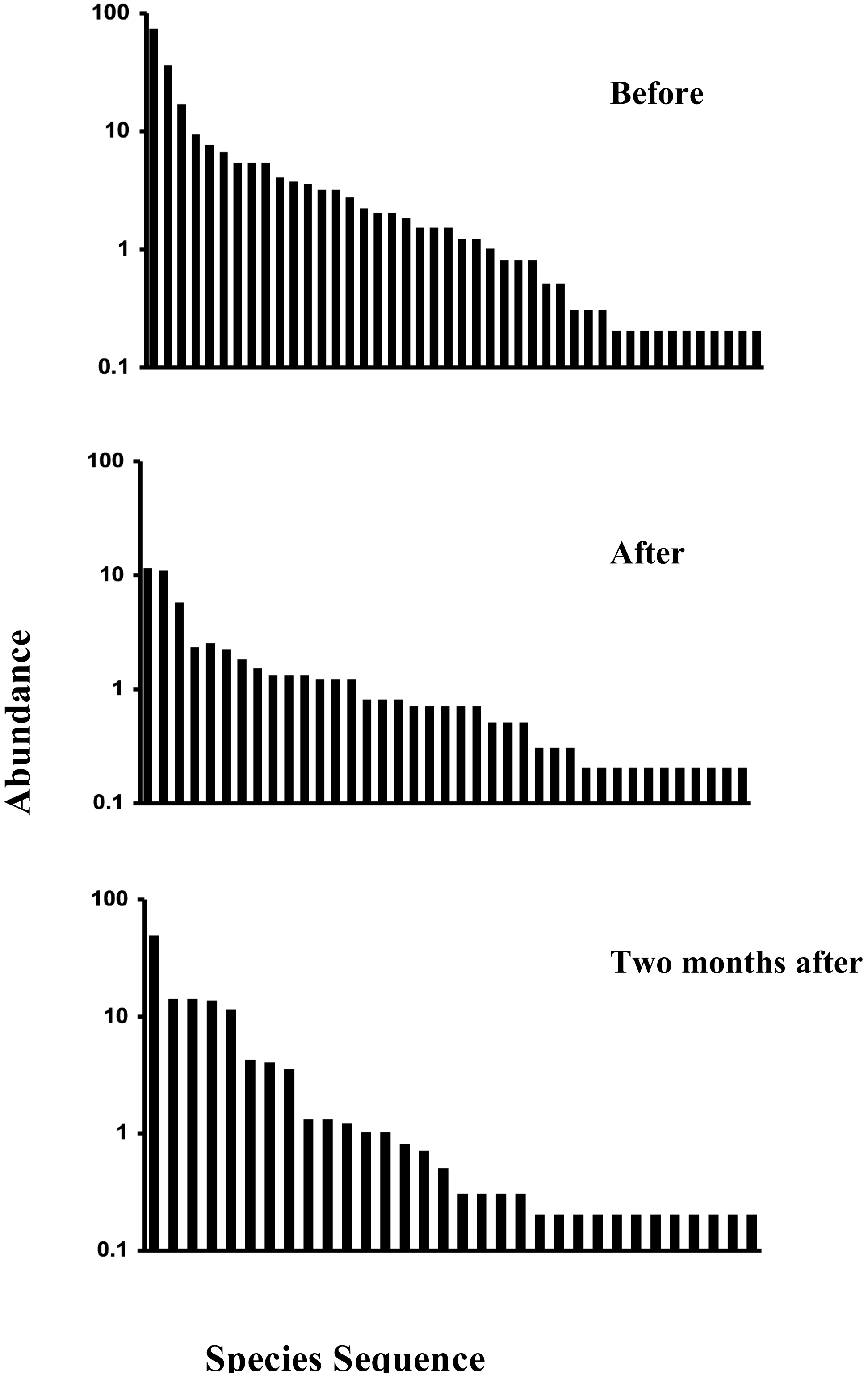

Figure A2-18. Rank-abundance by sampling event at the species level (log scale).