

Establishing Reference Conditions for Streams and Measuring Ecological Responses to Management Actions Using Aquatic Invertebrate Biological Assessments¹

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The Sierra Nevada Ecosystem Project provided the first comprehensive status report on the condition and history of natural resources of this mountain region (Centers for Water and Wildland Resources 1996). The report concluded that aquatic habitats were the most altered and impaired ecosystems, after exposure of Sierra watersheds to 150 years of landscape changes resulting from activities such as hydraulic mining, damming and diversions of streams, road building, livestock overgrazing, timber harvest, hard-rock mining, and introductions of exotic species. Continued assessment of watershed conditions is needed to identify problem areas, follow trends, establish standards, and document the effectiveness of restoration actions. Among the most promising biological tools for such monitoring needs is the use of aquatic insects as indicators of habitat and water quality. Watersheds provide an organizing unit for defining local and cumulative effects of landscape alterations and for planning management and conservation. This paper provides an outline of the use of aquatic invertebrate monitoring in guiding watershed management.

A summary of aquatic invertebrate status in the SNEP report (Erman 1996) found that the invertebrate fauna was known primarily from geographically localized studies, special habitats, or taxonomically limited surveys of particular faunal groups (such as stoneflies). In addition, the inventory of the known aquatic insects from the Sierra Nevada showed a high proportion of endemics, including such groups as stoneflies (25 percent) and caddisflies (19 percent), whereas most other groups had received only limited survey attention.

The SNEP report also classified the aquatic environments of the Sierra Nevada (Moyle 1996a), scored the biological health of watersheds (Moyle and Randall 1996), and presented a strategy for conservation of aquatic biodiversity (Moyle 1996b). Some 66 aquatic habitat types were identified in the Sierra Nevada, including standing and flowing waters in west-slope and east-slope geographic provinces. Declines in aquatic biodiversity were documented using data that indicate decreasing range, abundance, or even extinction of more than half the 70 species of native amphibians and fish. These declines were attributed to the loss and impairment of habitat, especially lowland habitats, such as terminal lakes and desert springs, and along many impounded streams at lower elevations. The number and proportion of native aquatic vertebrates and absence of dams, reservoirs, and roads were used to measure biotic integrity of watersheds, rank watershed health, and identify aquatic diversity management areas (ADMAs) for conservation.

The SNEP aquatic status reports indicated the need for invertebrate biological monitoring and inventory data to improve assessment of resource conditions, define ecological health,

¹ This paper was presented at the Sierra Nevada Science Symposium, October 7–10, 2002, Kings Beach, California.

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document habitat stressors and disturbance sources, and develop guidance for conserving native biodiversity (as in ADMAs). The need for bioassessment monitoring should be placed ahead of taxonomic inventory because the data generated are more useful in defining ecological integrity of habitats to provide a foundation for informing resource management decisions and feedback to adaptive management programs.

Principle of Bioassessment

Aquatic insects and other invertebrates are central to the function of stream ecosystems, consuming organic matter (wood and leaf debris) and algae and providing food to higher trophic levels (fish and riparian birds). These organisms also have varying degrees of pollution tolerance and so may be used as indicators of water quality and habitat conditions. For example, distinctive shifts in the structure and function of the aquatic invertebrate community can often be detected above and below a pollution source. Use of the stream invertebrate fauna in evaluating stream ecosystem health is known as bioassessment. This technique uses collections of the benthos (bottom-dwelling fauna) to evaluate the relative abundance of different taxa, feeding guilds, pollution indicators, and diversity to develop a quantitative basis for measuring ecological attributes of the stream. Monitoring relative to reference sites (having little or no impact but similar physical setting) or over time within subject sites, or both, then permits impact problems or recovery to be quantified (Davis and Simon 1995, Rosenberg and Resh 1993). Aquatic invertebrate bioassessment has also become an important means for defining biological integrity of natural waters as required for implementation of the Clean Water Act (Karr and Chu 1999).

Components of Bioassessment Monitoring as Guidance in Water Quality Management

- An ambient monitoring network involving surveys conducted over a range of stream types and sizes (using probabilistic and targeted selection)
 1. Intensive—repeated annual sampling at established sites to measure interannual temporal variability
 2. Extensive—an expanding network of study reaches to measure spatial geographic variability
- Reference monitoring—selective sampling of least-disturbed stream sites as the foundation for developing biological standards or biocriteria
- Targeted monitoring—conducted at sites of concern for purposes of stressor identification, examination of metric response patterns, tracking of restoration, feedback for adaptive management, and appraisal of 303 (d) listed streams
 1. Using disturbance/stressor gradients to study dose-response relationships between stream benthic community structure and different impact sources (for example, livestock grazing, sediment, acid mine drainage); set Total Maximum Daily Load (TMDL) targets
 2. Documenting ‘before-after’ case histories for restoration (by setting preproject baselines and follow-up with subsequent effectiveness monitoring)
 3. For listing or de-listing of 303 (d) impaired water bodies

Since the time of the SNEP report, about 600 stream bioassessment surveys have been conducted in the Sierra Nevada for a variety of purposes, providing a foundation of data on benthic invertebrate community structure. (*Tables 1 and 2 summarize the source, location, and type of information collected.*) These programs represent a geographic mix of localized

and dispersed sampling (intensive and extensive) that have used varied methodologies for collection and analysis but provide a starting point for comparing stream biotic integrity, taxa distribution lists, and ecological impacts across the Sierra Nevada.

Table 1— *Summary of recent and ongoing Sierra Nevada research and monitoring programs involving studies of stream invertebrates¹*

Organization and persons involved in collecting information	Type of information collected	Period of data collection	Location (s) of data collection
Larry Brown and Terry Short—USGS with NPS support	River restoration monitoring using algae and aquatic invertebrates	1993–1996	Merced River and Tenaya Creek, 13 sites Yosemite Valley
James Carter—USGS	Distribution of benthic invertebrates, water residence time, riffle-pool habitat and gradient	1990–1994	Merced River Yosemite Valley 8 stream sites
Jason May—USGS	Algae and invertebrate biomonitoring for NAWQA program	1996–1998	Upper Sacramento River basin; 10 streams in Sierra Nevada foothills
Joseph Furnish, U.S. Forest Service, and Charles Hawkins, Utah State University	Bioassessment for evaluations of biological integrity and condition of National Forest streams	2000–ongoing	Est. 155 stream sites throughout 10 National Forests of the Sierra Nevada
Ian Chan—UC Davis	Prescribed fire effects on headwater stream invertebrate communities	1995–1997 before/after	Mineral King Sequoia Natl. Park five 1° to 2° streams
Rosalie Leech and Vince Resh—UC Berkeley	Organic enrichment effects on streams by livestock	1998–1999	Blodgett Forest Amador County, 4 sites
Leah Rodgers and Vince Resh—UC Berkeley	Prescribed fire effects on stream ecosystem structure and function	1995–2004 before/	Blodgett Forest, Amador County 7 streams, 9 sites
Peter Cranston—UC Davis and Harold Werner —Sequoia National Park	Inventory of aquatic chironomidae from streams	2001–2002	Sequoia National Park; Kaweah R.-5 tributaries in <i>Sequoia</i> groves
Dorothea Panayotou, UC Davis TRG, CA Tahoe Conservancy	Bioassessment contrasts of stream restoration projects in Lake Tahoe watershed	2000–2002	Lake Tahoe basin primarily south and west 10–20 tributaries
Danny Boiano—Sequoia National Park, with Jean Krejca, Joel Despain	Cave invertebrate inventory (including aquatic fauna)	2003–2005	15 caves in Sequoia -Kings Canyon NP, and 1 in Yosemite NP
Jim Harrington and Pete Ode—California Dept Fish Game Aquatic Bioassessment Laboratory	Bioassessment monitoring of ambient water quality and spills pollution	1995–ongoing	80–100 stream sites —most in northern Sierra including references in upper Sacramento River
		Sum:	Est. 300 stream sites sampled to date, excluding repeated sites

¹Excluding volunteer and citizen group monitoring programs and research studies occurring more than 10 years ago (most summarized in Erman, SNEP report).

Table 2— Summary of recent and ongoing Sierra Nevada research and monitoring programs involving studies of stream invertebrates¹ (UC-Sierra Nevada Aquatic Research Lab, SNARL)

Organization and persons involved in collecting information	Type of information collected	Period of data collection	Location (s) of data collection
David Herbst and Roland Knapp—UC-SNARL	Seasonal / annual changes in stream habitat, fish, and invertebrates exposed to livestock grazing	1993–1996	Long Valley drainages of the east slope Upper Owens River 9 repeated sites
David Herbst, UC-SNARL with EPA support	Cumulative effects of livestock grazing on stream invertebrate community structure and function	1996–1998	Eastern Sierra from Upper Owens to Carson River watersheds 85 stream sites
David Herbst, UC-SNARL; Tom Suk, Lahontan Regional Water Quality Control Board	Bioassessment of impacts and recovery related to acid mine drainage	1995–ongoing	Leviathan Mine—tributaries to the East Carson River 16 stream sites
David Herbst, UC-SNARL; Tom Suk, Lahontan RWQCB; B. Emery, UC Santa Cruz	Baseline bioassessment monitoring for livestock grazing management	1999–2002 before/during	West Walker River and tributaries (9 treatment, 9 matched control sites)
David Herbst, UC-SNARL; Tom Suk, Lahontan RWQCB and TRPA	Baseline bioassessment for river restoration and sediment control	1998–2000 before/after	Upper Truckee River Lake Tahoe basin 8 sites on main stem
David Herbst, UC-SNARL City of S. Lake Tahoe	Bioassessment monitoring of channel restoration	1999–ongoing before/after	Trout Creek—3 sites South Lake Tahoe
David Herbst, UC-SNARL US Forest Service	Bioassessment monitoring of channel restoration	1999–ongoing before/after	Bagley Valley Creek (project and 3 controls)
David Herbst, UC-SNARL Tom Suk, Lahontan Regional Water Quality Control Board	Regional reference and test or index site bio-assessment sampling for biocriteria development in ambient water quality monitoring	1999–ongoing	Eastern Sierra basins: Upper Owens, Mono basin, E. Walker, W. Walker, E. Carson, W. Carson, Tahoe basin, Lower Truckee River 55 stream sites to date
David Herbst, UC-SNARL Cadie Olsen, Lahontan RWQCB	Biological water quality targets for sediment TMDL	2000–2001	Squaw Creek and Lower Truckee River 23 stream sites
David Herbst, UC-SNARL Scott Cooper and Erik Silldorff, UC Santa Barbara	Effect of introduced trout on stream community structure / function using paired watershed contrasts	2000–2002	Yosemite National Park 44 streams in Merced and Tuolumne drainages
Scott Cooper, UC Santa Barbara; David Herbst, UC-SNARL; Carolyn Hunsaker, PSW-USFS	Influence of prescribed fire and timber harvest practices on stream invertebrate communities	1999–ongoing before/after	Kings River Experimental Watershed 16 headwater streams in Sierra National Forest
		Sum:	Herbst, UC-SNARL and associates: >275 stream reaches sampled to date excluding repeated sites
David Herbst, UC-SNARL, Don Sada, UNR-Desert Research Institute	Spring invertebrate community analysis in relation to environmental disturbance, habitat type	1996–2000	More than 100 spring sources and spring-brooks surveyed in Lahontan and Owens Valley Basins

Using reference sites to define standards is an essential requirement for evaluating the impairment of streams. The choice of reference stream sites has been typically left to subjective judgments and qualitative screening of what appears to be the “best” streams. To

minimize errors in determining impairment and defend the use of streams as references, there is a need for a more objective selection procedure that rates streams using quantitative criteria to identify which streams are least disturbed. A protocol for reference selection is under development (D. Herbst and P. Ode), comprised of the following steps:

1. Define the geographic region and stream classes to be evaluated.
2. Identify, quantify, and score disturbance and stressors using Geographical Information System (GIS) tools. (This step is presently limited by poor spatial resolution in CalWater watershed planning areas, lack of correspondence of these units to hydrographic watershed boundaries, and incomplete coverage of land use and disturbance available in GIS formats.)
3. Examine frequency distribution of candidate stream scores and select least disturbed as references, using statistical criteria to set acceptance levels.
4. Ground truth reference sites for conformity to optimum quality of sample reach-level habitat (riparian, bank, substrate conditions). Also include test or index sites, selected from stream reaches with known histories of exposure to pollution or habitat degradation.

Applications of Bioassessment and Preliminary Results

As an example of biomonitoring programs under way in the Sierra Nevada, the Lahontan Regional Water Quality Control Board (T. Suk, program manager) and the Sierra Nevada Aquatic Research Laboratory (D. Herbst, principal investigator) have established intensive and extensive stream surveys in the eastern Sierra Nevada that cover the following watersheds: Upper Owens, Mono Basin, East Walker, West Walker, East Carson, West Carson, Tahoe Basin, Lower Truckee River, and Little Truckee River. This includes first- to fourth-order streams with mainly less than 4 percent gradients, from 5,000 to 10,000 feet elevation, and with more than 275 reaches sampled to date (about half as references). Targeted studies among these include:

- Disturbance stressors/gradients to: (a) set sediment TMDL targets, (b) examine the influence of exotic trout in fishless high Sierra Nevada streams, (c) study cumulative effects of livestock grazing, and (d) study prescribed fire and logging regimes in the Kings River Experimental Watershed [some of these as gradient or dose-response designs, some as replicated BACI, some as paired contrasts with/without stressor]
- Case histories developed from planned management and involving before/after sampling and trend analyses: (a) livestock grazing management (West Walker River and Bridgeport Valley); (b) acid mine drainage impairment and restoration (Leviathan mine Superfund site); (c) reconstruction of channelized, dredged, or eroded stream drainages (Trout Creek, Bagley Valley Creek, Upper Truckee baseline)

Another advantage of an intensive and extensive monitoring network is that it permits anticipation of the unexpected. For example, preexisting data have provided the basis for developing case histories for (1) effects of the 1997 New Year flood event, using many previously sampled east-slope streams; (2) effects of severe wildfire (Mill Creek, near Walker); and (3) invasion of the upper Owens River by the exotic New Zealand mud snail and subsequent ecological changes. Continued monitoring of these streams will allow assessment of the biological impacts and potential recovery over time.

Bioassessment studies along gradients of exposure to habitat disturbance and pollution have provided useful data for establishing the extent of impacts and setting recovery targets. For example, using sediment load predicted from an Agricultural Non-Point Source pollution

model (AGNPS), reference watersheds were selected to define the biological recovery target for a sediment TMDL (Herbst 2002a). The references had reduced levels of sediment load and higher biological integrity measures than the TMDL drainage. This approach provided goals for both the amount of sediment reduction needed and the biological status that would indicate recovery.

Cumulative effects of livestock grazing were studied by conducting surveys in streams exhibiting varied levels of grazing-related habitat degradation (bank erosion, sedimentation, and riparian loss). Measures of sediment deposition showed that this variable alone was associated with reduced abundance of the sensitive mayfly, stonefly, and caddisfly groups (EPT taxa). Where cover of fines and sand on the stream bottom was below 25 percent, all stream communities sampled comprised more than 50 percent EPT; where cover of fines and sand exceeded 25 percent, fewer than half of the streams had more than 50 percent EPT (*fig. 1*). Other eastern Sierra Nevada studies have shown that rangeland streams with the most severely degraded habitats have poor biological integrity and exhibit little seasonal change, and streams with less habitat degradation may either maintain healthy stream communities or suffer loss of biological integrity only during grazing and then recover by spring before the resumption of grazing (Herbst and Knapp 1999).

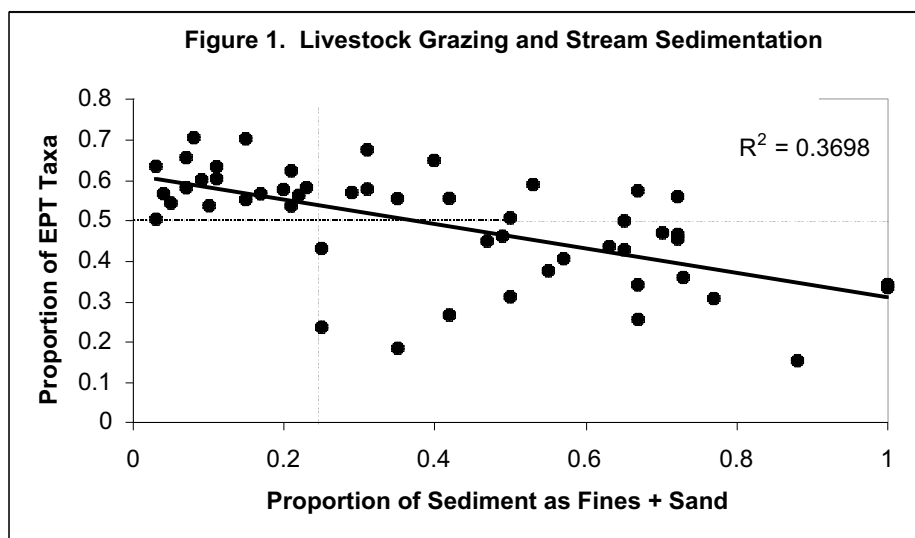


Figure 1— Livestock grazing and stream sedimentation.

Gradients of exposure to stressors can also be examined with distance from the source of degradation. Studies of acid mine drainage from the Leviathan Mine Superfund site have been conducted to define the longitudinal downstream extent of impacts and changes over time as remediation actions have been undertaken (Herbst 2002b). These studies have shown that, although there continue to be several miles of severely impaired stream communities, the use of treatment bioreactors, involving a microbial reversal of the oxidation and hydrolysis that cause acid mine drainage, has produced local recovery of a small stream (*fig. 2*). The biotic index, a measure of composite tolerance of the community to pollution (increases with predominance by organisms resistant to pollution), was reduced in Aspen Creek after bioreactors were established in summer 1999. This index declined to levels near that of the reference stream as more sensitive organisms were able to inhabit the treated flows while the untreated Leviathan Creek drainage remained impaired. Continued monitoring will evaluate whether this recovery persists and the success of other remediation strategies.

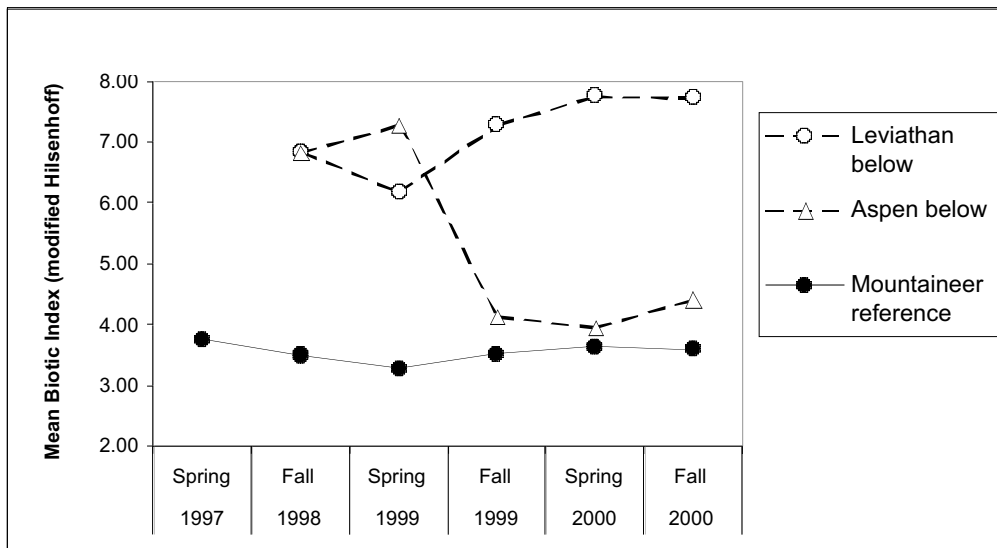


Figure 2— Post-treatment recovery from acid mine drainage.

These serve as a few examples of the extent and type of information generated through bioassessment monitoring; problems remain to be resolved before this type of information can be used most effectively to improve water resource management and biodiversity conservation in the Sierra Nevada.

Needs and Opportunities

This section highlights needs and opportunities for developing bioassessment monitoring as an effective tool for improving watershed management.

Map distribution patterns

Existing data of the macroinvertebrate community structure from bioassessment surveys currently comprise about 600 stream reaches. This provides an initial database for creating zoogeographic maps (taxa distributions and diversity contours) and identifying data gaps (evident for higher-elevation and headwater streams). Mapping biogeography and endemism through taxonomic inventories and establishing a network of monitoring stations as an elevation and latitude grid over Sierra Nevada stream drainages would provide information to evaluate long-term effects of climate change (earlier spring run-off, increased flood frequency, warmer summer stream temperatures, and increased frequency of intermittent stream flows).

Spatially analyze watersheds

GIS analysis for reference site selection will require coverages that have enhanced watershed resolution (from first-order streams, combined to form higher-order aggregate units) and more detailed information for identifying and quantifying stressors (roads and land use intensity). Use of landscape models such as AGNPS may also provide integrated nutrient and sediment loading predictions. Opportunities exist for integrating aquatic invertebrate bioassessment into models and evaluations of cumulative watershed effects. (This requires development of a case history database so that impacts can be better predicted and managed.)

Expand the ADMA concept of Moyle

Invertebrate data (including patterns of total diversity, endemism, sensitivity, biotic integrity) can be used as: (1) a planning tool for defining regional priorities for preserving biodiversity and (2) a means for identifying and protecting reference areas that serve as the basis for standards of biological integrity in water quality assessment. Data can be made available to the Forest Service, National Park Service, and others to encourage integration into conservation strategies that follow ADMA principles (for example, the Sierra Nevada Forest Plan Amendment “emphasis watersheds and critical aquatic refuges” for protecting and restoring watersheds and the Sierra Nevada Ecoregional Plan of The Nature Conservancy (TNC)—a portfolio of 500 sites identified for long-term protection and conservation planning).

Coordinate planned restoration management with monitoring case histories

Natural experiments may often be found in the planned management activities of the Forest Service and National Park Service. These activities provide opportunities for research investigations: foremost among these should be before-and-after studies of dam removal, exotic fish removals, controlled burns, livestock grazing practices, and stream channel restoration projects.

Use of monitoring feedback is a critical component of adaptive management decision-making. The value of aquatic invertebrate data as a performance indicator of the status of biotic integrity and change in streams should be recognized.

Think higher and larger

Thinking *higher* means to consider the role of headwater streams. The fauna of headwater streams should be examined as should the role of variations in intermittent flow conditions on the structure and function of stream communities and as habitat refugia from exotic fish predators. Headwater and other high-elevation streams are the least-understood aquatic environments of the Sierra Nevada.

Thinking *larger* translates to such inclusive assessments as White-Inyo Mountains, Owens Valley, Warner Mountains, and restored Tulare and Buena Vista Lakes. Another example of thinking larger includes the interconnected relationships to the biogeography of basin and range habitats in the Great Basin.

The existing environmental research community and planned Sierra Nevada Research Institute at the University of California at Merced (UC Merced) should develop partnerships with State, Federal, local, and private agencies and organizations to serve management with applied research and monitoring that helps guide decisions (such as “Vital Signs” monitoring in National Parks, development of biological criteria for water quality standards for the State Water Resources Control Board, and ranking of priorities for land acquisition and protection by The Nature Conservancy).

Educational opportunities can be developed by working with community watershed groups and schools (for example, the Yosemite Institute stream biomonitoring program). An introduction to bioassessment for such groups can be downloaded from the following website (Herbst and others 2001, published by the State Water Resources Control Board): <http://www.swrcb.ca.gov/nps/docs/FinRevCAStreamBiosurvey.doc>

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