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BIOMONITORING TECHNIQUES FOR ASSESSING TOXICITY IN NATIONAL PARK WATERS

By
Del Wayne R. Nimmo
John Karish
Terence Boyle
Nancy Hoefs
Mary Willox
William Lamar

Throughout recent history, animal and plant species have served as indicators of environmental quality. For instance, fishery biologists have long associated the presence of robust populations of fish to good water quality in lakes and streams, and the presence of certain species of plants have been used to classify wetlands in the United States for special protection. Recently, the decline of the delta smelt, *Hypomesus transpacificus*, populations has received much attention in San Francisco Bay, California, as an indicator of decreasing water quality. These examples are considered by scientists to be *biomonitors*. "Bi" or "bio" is derived from the Greek bios or mode of life and "monitor" meaning to check, test, watch or keep track of. In other words, biomonitoring is analogous to a thermostat which senses and controls the temperature of a room; but instead of a mechanical device measuring temperature, living organisms are used to monitor or track the positive or negative changes in aquatic environments.

Prior to the mid-1970s, the Environmental Protection Agency (EPA) and predecessor agencies typically used technology-based and/or chemical-by-chemical approaches to regulate toxic pollutants and develop water quality standards in our Nation's wastewaters (Karr 1991). A special group of toxic pollutants, representing only a small fraction of the substances found in the environment, were targeted. This, consequently, placed emphasis on both the constraints of the technology and/or the use of chemical analyses to ensure that the standards were being met. In many instances, even though water quality standards were being met, aquatic communities were not present. Standards did not take into account the direct effects of: (1) combinations of various toxicants in the water, or (2) the interaction of physical characteristics of natural waters (i.e., pH, dissolved oxygen) with the toxicant(s).

It is these limitations, and a new emphasis on a key phrase in the Water Pollution Control Act of 1972 (and successive enactments) that prompted a change in National policy. In the enactments, the charge to "restore and maintain the physical, chemical, and biological integrity of the Nation's waters," was translated into the popular axiom, "fishable [and] swimmable" to strengthen the emphasis on the biological underpinning of the law. EPA has subsequently introduced biomonitoring in conjunction with, but not in place of, chemical analyses to regulate substances in wastewater (Federal Register 1984). Because living organisms are better indicators than individual chemical analyses in detecting the combined effects of chemical and physical factors in surface waters, this new focus has resulted in a savings of money, time, and resources in addressing complex water resource problems.

Management actions based on biomonitoring have resulted in the restoration and maintenance of the "biological integrity" or "community health" of waters and are more appropriate when used as the basis for detecting toxicity, protecting aquatic resources, and improving the overall water quality. Mitigation, as a result, has neither been under-protective or over-protective of the water resources because the degree of treatment is based on the health of aquatic communities in streams or lakes rather than being based solely on the results of technology. Lastly, biomonitoring can be used to assess the condition of surface waters due to other factors in a watershed, such as mining impacts (Nimmo et al. 1990), urbanization (Nimmo et al. 1991), or pesticides from agricultural runoff (Norberg-King et al. 1991).

Biomonitoring of surface waters can include both laboratory and/or field studies--bioassays and biosurveys respectively (Table 1). These studies, using bioindicators to assess the health of the aquatic environment, are better than traditional chemical sampling alone because the living organisms directly reflect the integrated dynamics of the chemical, physical, and biological environment which they inhabit.

Bioassays, both acute and chronic (short and long term) use a variety of single species test organisms. The daphnid, *Ceriodaphnia dubia* (Fig. 1), is a common crustacean found in lakes and ponds throughout the United States, and when maintained in the laboratory, will reach maturity and reproduce in just four days. The survival or reproduction rates (test endpoints) of the daphnids directly reflect the quality of the water in which they are maintained. The number of young produced over a seven day period in water from a study site, are then compared to those produced in a control water known to be free of toxicants. Fewer young are produced when toxicants are present, and when toxicants are high, the test organism will die. Growth rates of larval fathead minnows, *Pimephales promelas* (Fig. 2), also reflect the integrity or health of their environment. If they are exposed to toxic water, the fish will not grow normally or may show signs of stress; again, if concentrations of the toxicant are high enough, they, like the daphnids, will die.

Alterations in feeding behavior of an organism occurs as a result of environmental conditions. When, the amphipod, *Hyalela azteca*, is exposed to test water, either in the laboratory or *in situ* (in the field), the amount of leaf material it consumes is an indicator of the water's quality (Nimmo, unpublished manuscript). Plants such as the grass seed, *Echinochloa crusgalli*, are also used as biomonitors. Germination success and growth rates of seedlings are altered when exposed to toxic water (Walsh et al. 1991). Again, if the water is toxic, the seeds will not germinate or grow as well as in the control water.

Biosurveys of various community and population attributes are used to assess the health of the environment (Table 1). These studies involve the collection of an assemblage of organisms and populations that occur together and interact with one another in their aquatic environment. Density of organisms, the total number of taxa present, the number of pollution-sensitive taxa present, and calculations of community diversity are commonly used by state and federal agencies. Indices such as the Index of Biotic Integrity and the Invertebrate Community Index combine these and other individual fish and macroinvertebrate community and population attributes such as species richness, relative abundances of specific tolerant or intolerant populations, and opportunistic or dominant species, to reflect the prevailing health of the aquatic environment.

A study at Wilson's Creek National Battlefield, Missouri, (WICR) demonstrated the use of both biosurveys and bioassays in identifying impacts from nonpoint sources within the Wilson's Creek watershed. Initial biomonitoring conducted on four separate occasions in 1988 and 1989, within the battlefield, included macroinvertebrate and fish population and community surveys. Results indicated that macroinvertebrates in Wilson's Creek were conspicuously low in number or absent altogether. The number of pollution-sensitive EPT (Ephemeroptera, Plecoptera, and Trichoptera) taxa expected in a typical Ozark stream is between 18 and 22 (Dieffenbach and Ryck 1976); however, only 8 EPT taxa were found in Wilson's Creek. Plecoptera, considered extremely sensitive to organic enrichment and heavy metal pollution (Surdick and Gaufin 1978) were conspicuously low in numbers or absent from collections. Species diversity was also lower than expected for an Ozark stream. Diversity values, measured using Shannon H', ranged from 0.89 to 2.53, unlike a pristine stream in the region where values greater than 3 would be expected (K.W. Stewart. University of North Texas. pers. comm.). Fish community biosurveys showed that the relative percent of pollution tolerant species found in Wilson's Creek was markedly higher than in the reference streams within the region, and pollution intolerant species were depleted or missing. The number of percids (darters) and centrarchids (sunfish), including both smallmouth, *Micropterus dolomieui*, and largemouth bass, *M. salmoides*, found in Wilson's Creek were also fewer than would be expected in the region.

These findings prompted additional biomonitoring studies involving single species bioassays with daphnids. Results of these bioassays, done in the fall of 1989, indicated that several tributaries and segments of the creek, both inside and outside the park (Sites 5-10, Fig 3), were chronically toxic; significantly different than control site #1 ($P<0.05$). One conclusion derived from this study was that whatever affected the macroinvertebrate and fish communities apparently was toxic to daphnids. Another conclusion was that toxicity could have been enhanced by severe drought conditions that concentrated toxicants from a variety of sources in the drainage.

Additional bioassays of the Wilson's Creek watershed were conducted approximately 18 months later (May 1991) under normal precipitation conditions. Toxic conditions were again identified at site 6 (Fig.3) using single species bioassays with daphnids. All of these biomonitoring studies (including bioassays and biosurveys) indicate that the biological health of Wilson's Creek was being impacted from nonpoint sources. As a result, special techniques referred to as Toxicity Identification Evaluation (TIE) procedures (Norberg-King et al. 1991) were used to (1) identify the physical/chemical characteristics of the toxicant or toxicants and (2) determine the appropriate analytical techniques to verify the toxicants responsible.

We are convinced that the use of biomonitoring is valuable for assessing the integrity/health of waters that travel through our National Parks, as was the case at Wilson's Creek National Battlefield. After three years of conducting such studies in 4 additional parks, we agree with Hester (1991) who stated, "many of the issues parks face are the same issues the nation faces. . .often actions many miles away that pollute water or air will affect parks downstream or downwind." We believe that incorporation of biomonitoring into resource inventory and monitoring programs is needed to assure the health of the aquatic resources within our National Riverways and Parks.

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Table 1. Biological indicators used to assess the condition of a water resource to protect both human and aquatic health (Modified from Karr 1991).

BIOASSAY--procedure of exposing test organisms, usually in a **laboratory setting**, to various concentrations of suspected toxicants or dilutions of whole effluent.

- A. Single Species
  (may involve selection of indicator species)
    1. Tissue analysis for bioaccumulation
    2. Biomarkers--genetics or physiology
    3. Biomass/yield
    4. Growth rates
    5. Gross morphology (external or internal)
    6. Behavior
    7. Disease or parasitism frequency

BIOSURVEY--process of collecting a representative portion of the organisms **from the environment** (*in situ*) of interest to determine the characteristics of the aquatic community.

- A. Single Species
  (may involve selection of indicator species)
    1. Tissue analysis for bioaccumulation
    2. Biomarkers--genetics or physiology
    3. Biomass/yield
    4. Growth rates
    5. Gross morphology (external or internal)
    6. Behavior
    7. Disease or parasitism frequency
- B. Population/Community
  (may involve indicator taxa or guilds)
    1. Abundance/density
    2. Variation in population size
    3. Population age structure
    4. Species richness/diversity
    5. Relative abundances among species
    6. Tolerants/intolerants
    7. Abundance of opportunists
    8. Dominant species
    9. Community trophic structure

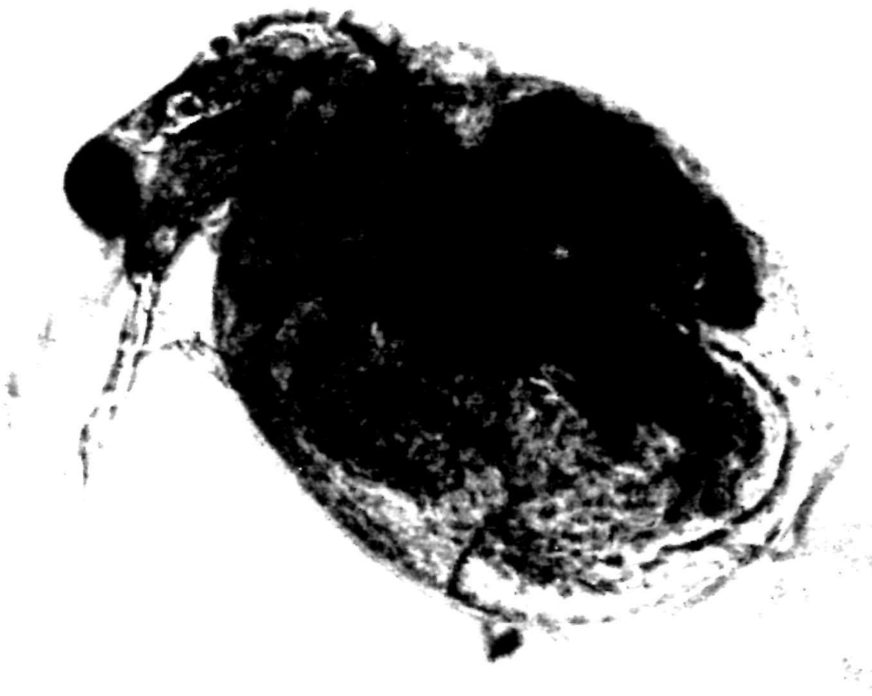


Figure 1. A mature daphnid, *Ceriodaphnia dubia*. Actual size approximately 2mm.

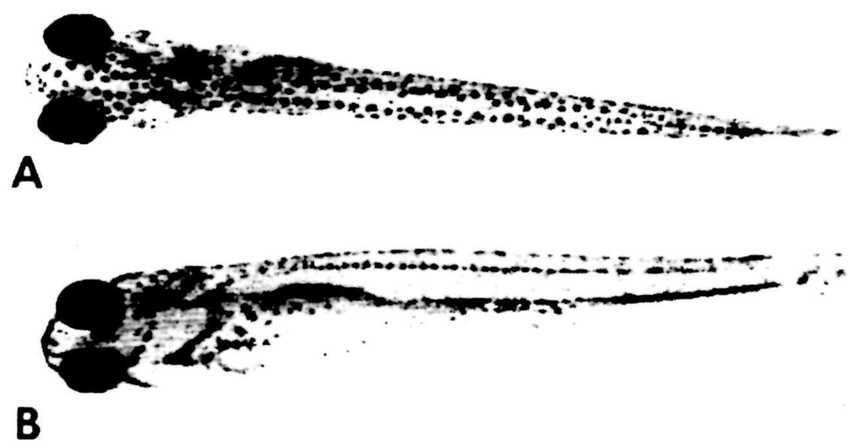
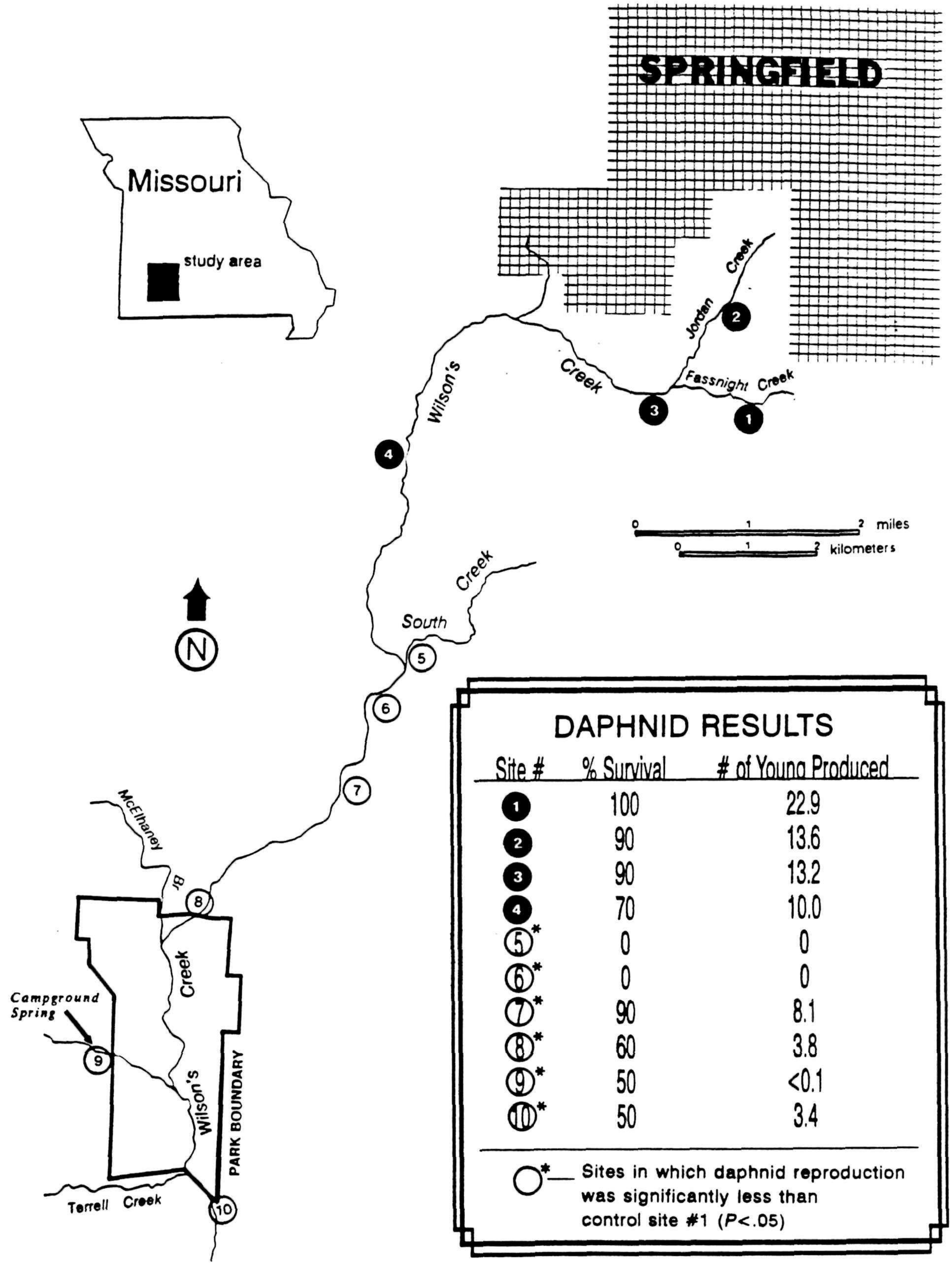


Figure 2. Larval fathead minnow, *Pimephales promelas*. **A** is a dorsal view, **B** is a ventral-lateral view. Actual size approximately 9mm in length.



DAPHNID RESULTS

Site #	% Survival	# of Young Produced
1	100	22.9
2	90	13.6
3	90	13.2
4	70	10.0
5*	0	0
6*	0	0
7*	90	8.1
8*	60	3.8
9*	50	<0.1
10*	50	3.4

○* — Sites in which daphnid reproduction was significantly less than control site #1 ($P<.05$)

Figure 3. Biomonitoring sites along Wilson's Creek, Missouri, fall 1989. The table depicts the results of a chronic 7 day single species bioassay using the test species *Ceriodaphnia dubia*. Percent survival refers to young daphnids which survived, matured, and produced young within seven days. The number of young produced is the average reproduction rate of adult female daphnids within seven days.