

Aquatic Macroinvertebrates

Introduction

In the arid American Southwest, surface water is a scarce feature on the landscape. Aquatic and riparian habitats make up less than 2% of the landmass, but are home to a disproportionately large number of species, making these habitats among the most productive ecosystems in the region (Asplund & Gooch 1988, Briggs 1996). They are also among the most endangered ecosystems, facing threats in the form of pollution, development, logging, grazing, and climate change, among others. In order to protect, maintain, and restore aquatic and riparian ecosystems, it is important that we measure and evaluate the condition of the organisms living there. One group of organisms that helps scientists to monitor the health of freshwater ecosystems is aquatic macroinvertebrates.

Aquatic macroinvertebrates are small organisms which live part or all of their lives in water and have no internal skeletal system (figs 1 and 2). They are ubiquitous in freshwater ecosystems around the world and are found in both lotic systems—systems of flowing water, such as streams, rivers and springs, as well as in lentic systems—systems with standing or still waters, such as lakes, ponds and tinajas (depressions in rock that capture and hold water from rain or floods). They comprise a rich and diverse group of organisms that includes insect larvae, worms, snails, crayfish, and other crustaceans, such as clam shrimp, fairy shrimp, and water fleas. They also include many invertebrate species that are typically associated with terrestrial habitats, but spend some portion of their life as aquatic organisms (for example butterflies and moths in the family Pyralidae).

Aquatic macroinvertebrates are ecologically significant because they have the ability to integrate changes in both the aquatic and associated terrestrial environment. This sensitivity to environmental change helps scientists who study aquatic macroinvertebrates to detect physical, chemical, and biological changes in the ecosystems where they live.

Distribution

Aquatic macroinvertebrates can be found throughout the southwestern United States, from the high elevation

OVERVIEW



PHOTO: DAVID BUCHWALTER, NABS

Figure 1. Example of an aquatic macroinvertebrate: Perlodid stonefly (*Baumanella* sp.)

coldwater montane streams in northern New Mexico and southern Colorado, to the warm water bodies at lower elevations in southern Arizona, New Mexico, and Texas. Many species occur in most or all of these habitats, while others have very limited distributions. For example, the Quitobaquito spring snail (*Tryonia quitobaquiae*), a very small aquatic snail (roughly the size of a gnat) only occurs in Quitobaquito Springs in Organ Pipe Cactus National Monument. Similarly, the Montezuma Well springsnail only occurs at Montezuma Well, a unique limestone sink pool within Montezuma Castle National Monument. Finally, the playa lakes in the Chihuahuan Desert parks contain specialized freshwater assemblages of invertebrates, such as clam shrimp and fairy shrimp, which provide important food for migrating waterfowl.

Ecology

Like all other organisms, aquatic macroinvertebrates have species-specific habitat requirements that include a range of physical conditions and sources for food. For example, they require an appropriate range of such abiotic factors as pH, dissolved oxygen, and temperature. Some species can tolerate wider fluctuations of these factors and can survive in a range of stream and water quality conditions. Others have very narrow tolerance ranges, and large fluctuations



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 Figure 2. Black fly (*Simulium decorum*) larvae and pupae

in pH and temperature can threaten their survival. Food sources for aquatic macroinvertebrates range from aquatic plants and algae to riparian vegetation and woody debris and leaves. Diversity in food sources can promote a rich aquatic faunal community.

Habitat

Most aquatic macroinvertebrates live in either the hyporheic zone or benthic habitat of freshwater systems (figs 3, 4, and 5). The hyporheic zone is the area of saturated soils where groundwater and surface water mix. Typically,



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Figure 3. Collecting macroinvertebrate sample with a kick net at Gila Cliff Dwellings National Monument

organisms such as amphipods, isopods, and ostracods live in this zone in southwestern streams (Boulton et al. 1992). Benthic species spend most of their life cycle dwelling on bottom sediments such as algae, rocks, or woody debris. Examples of benthic organisms include mayflies, caddisflies, and dragonflies. Both habitat types play important roles in the aquatic ecosystem. Hyporheic habitats are believed to serve as refugia for benthic species during disturbances such as floods and droughts. Benthic habitat not only provides refuge for many of the aquatic macroinvertebrates, but also is the area where much of the processing of primary production occurs.

Life history

Aquatic macroinvertebrates encompass thousands of species with varied life history strategies, but most include three distinct morphological stages: the larval stage, the pupal stage, and the adult stage. The timing, length, and development of these stages vary from species to species. In many, the larval stage occurs exclusively in the aquatic environment and can be quite long, lasting up to five years in the case of some Odonates (dragonflies and damselflies). During the pupal stage organisms undergo morphological changes as they develop structures required for mating and reproduction in adulthood (Voshell 2002). Adult stages are typically terrestrial and relatively short, usually lasting no longer than one or two weeks. One exception to this pattern are the beetles within the Order Coleoptera, whose members typically live in the aquatic environment as both larvae and adults.

Life history strategies of aquatic macroinvertebrates (e.g., the length and number of life cycle stages, development, emergence, and dispersal) have evolved over time, influenced by the physiological attributes of individual species and how the species interact with their environment. These strategies have enabled aquatic macroinvertebrates to proliferate in lotic ecosystems by taking advantage of seasonal differences in food supply and by timing life cycle stages (for example, delaying emergence into adulthood to avoid hostile environmental conditions) (Giller and Malmqvist 1998). Water temperature appears to be a major factor in determining how specific species of aquatic macroinvertebrates develop, affecting the length of egg incubation and subsequent hatching in species of Ephemeroptera (mayflies) and Plecoptera (stoneflies), as well as growth and maturation through the larval stages (Ward 1992).

Ecological role

Primary production plays a key role in determining aquatic community structure and function in stream ecosystems.

Products of primary production found in aquatic ecosystems come from two sources: the growth of algae and plants in streams (autochthonous inputs); and organic matter originating from the surrounding riparian and upland vegetation (allochthonous inputs). Aquatic macroinvertebrates play a key role in nutrient cycling in aquatic ecosystems because they are the primary processors of organic materials. Many streams, especially those in the Southwest, are controlled primarily by allochthonous inputs of energy (Cummins 1974, Fisher 1995). Some studies have suggested that aquatic macroinvertebrates are responsible for processing up to 73 percent of riparian leaf litter that enters a stream (Covich et al. 1999). This nutrient rich food source in turn increases growth rates, biomass, and survival of aquatic macroinvertebrates. In southwestern streams, this secondary productivity is among the highest in the country, with rates 2-13 times greater than secondary productivity found in streams in the eastern United States (Fisher & Gray 1983).

Functional feeding groups

Aquatic macroinvertebrates serve multiple functions in freshwater ecosystems. In addition to their role as primary consumers processing live organic material, they also serve as detritivores, consuming decomposing organic matter; predators, consuming macroinvertebrates and other small organisms; and prey, serving as food for fish, amphibians, reptiles, aquatic birds, and mammals. Many species of aquatic macroinvertebrates have evolved highly specialized



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Figure 5. Canyon de Chelly National Monument

feeding structures and behaviors in order to adapt to different food sources and competition within the aquatic environment. As a result, aquatic ecologists have categorized the many species of aquatic macroinvertebrates into four functional feeding groups (Cummins 1973) which can be used to describe how aquatic ecosystems function: shredders, collectors, grazers (or scrapers), and predators.

- **Shredders** are responsible for processing coarse particulate organic matter (CPOM). CPOM is greater than 1 mm in size and typically derived from allochthonous sources, such as woody debris, leaves, and other vegetation from the neighboring riparian corridor. Examples of shredders in the Southwest include the caddisfly *Heteroplectron californicum* and the stonefly *Zapada cinctipes*.
- **Collectors** filter and collect smaller particles of organic matter (FPOM) found in the water column and bottom sediments. FPOM can range in size from 0.01-1.0 mm and usually arrives in water columns and benthic sediments as a result of CPOM being broken up by shredder species. Examples of collector species include the beetle *Zaitzevia parvula* and the Dipteran (true flies) *Antocha monticola*.
- **Grazers** are found on rocks and woody debris, feeding on periphyton, detritus, and submerged aquatic plants. Most gastropods (snails) are grazer species; other grazers in the Southwest include the caddisfly (*Helicopsyche borealis*) and the beetle (*Optioservus quadrimaculatus*).
- **Predators** prey on animal tissue. The primary food sources for this group are other aquatic macroinver-



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Figure 4. Glen Canyon National Recreation Area

tebrates. Many southwestern dragonflies, such as the riffle darter (*Opolonaeschna armata*) and Pacific spiketail (*Cordulegaster dorsalis*), are voracious predatory species.

River Continuum Concept

According to the River Continuum Concept (RCC), the presence and abundance of functional groups at any point along a lotic ecosystem may be predicted by considering the physical process that formed the streambed and the amount of sunlight occurring at that point. The RCC, proposed by Vannote et al. (1980), predicts that aquatic macroinvertebrate communities will change in functional composition as one moves downstream, further away from the headwaters. Lower order streams are typically narrower and dominated by dense riparian vegetation, which shades the stream and restricts sunlight availability at the stream surface. Energy inputs in low order streams are the result of allochthonous sources, primarily in the form of litter from riparian vegetation. The RCC predicts that the aquatic macroinvertebrate community in such streams should reflect the food sources available in the stream. As a result, the community in lower order streams should be dominated by shredder and collector species. Shredder species will forage on large allochthonous inputs and turn them directly into biomass. Any remaining finer particles (FPOM) from the initial breakdown of CPOM, either through natural stream processes or shredder feeding, will be taken up by the collector species. Grazers and predators should also be present, but in lower abundances because they are less functionally important to the community.

According to the RCC, as stream order increases, aquatic macroinvertebrate communities should shift to reflect that change. In mid-order streams, channel width increases and riparian vegetation shades less of the stream, permitting more sunlight to reach the stream surface. Allochthonous energetic inputs into the system are reduced and autochthonous inputs in the form of periphyton become more important. As a result, the community shifts from being dominated by shredders and collectors to being dominated by grazers and collectors. The abundant periphyton is taken up by grazer species and transferred into biomass. Collectors are equally abundant as grazer species, so that any FPOM leakage from upstream communities as well as FPOM created from the increased periphyton is taken up by the assembled community members. In the largest rivers, FPOM is the dominant energy input in the system. Large rivers also experience a decrease in light penetration compared to mid-order streams. As a result, the RCC predicts that aquatic macroinvertebrate communities in large-order streams should be dominated by collector species due to the increased FPOM present and the loss of periphyton to the system.

The RCC has been the accepted paradigm of stream ecology since it was first proposed nearly 30 years ago. However, there is debate about how lotic systems in arid regions, such as the Southwest, fit into the model. Studies of southwestern streams with high autochthonous primary production show that the aquatic macroinvertebrate communities are dominated by collector species and not shredder species as the RCC would predict (Fisher et al. 1982; Jackson and Fisher 1986). It has been suggested that large flash flood events, prevalent in these systems, may be responsible for this aberration. After flash floods occur, large fluxes of allochthonous FPOM enter the system. Aquatic macroinvertebrate communities appear to be structuring themselves, particularly in summer months, to take advantage of these increased FPOM loads.

This community structuring appears to be an occurrence that is biologically unique to lotic systems in the Southwest.

Status of aquatic macroinvertebrates in the Southwest

Across the U.S., aquatic fauna face a greater threat of extinction and population decline than their terrestrial counterparts. Mussels, dragonflies, and damselflies are among the most imperiled aquatic macroinvertebrates in freshwater ecosystems (Richter et al. 1997). Introductions of non-native species and changes in the natural hydrology of streams and rivers have resulted in the decline of aquatic macroinvertebrates. Climate change may also pose a threat to this group of organisms in the future.

Non-native species

Aquatic ecosystems are usually surrounded by large contiguous areas of land, and as a result, are extremely isolated. This isolation has allowed aquatic communities to evolve with little potential for species interactions or migrations between watersheds. For example, communities along the Colorado River Basin have a much higher potential for interaction and species exchange within that watershed than they experience with communities from the Rio Grande River Basin. Because of this isolation, the effects of species introductions into aquatic ecosystems are more significant and exaggerated than they are in terrestrial ecosystems (Riccardi and Atkinson 2004).

Introductions of non-native aquatic macroinvertebrates have had detrimental effects on many native species in national parks in the Southwest. Two non-native species that have scientists concerned are the zebra mussel (*Dreissena polymorpha*) (fig. 6) and the quagga mussel (*Dreissena bugensis*). These species can reduce aquatic macroinvertebrate diversity and abundance through competition for resources, particu-



Figure 6. Non-native zebra mussel (*Dreissena polymorpha*)

larly FPOM, and decreasing water quality. These mussel species have been found in lentic ecosystems around the southwest. The primary mechanism for their introduction has been through contaminated boats and boat trailers entering these systems.

The Asian clam (*Corbicula fluminea*), native to southern and eastern Asia and Africa, has made its way to Texas, southern New Mexico, and western Arizona (U.S. Geological Survey 2001). This non-native species can alter benthic substrates and compete with native mussels for space and food.

Another aquatic invader affecting lentic communities in national parks on the Colorado Plateau is the virile crayfish (*Oroconectes virilis*). Unlike mussels in the lakes of the Southwest, organisms in rivers and streams on the Colorado Plateau have evolved without the presence of crayfish. The virile crayfish's ability to feed at multiple trophic levels can cause declines in aquatic macroinvertebrates across all functional groups within a community. The resulting depauperate community is then at risk to future perturbation due to a lack of species redundancy in the community. Functional roles that were once filled by many species of aquatic macroinvertebrates are replaced by one or a few. If the remaining species cannot adapt to future perturbation experienced by the system, then overall function of that ecosystem will decline.

Altered flow regimes

Changes in the natural hydrology of streams and rivers have contributed to the decline of aquatic macroinvertebrates in the Southwest and across the country. Activities such as water impoundment, groundwater mining, conversion of floodplains into agricultural lands, diversion of water for irrigation and power generation, and channelization alter the natural flow regimes of streams and rivers. These changes include (1) a reduction in the amount of water flowing in a stream or river, (2) a loss of flow variation, and (3) altera-

tions in the stream channel. An estimated 85% of rivers and streams in the U.S. have been affected by some form of flow alteration (Poff et al. 1995, National Research Council 1992).

Water impoundment through construction of a basin or obstruction of a stream depletes surface water and groundwater flow and can result in decreased habitat and food availability for aquatic macroinvertebrates, leading to a decline in species richness and alteration of community structure. Groundwater depletion can also result in a loss of nutrients vital to algal organisms, which can cause further change in community structure (Scott et al. 2005 and Dahm et al. 2003).

Water impoundment and channelization (any alteration of a stream channel) not only can alter the amount and speed of water flow, but can also reduce flow variability. This, in turn, can reduce biodiversity and abundance through the loss of native species that evolved with natural flow variability (Scott et al. 2005). Species adapted to the new static flow regimes may increase, resulting in an altered community structure. On large rivers in the Southwest, the loss of natural variability in flow regimes has also led to a decrease in the transport of nutrient-rich sediments as well as altered water temperatures. Studies have shown significant decreases in aquatic macroinvertebrate diversity in places like Grand Canyon National Park (Blinn and Cole 1991), and Flaming Gorge Dam, where temperature changes as a result of the construction of the dam caused Ephemeroptera richness to decline from 30 species to a single species (Vinson 2001).

Finally, channelization of streams to straighten, widen, divert, narrow, or otherwise change the course or size of a stream channel can significantly alter stream flow, causing increased flow velocities, turbidity, and sedimentation (Scott et al. 2005). Similar to the effects of changes in flow variability, increased flow velocities, sedimentation, and turbidity lead to

- a decline in the species that have adapted to the natural conditions which existed prior to channelization.
- temperature changes in the water
- altered oxygen concentrations
- altered community structure due to the loss of habitat

Climate change

Lotic ecosystems in the Southwest experience a large annual variation in flow. These flows range in extremes from large flash flood events (spates) to long periods of drying and intermittency. Although aquatic macroinvertebrates have evolved under these harsh conditions for thousands of years, it is uncertain how these communities would respond

to increased spate events and prolonged periods of drying that could accompany climate change. Flash floods have the potential to decimate aquatic macroinvertebrate abundance during a single event (Fisher et al. 1982). However, communities are highly resilient to such disturbance events. Studies on streams in the Southwest have shown that populations can recover to their pre-flood abundances in as little as three weeks through aerial recolonization by adults (Fisher et al. 1982; Grimm and Fisher 1989). Increased intensity of events, combined with greater frequency, could affect how quickly communities respond in the future.

Climate change is predicted to bring an increase in drought frequency of 66-90% (Gitlin et al. 2006). Increased drought will likely decrease the amount of benthic habitat available, and therefore the abundance and diversity of the aquatic macroinvertebrate population. While the hyporeic zone has the potential to serve as refugia during such times, not all species present will be able to take advantage of it. In addition, drought could lead to further declines in macroinvertebrate populations due to a lack of allochthonous inputs into the system. Upland vegetation could potentially experience high rates of stress and mortality, leading to a decrease of riparian-derived CPOM entering the system. As a result, shredders and collectors could experience a decline in food resources, leading to increased mortality and lower species abundance.

Monitoring aquatic macroinvertebrates

The utility of monitoring aquatic macroinvertebrates to investigate ecosystem health has long been recognized by ecologists who have used this technique:

- to assess the results of management actions implemented in a system (e.g. exotic species removal)
- to determine the effects of a pollutant on the system
- to monitor water quality compliance issues (Rosenberg and Resh 1993).

These organisms are the best indicators of freshwater ecosystem health for a number of reasons:

- They can present a wide range of responses to changes in environmental conditions and stress because of the large variety of organisms that make up this group.
- They serve as excellent indicators of long and short-term change. Many species have long-lived life cycle stages that allow them to integrate effects of land and water use in the watershed, making them sensitive to changes in the physical and chemical environment (Scott et al. 2006; Maretet al. 2001).

- When combined with physical and chemical water assessment, aquatic macroinvertebrate monitoring provides a comprehensive evaluation of watershed condition (Karr 1991).

Macroinvertebrate monitoring is planned or underway in all of the I&M networks of the Southwest (table 1, figs. 7-9). The overall monitoring objectives include tracking changes in the composition and abundance of aquatic macroinvertebrate assemblages and in habitat condition.

We will also investigate relationships between aquatic macroinvertebrate indices and other network vital signs, such as fish communities, water quality and quantity, and stream channel morphology.

Table 1. Ongoing or planned macroinvertebrate sampling in the Southwest.

I&M Network and Park Unit
Southern Plains Network
Chickasaw National Recreation Area
Lyndon B. Johnson National Historical Park
Pecos National Historical Park
Sonoran Desert Network
Gila Cliff Dwellings National Monument
Montezuma Castle National Monument
Organ Pipe Cactus National Monument
Saguaro National Park
Tumacacori National Historical Park
Tuzigoot NM (TUZI)
Southern Colorado Plateau Network
Bandelier National Monument
Canyon de Chelly National Monument
Glen Canyon National Recreation Area
Grand Canyon National Park
Mesa Verde National Park
Chihuahuan Desert Network
Amistad National Recreation Area
Big Bend National Park
Carlsbad Caverns National Park
Guadalupe Mountains National Park

With monitoring data, park resource managers will be able to make more informed management decisions regarding aquatic resources within their parks. Network monitoring results are available on the Learning Center website under the "Projects" tab.



Figure 7. Processing a sample at Gila Cliff Dwellings National Monument

NPS PHOTO



Figure 8. Macroinvertebrate sample

NPS PHOTO



Figure 9. Collecting samples in Grand Canyon National Park

PHOTO: NPS/SCPN

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