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Lessons from a Long-term Study of Springs and Spring Invertebrates (Sierra Nevada, California, U.S.A.) and Implications for Conservation and Management

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Abstract

Long-term studies (over 20 years) of the biota and physical/chemical properties of Sierra Nevada cold springs (west side Great Basin) showed the highly individualistic nature of springs even within the same stream basin. Spring invertebrate assemblages differed greatly from one spring to another, as did timing of insect emergence and abundance of species. Springs were studied before, during, and following major drought. Invertebrate species richness was greater in deeper, more permanent springs with high concentrations of dissolved ions, especially calcium. Spring permanence was determined by direct observation over time, measurement of discharge variability, correlation of discharge with ionic concentration, and water dating with chlorofluorocarbon and tritium.

Only five major groups of aquatic invertebrates were found in all 21 springs surveyed: nematodes, oligochaetes, water mites, caddisflies, and chironomids. The absence of flatworms and stoneflies in a spring indicated that a spring was not permanent over the long term. The presence or absence of snails and clams was variable and not dependent on permanence alone. Benthic sampling did not adequately describe the insect species composition of a spring as revealed by year-round emergence trap sampling of adults. Insects emerged throughout the year from springs depending on species, and some larvae moved downstream or upstream at critical life stages. Net spinning caddisflies were absent in spring sources and mayflies were in low numbers. More permanent springs were high in species richness out of proportion to their size and were habitats for rare, relict, and/or endemic species. The presence of moss mats indicated that springs were permanent.

Some species were confined to spring sources; others were distributed downstream for some distance, depending on the nature of the spring and species requirements.

Introduction

The study of spring invertebrates has progressed rapidly in North America over the past 20 years. Three major collections of papers on springs have been published since 1991. The first of these (Williams and Danks 1991) was a symposium held at the 1989 annual meeting of the Entomological Society of Canada and concentrated on spring work in Canada but also included a few papers on work in the United States. The second (Ferrington 1995) was the result of a symposium organized by M. Blackwood and L. Ferrington and held at the North American Benthological Society 1993 annual meeting. The third was a compilation of papers on recent spring work from Europe, North America, Australia, and Japan organized and edited by L. Botosaneanu (1998).

Taken together, these three publications indicate a diversity and acceleration of work in North America on several taxonomic groups found in springs and point to new areas of research in spring studies. But until this present symposium in Las Vegas, no group of North American researchers and managers—geologists, hydrologists, biologists, and social scientists—has mutually explored the questions and issues of conservation and management of springs. This symposium and the recently published guide to managing, restoring and conserving springs in the western United States (Sada *et al*. 2001) represent a needed new perspective on these special habitats.

A review of published literature in North America prior to about 1980 might have led one to believe that springs were depauperate habitats of relatively low productivity with few organisms of interest except for some rare fish (as reviewed in earlier work, Erman and Erman 1990). Since then, studies on most of the major groups of invertebrates that are well-adapted to springs have shown that many springs are rich in species, especially for their often small size, and/or are habitats for rare and endemic species that are restricted to those springs (but see Davidson and Wilding 1943, for an early North American study that reported high invertebrate richness in springs). By contrast, in Europe, springs have long been studied and recognized as isolated refuges for invertebrate species living in the constant temperature of springs at latitudes or altitudes higher or lower than their normal range (e.g., Nielson 1950; Botosaneanu and St. Negrea 1961). More recently, researchers in North America have begun to catch up with European scientists. For example, spring studies have been conducted on aquatic mites (Smith 1991), snails (Hershler and Sada 1987; Hershler 1989), ostracods (Forester 1991), caddisflies (Erman and Erman 1990; Morse and Barr 1990; Myers and Resh 2002), chironomids (Colbo 1991; Blackwood *et al*. 1995; Ferrington 1998), and aquatic beetles (Roughley and Larson 1991). This list is presented only to illustrate the diversity and breadth of taxonomic invertebrate work being done now on spring species in North America. It is far from a complete listing of recent studies on spring biota in North America.

Three sets of small, fishless springs (21 springs total) on the eastern and western sides of the northern Sierra Nevada (western edge of the Lahontan basin in some cases) have been studied for over 20 years before, during, and following a severe drought in California (Erman 1989, 1992, 1998; Erman and Erman 1990, 1992, 1995; Rademacher *et al*. 2001). These long-term studies have allowed us to make comparisons among springs within watersheds and among watersheds, over time, as hydrologic conditions changed.

Spring Descriptions and Physical/Chemical Factors

Fourteen springs in the Sagehen Creek Basin on the east side of the Sierra Nevada, Nevada County, California, U.S.A., were initially chosen for detailed study. The project was later expanded to include seven springs on the west side: three in the Onion Creek Basin, Placer County, and four in the Lincoln Creek Basin, Sierra County. All 21 springs were between 1,963 m and 2,408 m elevation, were thought to be permanent and of relatively constant conditions at the time they were selected for study, and were in second-order stream basins that contained three or more springs for comparison. Subsequent droughts in the Sierra Nevada proved that some of the selected springs were not permanent throughout the years of study. All springs in this study arise from igneous rock, primarily granite and andesite.

In the Sagehen and Onion basins, springs are separated by large tracts of dry land in the summer and fall. Several of the springs and spring streams are isolated on high slopes. In the Sagehen basin, some springs are associated with nearby minerotrophic peatlands but these, too, are surrounded by dry areas. Only in the Lincoln basin are springs connected by wet meadow areas and the nearby Lincoln Creek. In winter, the larger spring sources remain open and green even during heavy snow. Springs are visited frequently by a wide variety of mammals and birds.

Some of the Sagehen Creek springs were the sites of logging camps around 1900 and of sheep camps. Sheep grazing occured in the Sagehen basin, and in some of the springs during our studies, and cattle grazed in the Lincoln basin, but the springs chosen for study were relatively undisturbed. Old spring boxes built at the sources still exist at some springs. One spring has been used as the water supply for the University of California, Berkeley, Sagehen Creek Field Station since the 1950s. Except for the Onion Creek springs, located in a U.S. Forest Service Research Area, all of the Sagehen Creek and Lincoln Creek springs are in areas where logging and road building occur, or potentially will occur, nearby or on slopes above the springs.

For a complete description of methods used for measuring temperature, pH, specific conductance, total alkalinity, calcium, magnesium, solar radiation, discharge and hardness in springs, see Erman and Erman (1990, 1992, 1995). Elevation, distance to the nearest spring, distance to stream, aspect on slope (direction spring faces), and substrate (clear gravel, flocculent organic matter overlying gravel, mats of moss or other vegetation over gravel, or a combination) were also determined. Some springs originated from deep holes (limnocrenes) but most emerged as shallow flowing water (rheocrenes). The standard European spring classifications—limnocrene, rheocrene, and helocrene—were of limited usefulness in describing these Sierra Nevada spring habitats because springs had traits of two or all three of the types.

A later study by Rademacher *et al*. (2001) investigated spring water ages using chlorofluorocarbons and tritium/^{3}He dating techniques on 12 of the springs in the original studies.

Invertebrate Sampling Considerations

An invertebrate sampling program was devised at the outset of the study to protect the springs from repeated substrate sampling and to collect the adult forms of insects necessary for species identification. Bottom substrate sampling was limited, therefore, to no more than two sampling periods during the studies, in the spring and fall of the year. Pyramid emergence traps were placed over the springs and operated year-round in some springs. Complete descriptions of sampling have been published previously (Erman and Erman 1990, 1995) and will not be described again here. A plan for the pyramid traps is available from the author.

If springs are to be studied over time, bottom substrate sampling becomes a major disturbance factor in the habitat and should be limited when possible. In addition, substrate samples significantly underestimated the number of species in a spring (Erman 1998), and adult forms of insects are necessary for species identification. In most cases, these forms must be males because the taxonomic keys are usually written only for males. Hand-collecting at the springs can help make associations between larval forms in the water and terrestrial adults, and this method was used as well, but the emergence traps were highly satisfactory for continuous sampling and were emptied weekly. A fixed-frame trap was used for sites close to roads and a folding, more transportable trap for sites accessible only by foot. Bears occasionally disturbed the traps. Spiders (*Tetragnatha* sp.) sometimes built their webs in the tops of some traps and had to be removed. Human disturbance was not a problem, perhaps because the springs were either near a university field station or in remote areas.

The literature on springs is often confusing about what constitutes spring source species. Part of the reason may be the type of sampling or collecting method used. The use of black lights may give misleading results because black lights are specialized attractants and can draw in insects from great distances or may not attract day-flying insects at all.

Another reason for confusion in the published literature is a lack of clarity about defining where sampling has been conducted in a spring-fed system and, even, what is considered a spring. For the purposes of these studies, a spring was defined as the spring source where water emerged from the ground. All sampling was done within the same temperature zone, no more than 10 m from the source. Downstream areas that differed by 2°C or more from water temperature at the source were considered spring streams rather than springs. This distance varies greatly from spring to spring because it depends on water volume, aspect on slope, and cover.

Movements of invertebrates up and down spring streams at different life stages have been documented for several species (e.g., Erman 1981, 1986; Hayford and Herrmann 1998) and may be another source of sampling differences in spring systems and at spring sources if substrate samples, only, are collected. By moving along a spring stream gradient aquatic animals are able to change their thermal environment, locate better food supplies, or find more suitable pupation sites. Therefore, they may move in and out of the constant temperature of the spring source and, while dependent on the spring for part of their life cycle, are not present all the time.

Importance of Springs as Habitats Contributing to Diversity

The Trichoptera species found during these spring studies have been discussed in detail in other publications (Erman 1989, 1992; Erman and Erman 1990, 1995). Life cycles of some species have been described (Erman 1981, 1984a, 1984b, 1986, 1987, 1997; Wiggins and Erman 1987). Other major groups of spring invertebrates have also been analyzed (Erman 1998). Therefore, in the present paper, invertebrate species are discussed in general terms only.

Five major groups of invertebrates were found in all springs of our studies. They were nematodes (Nematoda), segmented aquatic worms (Oligochaeta), water mites (Acari), caddisflies (Trichoptera), and chironomids (Chironomidae: Diptera). Flatworms (Turbellaria) and stoneflies (Plecoptera) were absent in some springs. Their absence indicated that a spring was not permanent through the drought years. Snails and clams were found in some springs and their presence or absence was not only dependent on drought, but also on other features of the spring. In general, they were either abundant or absent in a spring. A large group of caddisflies called net spinners or fixed retreat makers were absent from the springs except for one species of Philopotamidae, but other net spinners were present downstream in some spring streams. Mayflies (Ephemeroptera) were neither abundant nor diverse in these springs.

Several other groups of macroinvertebrates were collected in these studies (Erman 1998), but not in high enough numbers to show obvious general patterns. The sampling methods were not adequate for small-sized animals like ostracods, copepods, or tardigrades, although they were present in some springs.

By sampling springs, spring streams, and other aquatic habitats throughout a second-order stream basin (Sagehen Creek, Nevada and Sierra Counties), habitat distribution of all caddisfly species in the basin (Erman 1989) and the number of species that were restricted to springs were determined. Seventy-eight species of caddisflies were found in the basin; 36 of these were collected in springs. The maximum number collected from a single spring was 18 species. Nine species were restricted to springs and 12 were restricted to springs and spring streams. Five others were collected only in spring streams but never in springs. Fifteen species were collected in other habitats as well as in springs and spring streams. Over half of the caddisflies in the basin, then, were using springs and/or spring streams during all or part of their aquatic life cycle, evidence for the importance of springs and spring streams to aquatic invertebrate habitat and species diversity.

Emergence traps set at measured distances along two spring streams showed that some caddisfly species lived in relatively short segments of the streams, in narrowly specialized habitats, while others were found throughout the length of the stream and were more adaptable to changing temperature and currents along the stream gradient. Species assemblages changed rapidly along these small spring streams (Erman and Erman 1990; Erman 1992). In one stream, Trichoptera species similarity (Jaccard's index) was 38 percent between the spring source and a site 270 m downstream and only 20 percent between the spring source and a site 450 m downstream where the stream ended in a peatland.

In the second spring stream, larger than the first, species similarities with the spring source were 40 percent at 1 km downstream and 22 percent at 1.8 km downstream just above the confluence of the spring stream with a larger second-order stream. In both cases, species were both replaced and added to, along the stream gradient (Erman and Erman 1990; Erman 1992).

In mountainous areas, springs and small headwater streams are isolated and are often habitats for rare and endemic species (Erman and Nagano 1992; Erman 1996). These habitats contribute significantly to the diversity of several groups of aquatic invertebrates. The importance of this diversity is not always recognized by those making management decisions that affect springs and spring streams. Management of these waters too often has a single species focus primarily directed to whether or not the habitat supports fish or provides water to livestock.

Much of the work on springs, up to now, has been done by systematists or taxonomists who are interested in a single taxon of animals. A single taxon focus can lead to incorrect assumptions about species richness overall. It is important to remember that springs with low numbers of species or no representatives in one group of invertebrates may be rich in others. In addition, spring types differ widely throughout the world.

Photographs are revealing and useful for documentation in spring survey work and for monitoring spring disturbance. See, for example, pictures of springs in semiarid rangelands in Oregon (Anderson and Anderson 1995); in parts of Canada (van Everdingen 1991); mound springs in Australia (Knott and Jasinska 1998); in Italy (Cantonati 1998; Cianficconi *et al*. 1998); in the Sierra Nevada, California (Erman 1998); and in desert areas of California and Nevada (Hershler and Sada 1987).

Spring Stability and Species Richness

The springs that were highest in species richness were the most stable springs throughout the years of the study, that is, they had the least change in water discharge and temperature. These were also the springs with higher concentrations of calcium and magnesium; and they had higher specific conductance, alkalinity, and pH. All but one spring declined in discharge during the drought years (Erman and Erman 1992, 1995). Small size of a spring did not indicate instability and, in fact, some of the smallest springs, hardly more than seeps, proved more permanent and constant than larger springs over time.

Caddisfly (Trichoptera) species richness was positively correlated with an intercorrelated complex of calcium, magnesium, specific conductance, alkalinity, and pH. Of these five factors, calcium showed the highest correlation with species richness and was a proxy for spring permanence (Erman and Erman 1995).

In broad spring survey work it would be more efficient to measure conductivity than calcium to predict stability, species richness and the greater possibility of rare or endemic species being present. Another indicator of permanence over time, that may be useful in spring surveys, was the presence of large mats of moss or other vegetation like *Veronica americana*. Such indicators, of course, would depend on the range of possibilities within the area being surveyed.

A direct cause and effect relationship between moss mats and increased invertebrate diversity was not clear. Many of the invertebrate species abundant in the springs with moss were not in the moss but, rather, in clear gravel zones adjacent to the moss. Nor was there a clear relationship between moss presence and physical/chemical factors although there was a trend. The presence of moss is apparently a sign of spring constancy and persistence, as well as a factor in habitat diversity. Figure 1 shows a summary of some of the relationships between caddisfly species richness and physical/chemical attributes of the springs.

Trichoptera species richness was negatively correlated with fluctuation in discharge (r^2=0.527) and with solar radiation. In other words, springs in which water discharge fluctuated the least over the years of drought had higher numbers of species (Figure 2). And shaded springs had higher numbers of species than springs with more sunlight (Erman and Erman 1990, 1995).

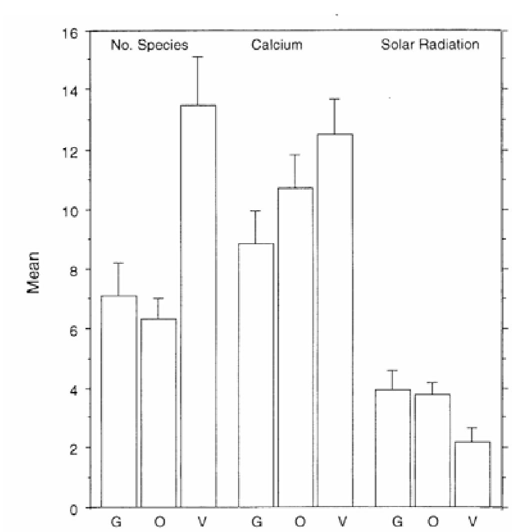

Figure 1. Mean conditions (with +1 standard error bars) in springs with primary substrates of clear gravel (G), flocculent organic matter overlying gravel (O) or vegetation over gravel (V) showing the number of caddisfly (Trichoptera) species, calcium concentration (mg/L), and solar radiation (MJoules/m^2 per year/1,000).

A recent study to determine the age of water in 11 of the springs in the Sagehen basin, using chlorofluorocarbons (CFCs) and tritium/^{3}He dating techniques, found that ages varied from less than 5 years to almost 40 years (Rademacher *et al*. 2001). The water age is the time it takes for the water to go into the ground and re-emerge at the spring source. The relationship between age of spring water, as determined by chlorofluorocarbon-11 dating, and caddisfly species richness is shown for eleven of the Sagehen basin springs and one Onion basin spring (Figure 2). There was a positive association (Wilcoxan Rank Sum Test, $P < 0.01$), that is, the older the spring water, the higher the species richness; but it was not as significant as the negative association with fluctuation in discharge ($P < 0.01$).

Individual Nature of Springs

No invertebrate assemblage types were found associated with chemical/physical attributes of springs. Springs differed widely in species composition and richness. Nevertheless, some species were indicators of certain characteristics of springs. Temperature explained the presence of species found only in the warmest springs and of species found only in the coldest springs. Some species were present in smaller springs with low discharge and others in springs with higher discharge (Erman and Erman 1990) and may have been affected by current. One species of caddisfly found during these studies is adapted to drought (i.e., requires a drying habitat to complete its life cycle) and was found in large numbers in just one temporary spring that dried by autumn every year.

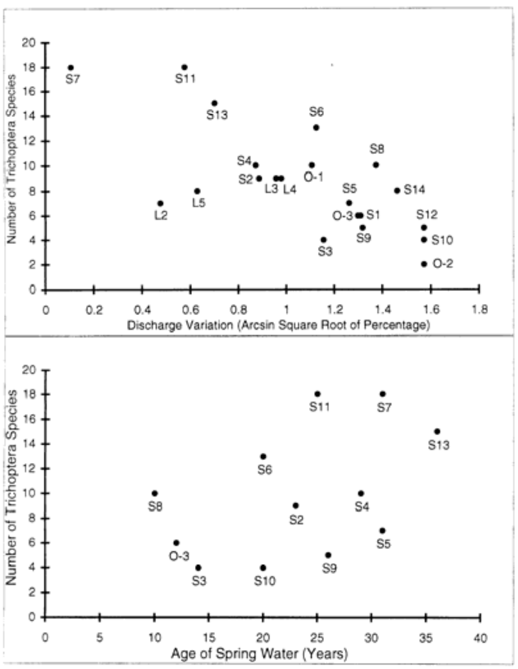

Figure 2. Relationship between variation in discharge (during predrought and drought conditions) and number of caddisfly species in 21 Sierra Nevada springs contrasted with the relationship between age of spring water (as determined by chlorofluorocarbon-11 dating) and number of caddisfly (Trichoptera) species in 12 of the same springs.

Springs in other areas have quite different groups of invertebrates and physical/chemical factors, for example, the limestone springs studied by Glazier and Gooch (1987) in the Appalachians and the desert spring systems investigated by Hershler and Sada (1987) in California and Nevada. It is, therefore, not possible to make assumptions about what animals will be in springs before they have been studied. In spring systems where water is interconnected one might expect to find more similarity of spring types and invertebrate species than was found in these rather isolated mountain springs (but see Erman 1998 for an analysis of five Sierra springs that were thought to be similar, and possibly from the same water source, and yet proved to be dissimilar in species).

The Sierra springs with the highest numbers of mollusks (snails or clams), turbellarians and amphipods were also the springs with the highest numbers of insects. And, so, they did not fit the model proposed by Glazier (1991) that hard-water springs are dominated by amphipods and/or isopods, mollusks, and triclads (Turbellaria) and that relatively soft-water springs are dominated by insects. These Sierra springs fit between Glazier's two groups of Appalachian springs based on the relationship between alkalinity and conductivity (Erman 1998) and would be classified at the high end of soft water. None are acidic. Williams and Williams (1998) also tested this hypothesis by Glazier on a group of 15 springs in Southern Ontario and found no correlation between the combined percentages of amphipods and/or isopods, mollusks, and triclads and hardness of water. Myers and Resh (2002), likewise, found the hypothesis did not fit Great Basin springs.

The caddisfly species that was most abundant in the springs of one of the western Sierra basins in this study was not present (with the exception of one larva) in the springs of the eastern Sierra basins. The habitats were similar and all other caddisfly species in the western springs were also found in the eastern Sierra springs (but the reverse was not true). The success of a species in a spring may depend on the order in which that species arrives at a spring and how it interacts with species already there.

Some of the caddisfly species in springs appear to have little or no long distance flight ability. Wings are reduced and near flightless mating behavior takes place on vegetation just above the spring (e.g., Erman 1984b, 1997). Dispersal by flight in such species is probably not much more likely than it is for a snail or a worm. Passive dispersal of eggs on fur or feathers is a possibility. Some invertebrate eggs may be transported in animal digestive tracts from spring to spring.

Conservation and Management of Springs and Spring Species

A model from Australia for beginning the process of conserving springs and spring species was presented at this symposium by Winston Ponder. Western North American researchers could benefit from the kind of regular meetings now being held to conserve the Mound Springs of Australia. The cooperation of many government agencies (for example, the U.S. Forest Service, Bureau of Land Management, Fish and Wildlife Service, state fish and game departments, regional water quality control boards) and special interest groups will be essential for the conservation and restoration of springs in western North America. The educational process of what is at stake, biologically, has begun but has a long way to go.

Unprecedented growth of human population across the western U.S. is causing the loss of springs through water consumption and construction that obliterates springs. Pumping and diversion of water from springs may be the most immediate threat to spring species and, at the extreme, eliminate springs completely. But even limited pumping or diversion may create unstable conditions through fluctuating water levels and temperature changes and, thereby, eliminate species. This study on Sierra springs indicates that stability and permanence are features that produce species richness. The use of spring biota of mountain areas has been suggested for long-term monitoring of acidification and organic pollution specifically because of the stable conditions of undisturbed springs (Cantonati and Ortler 1998).

A study of the badwater snail in Death Valley has shown that municipal water diversion and habitat trampling have adversely affected populations. Diversion of water from springs in the Funeral Mountains for municipal use and irrigation has reduced springs to approximately 15 percent of historical levels (Sada 2001). Loss of springs through pumping is currently probably a larger problem in valley and desert systems than in mountainous areas.

Overgrazing by livestock is another major threat to western springs, especially where animals are not herded or moved rapidly through wetlands. Cows tend to stay in wetland areas and degrade them by eliminating vegetation and shade and increasing water temperature. They trample banks leading to siltation in springs and streams and eliminate habitats for invertebrate species by filling the interstitial spaces around rocks and gravel. The overgrazing problem seems more easily solved than the problems of increasing water demands. But it will require, first, the acknowledgment that a problem exists and, second, the cooperation from enlightened land managers in our state and federal agencies and from the ranching community.

The three sets of springs in our studies were selected partly because they were relatively undisturbed by livestock grazing. But some of the Sagehen basin springs were grazed by sheep that were moved through the wetlands quickly at the end of summer and seemed only to cause some disturbance around springs during the drought years when they may have been left in the areas longer. Cattle grazing occurred in the Lincoln basin where it was concentrated along the second-order stream (and has caused considerable damage) but not in the springs. Efforts to find sets of springs for long-term study were hampered by the disturbed conditions found at many springs in the early 1980s on U.S. Forest Service land in northern California. Some springs were little more than mud holes with no vegetation remaining around the edge of the springs. It is hoped that in the intervening years conditions have improved.

Timber harvesting can have impacts on springs and spring species. As reported earlier, higher species richness was found in shaded springs than in exposed springs. In addition to reducing shade, logging can increase spring flow and lead to greater flow variability. And sedimentation into springs is a problem whether it comes from logging, grazing, or construction. Both federal and private timber lands in California have regulations protecting wetlands, but the adequacy of these regulations and their enforcement is unknown. Hydrogeologic mapping has been used to delineate protection zones around springs for the protection of drinking water for humans (Jensen *et al*. 1997). It may be necessary to use similar methods for spring protection, generally, especially where large land-disturbing activities such as logging and herbicide applications are being proposed.

The problems of single species management by state and federal agencies continue in springs and spring streams. Such activities as planting non-native fish in fishless springs or in spring streams, poisoning spring streams with rotenone or using herbicides to reduce a non-native plant species are done without regard for the diverse native fauna living in these habitats. Ironically, such activities are currently being done to "save" some endangered species or habitat at the same time they may cause other species to disappear or become endangered, an unfortunate perversion of the Endangered Species Act.

A five-year study on a river in Utah (Mangum and Madrigal 1999) found that "up to 100 percent of Ephemeroptera, Plecoptera, and Trichoptera [mayflies, stoneflies, and caddisflies] were missing after the second rotenone application. Forty-six percent of the taxa recovered within one year, but 21 percent of the taxa were still missing after five years." They further found that at least 19 species were still missing five years after the rotenone treatments ("at least" means some taxa were identified only to genus and may have included more than one species.)

Mechanical species-specific methods of removal of non-native species are essential if rare and/or endemic spring species are to be conserved. Where mechanical removal is not possible, it is probably better to leave the system as it is. Some level of mechanical removal is almost always possible, however, but has to be done on a continuing basis. Total eradication is usually an unobtainable objective in pest management and may cause more harm than good.

There is often an incorrect assumption in environmental assessments that invertebrate species can repopulate areas where they have been eliminated, but because many species live within narrow parameters along stream gradients, repopulation is not always possible at the species level. This misunderstanding seems to arise from confusion about the difference between aquatic invertebrates in general (or quantity of invertebrates) and individual species. Some species of aquatic invertebrates will nearly always eventually repopulate any aquatic habitat capable of supporting life, but they will not necessarily be the same species that originally occupied the habitat. The risk of harm from poisons is high to species endemic to springs and spring streams.

Moving invertebrates from one spring to another in an effort to restore spring populations has risks. The possibilities for errors are great. It is difficult enough to determine invertebrate species when they are preserved, dissected, and identified under a microscope. And it is impossible to identify many species when they are alive and in the hand. In addition, the chances of transferring other microorganisms, in the water or on the individuals being moved, is a risk. Moving invertebrates from one spring to another is too likely to become just another non-native species problem in time, and may destroy the biogeographical record present in springs. It seems wiser to concentrate spring restoration efforts on restoring habitats than on moving species.

Conclusions

Over the last 20 years, knowledge of springs in North America has rapidly expanded. It is now known that species and species richness vary widely among springs, that endemic and rare species are present in springs, that there are large physical/chemical differences among springs, that stability of springs leads to species richness, and that spring communities are interactive with communities downstream. It is also known that spring habitats are disappearing at an alarming rate, and a great deal is known about what can be done to preserve springs and species. Education and conveying the knowledge of research scientists to land and water managers in state and federal agencies and to the public seems the logical next step to spring conservation and restoration.

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