PERSPECTIVES

Copeia, 1995(4), pp. 989–991

Springs and Spring Runs as Unique Aquatic Systems

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FRESHWATER habitats are commonly (and appropriately) divided into lentic and lotic. The lotic habitats are then subdivided by stream order. A headwater stream is a first-order stream; and when two first-order streams join, they form a second-order stream. When two second-order streams join, they form a third-order stream, etc. This results in an easy stream size categorization, i.e., a sixth-order stream is larger than a fourth-order stream, etc.

This system is less effective in karst areas. Two large springs may form two large creeks that lose more than half of their volume in a recharge zone so that, when they combine to form a second-order stream, that second-order stream has less volume than either spring run outflow. Additionally, large first order spring runs may far exceed higher order streams in discharge.

Springs and spring runs are vastly different than most other streams. Typically, spring waters are clear, are stenothermal, and have little flow variation. In contrast, first-order streams may be murky, may be eurythermal, and may have major flow variations from storm events. These differences result from the distance between the spring and its recharge zone. That distance would dampen the impact of any storm event. "Normal" streams seldom have that dampening impact.

Most springs have a temperature close to the average annual air temperature for that region. Few vary by as much as 1 C. Some springs may be warmed as their aquifer passes by an underground heat source. Nevertheless, these hot or warm springs are stenothermal at an elevated temperature. Aquifers are also impacted by the potentially soluble solids they pass through, thus saline springs. In karst areas, the aquifers often have high concentrations of calcium carbonates or similar salts.

The distances (and times) that waters occupy aquifers may be quite extensive. For example, some of the water that emerges from San Marcos Spring in Texas has its recharge source 200 km west, and water emerging in San Solomon Spring in Texas has one of its recharge sources 130 km northwest. Actions in any recharge zone can impact the quantity and quality of the water emerging from the springs. The latter example is complex, as the distant source has relatively high dissolved solids and the nearby (> 50 km) recharge zone is low in dissolved solids.

Many springs and spring runs have a biota that is adapted to these conditions. For example, spring fishes of the genus *Crenichthys* occupy springs in the White River System and Railroad Valley in Nevada. These springs have elevated temperatures and low dissolved oxygen (Sumner and Sargent, 1940; Hubbs and Hettler, 1964). Spring fishes abound near the springs but are seldom found at a distance. Additionally, most members of the *Gambusia nobilis* species group inhabit springs in Texas and northern Mexico and seldom are found far from the spring sources.

As they flow downstream, spring runs are exposed to ambient air temperatures. Those ambient air conditions impact the spring run attributes by decreasing thermal stability and increasing the potential of supplemental flows from storm events (= increased flow variation and turbidity). The volume of spring flow will impact the extent of thermal consistency, and a large volume may dampen the impact of a storm event. Large springs commonly have a spring run adapted biota. The downstream biota is commonly made up of a different assemblage of species. The two biotas may have some species in common as well as some most abundant or exclusively in one assemblage. For example, *Crenichthys* occupies Nevada springs, and *Gila* occupies downstream areas; and no *Gila* are in the springs and no *Crenichthys* far downstream. Similarly, *G. geiseri* occupies Texas springs, and *G. affinis* is found downstream. No *G. affinis* have been found in the springs and no *G. geiseri* far from the springs.

The area occupied by the spring run endemics is impacted by the volume of spring discharges. When the aquifer is at its maximum, the spring run endemics have a large area of suitable habitat. During droughts, suitable habitat for spring run endemics is reduced and may be restricted to the proximity of individual springs (thus, speciation may occur). Artificial droughts (removal of ground water) may complicate the evolution and survival of spring endemics.

Large springs typically have a spring run fauna. Texas has more than 1000 springs or spring complexes (Brune, 1981), but fewer than 20 have spring-limited fishes. All of these are among the 100 largest springs in Texas. I presume that the smaller springs have insufficient area for adaptation to stenothermal conditions.

All of the Texas spring adapted endemic *Gambusia* live (or lived) in large stenothermal springs and spring runs [*G. nobilis* (Hubbs and Springer, 1957), *G. gaigei* (Hubbs et al., 1986), *G. geiseri* (Hubbs et al., 1980), *G. amistadensis* (Peden, 1973), *G. heterochir* (Hubbs, 1971), *G. georgei* (Hubbs and Peden, 1969)]. Each has (or had) a population of *Gambusia affinis* in downstream waters. Spring runs have endemics. As water flows downstream, stenothermal attributes are degraded. Eurythermal sections are occupied by *Gambusia affinis*. One example is found in the study of interactions between *Gambusia affinis* and *G. heterochir* in Clear Creek, Menard County, Texas (Hubbs, 1971). Three regions were studied: the eurythermal area that had thermal coefficients of variation ranging from 19.7 to 41.6 had one *G. heterochir* female and 11,690 *G. affinis* females; one stenothermal area had coefficients of variation from 1.5 to 20.0, and 2% of the *Gambusia* females were *G. heterochir*; and the other had coefficients of variation of 4.8 to 18.8, and more than half the *Gambusia* females (4803) were *G. heterochir*. Males had similar patterns of abundance, but there were more *G. heterochir* males in habitats dominated by *G. affinis*. The third region was separated from the other two by a distance as short as two meters.

The principle of spring runs being special stream systems is not restricted to western (= xeric) states such as Nevada and Texas. Examples are the specialized biota in Doe Run, Kentucky (Minckley, 1962); the watercress darter, *Etheostoma nuchale*, endemic to two springs in Alabama (Howell and Black, 1976); *Etheostoma cragani* in Oklahoma (Matthews et al., 1985); and *Etheostoma palidodorsum* in Arkansas (Robison and Buchanan, 1984). Similarly, in Texas, *Cyprinella proserpina* occupies spring runs, and *Cyprinella lutrensis* abounds downstream (Rhodes and Hubbs, 1992); various species of *Dionda* occupy stenothermal habitats, and *Pimephales* is in downstream eurythermal habitats.

Similarly, the invertebrate biota of spring runs are equally unique (Bowles and Arsuffi, 1993). Plants in spring runs may represent spring adapted endemics such as *Zizania texana* (Emery, 1967). Salamanders may be restricted to springs and their aquifers (Tupa and Davis, 1976; Chippendale et al., 1993).

The spring and spring run endemics often have narrow geographic distributions and are listed by state and federal governments as threatened or endangered (Williams et al., 1989). The overriding problem is the high financial value of clear, clean water in the American southwest and elsewhere. High levels of pumpage for human use have negatively impacted stenothermal endemics and have resulted in court decisions such as Pecos County Water Control District No. 1 vs Clayton W. Williams et al. (1951, unpubl.) and Sierra Club and Guadalupe Blanco River Authority et al. vs Manuel Lujan Jr. et al. (1993, unpubl.). Commonly the issue is one set of economic value vs a different set of economic use. For example, the Comanche Springs controversy included surface water irrigators vs irrigators pumping from that aquifer. Additionally, the Edwards aquifer case pitted irrigators and the San Antonio water users against recreational water users in San Marcos and New Braunfels. Consequently, the legal issue is commonly people vs people and the environment. Each instance is complex, and resolution of the controversies requires an understanding of all interests. Spring runs have a unique biota and are faced with unique problems. Consequently, they differ from other ecosystems as a group in biotic and physiochemical factors and have common characteristics in the socioeconomic realm.

Acknowledgments.—The rationale behind these discussions benefited from discussions with J. E. Brooks, G. Divine, R. J. Edwards, G. P. Garrett, D. Hendrickson, E. R. Pianka, and D. L. Propst.

Literature Cited

Bowles, D. E., and T. L. Arsuffi. 1993. Karst aquatic ecosystems of the Edwards Plateau region of central Texas, USA: a consideration of their importance, threats to their existence, and efforts for their conservation. Aquatic Cons. Marine and Freshwater Ecosystems 3:317–329.

Brune, G. 1981. Springs of Texas. Branch-Smith, Inc., Fort Worth, TX.

Chippendale, P. T., A. H. Price, and D. M. Hillis. 1993. A new species of perennibranchiate salamander (*Eurycea*: Plethodontidae) from Austin, Texas. Herpetologica 49:248–259.

EMERY, W. H. P. 1967. The decline and threatened extinction of Texas wild-rice (*Zizania texana* Hitchs). S.W. Nat. 12:203–204.

HOWELL, W. M., AND A. BLACK. 1976. Status of the watercress darter, *Etheostoma nuchale*. Proc. S.E. Fishes Council 1:1–3.

HUBBS, C. 1971. Competition and isolation mechanisms in the *Gambusia affinis* × *G. heterochir* hybrid swarm. Bull. Texas Mem. Mus. 19, Austin.

———, AND W. F. HETTLER. 1964. Observations on the toleration of high temperatures and low dissolved oxygen in natural waters by *Crenichthys baileyi*. S.W. Nat. 9:245–248.

———, AND A. E. PEDEN. 1969. *Gambusia georgei* sp. nov. from San Marcos, Texas. Copeia 1969:357–364.

———, AND V. G. SPRINGER. 1957. A revision of the *Gambusia nobilis* species group, with descriptions of three new species, and notes on their variation, ecology, and evolution. Tx. J. Sci. 9:279–327.

———, R. J EDWARDS, AND E. MARSH. 1980. The status of the San Marcos gambusia, *Gambusia georgei*. Endangered Species Report 9, U.S. Fish and Wildlife Service, Albuquerque, NM.

———, G. HODDENBACH, AND C. M. FLEMING. 1986. An enigmatic population of *Gambusia gaigei*. S.W. Nat. 31:121–123.

MATTHEWS, W. J., J. J. HOOVER, AND W. B. MILSTEAD. 1985. Fishes of Oklahoma springs. S.W. Nat. 30: 23–32.

MINCKLEY, W. L. 1962. The ecology of a spring stream, Doe Run, Meade County, Kentucky. J. Wildl. Monogr. 11:1–124.

PEDEN, A. E. 1973. Virtual extinction of *Gambusia amistadensis* n. sp., a poeciliid fish from Texas. Copeia 1973:210–221.

RHODES, K., AND C. HUBBS. 1992. Recovery of Pecos River fishes from a red tide fish kill. S.W. Nat. 37: 178–187.

ROBISON, H. W., AND T. M. BUCHANAN. 1988. Fishes of Arkansas. Univ. of Arkansas Press, Fayetteville.

SUMNER, F. B., AND M. C. SARGENT. 1940. Some observations on the physiology of warm spring fishes. Ecology 21:45–51.

TUPA, D. D., AND W. K. DAVIS. 1976. Population dynamics of the San Marcos salamander, *Eurycea nana* Bishop. Tx. J. Sci. 32:179–195.

WILLIAMS, J. E., J. E. JOHNSON, D. A. HENDRICKSON, S. CONTRERAS-BALDERAS, J. D. WILLIAMS, M. NAVARRO-MENDOZA, D. E. MCALLISTER, AND J. E. DEACON. 1989. Fishes of North America endangered, threatened or of special concern: 1989. Fisheries 14:2–20.

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