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Chapter 3

Effects of Acidic Runoff Episodes on Fish Populations and Diversity in Pennsylvania

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ABSTRACT

This paper provides an overview of fisheries studies in headwater Pennsylvania streams that are subjected to acidic runoff episodes. During such episodes it is common for pH to decline by more than one unit to values approaching 4.5 and for total dissolved aluminum to increase to 400 ug/L. Brook trout (*Salvelinus fontinalis*) embryos incubate in stream gravel over winter and are vulnerable to high mortality caused by acidic episodes. In situ bioassays have been used to demonstrate that acidic episodes can result in >80% mortality of brook trout and sculpins (*Cottus spp.*). Brook trout are displaced downstream in response to acidic episodes. Displaced fish frequently congregate in areas where alkaline groundwater seeps or tributaries enter main channels. These chemical refugia seem to mitigate the lethal effects of episodes. Population density of brook trout is strongly related to episode severity, and many populations seem to be transient because of periodic lethal conditions caused by episodes. Streams subjected to acidic episodes support fewer fish species than they did 25 to 30 years ago. Thus, fish biodiversity also seems to be a function of episode severity.

INTRODUCTION

During the past 15 years, faculty and graduate students here at Penn State have been actively engaged in research dealing with the effects of acidic runoff events on stream fish communities. This paper provides an overview of these studies and summarizes important findings made here and elsewhere. One of our major studies, part of the Episodic Response Project (ERP), was done in collaboration with research teams in the Catskill and Adirondack regions of New York, scientists from the Environmental Protection Agency, and several consulting firms (Wigington et al., 1996). We shall frequently refer to results of this project, because a number of important generalities emerged from it.

The approach we have taken in this paper is to first review the effects of acidic episodes on individual organisms, starting with early life stages and then juveniles and adults. We briefly examine population-level effects and conclude with community-level effects. Much of our work on individual organisms and populations focused on brook trout, though we worked extensively with mottled sculpins (*Cottus bairdi*) and slimy sculpins (*C. cognatus*). These three species are among the most common fishes in headwater streams that are vulnerable to acidic episodes.

STUDY SITES

The most intensive fisheries studies were conducted in five streams on the Northern Appalachian Plateau: Baldwin Creek and Linn Run in southwestern Pennsylvania, and Benner Run, Roberts Run, and Stone Run in the north-central region (Fig. 1). Baldwin Creek and Benner Run were used as reference sites, because they showed little or

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no evidence of acidic episodes. All streams were first or second order, and their watersheds were largely covered with hardwood trees. All watersheds were within public lands, and there were no human disturbances, other than acidic atmospheric deposition, that might have influenced water quality or fish communities. Wigington et al. (1996) provide summaries of physical characteristics of all ERP study streams.

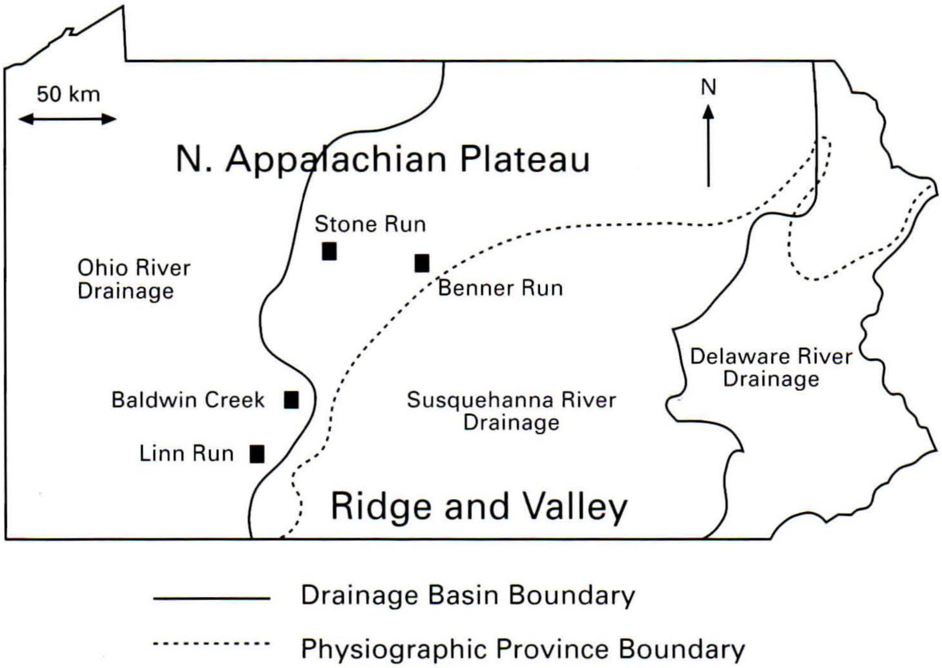

Fig. 1. Pennsylvania streams used in fisheries studies of acidic runoff events. From Gagen et al. (1994).

RESULTS AND DISCUSSION

Early Life Stages

Fiss and Carline (1993) provided direct evidence showing that acidic episodes cause mortality of brook trout eggs and alevins. They found that survival of brook trout embryos in natural redds in three ERP streams ranged from 16 to 68% and was inversely related to concentrations of inorganic monomeric aluminum (Al_{im}). They also conducted in situ bioassays with brook trout alevins; survival ranged from 51 to 95% and was inversely related to Al_{im}. Jordahl and Benson (1987) conducted similar studies in West Virginia streams. Survival of brook trout eggs ranged from 4 to 7% and that of alevins ranged from 0.4 to 3% in two streams with low pH (4.7-5.8). In contrast, combined survival of eggs and alevins in a stream with a high pH (6.1-7.2) was 77%.

Juveniles and Adults

In situ bioassays in streams subjected to acidic runoff events have provided conclusive evidence that such episodes are lethal to resident fishes. In these bioassays, juvenile brook trout (ages 0.5 to 1.5 years) and adult sculpins were used. During spring runoff events, when episodes were most severe, mortality of sculpins and brook trout was as high as 90-94% in low pH streams, but generally less than 10% in reference streams (Gagen et al., 1993).

Van Sickle et al. (1996) showed that the median concentration of Al_{im} was the best single predictor (r^2=0.59) of brook trout mortality in bioassays among all ERP streams (Fig. 2). Multiple regressions that also included median Ca concentrations and minimum pH further improved the correlation coefficient (R^2=0.72). Median concentration of Al_{im} was the best predictor (r^2=0.86) of sculpin mortality in bioassays (Fig. 2). No other water quality variable accounted for a significant improvement in the correlation coefficient.

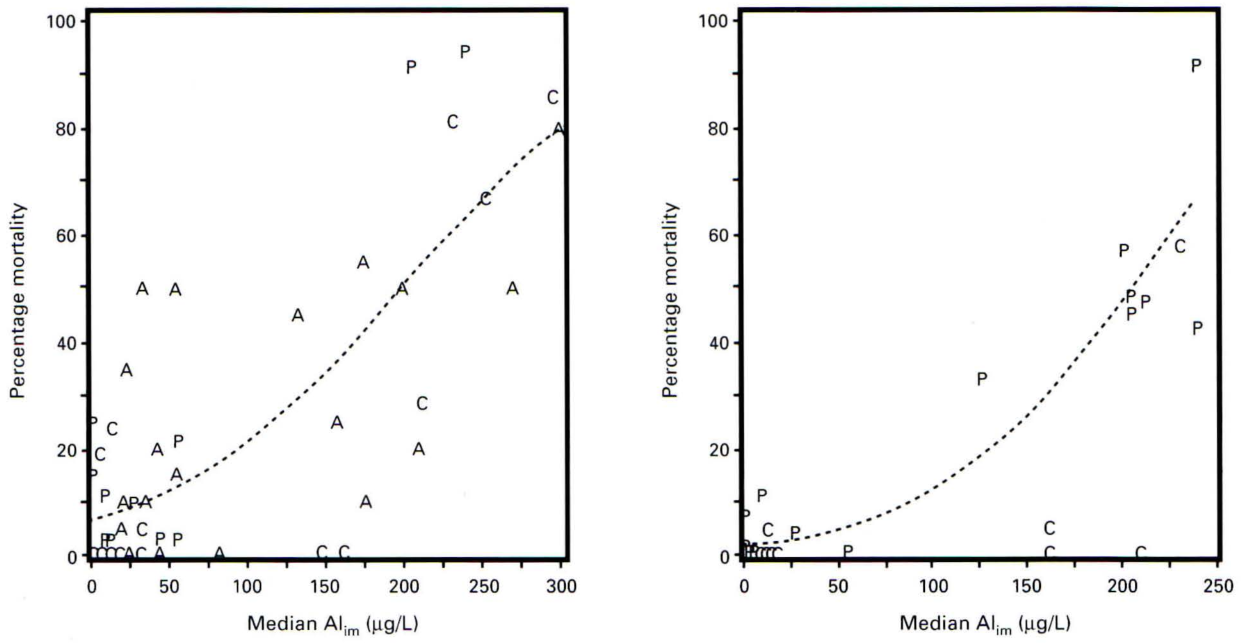

Fig. 2. Percentage mortality of brook trout and sculpins from in situ bioassays in relation to time-weighted median Al_{im}. Experiments were conducted in Adirondacks (A), Catskills (C), and Pennsylvania (P) streams. Figures from Van Sickle et al. (1996).

The only direct evidence showing that adult brook trout died in response to acidic episodes is from telemetry studies conducted by Gagen et al. (1994). During spring trials, five of 15 radiotagged brook trout died in Linn Run, and three of 10 died in Stone Run; no radiotagged brook trout died in the reference streams. We know of no evidence that suggests adult brook trout are less vulnerable to acidic episodes than juveniles.

Modes of Toxicity

The effects of low pH and high concentrations of Al on the physiology of trout and other species have been well documented. Low pH disrupts ionoregulatory functions, which are largely controlled by specialized cells on the gill membranes (Wood, 1989). Loss of essential ions, particularly Na and Cl, is the primary cause of death. This loss of ions is accelerated in the presence of Al, which affects chloride cells on gill membranes (Tietge et al., 1988). Wood (1989) found that if either Na or Cl fell below 30% of their normal value, death of rainbow trout (*Oncorhynchus mykiss*) occurred within hours. Gagen and Sharpe (1987) showed that juvenile trout held in Linn Run during acidic episodes lost up to 40% of total body Na; after seven days of exposure, mortality was 100% for rainbow trout, 100% for brown trout (*Salmo trutta*), and about 70% for brook trout.

Behavioral Responses

The most conspicuous behavioral response of trout to acidic episodes is downstream movement. Sharpe and Gagen (1992) stocked hatchery-reared brook trout and brown trout in Linn Run and simulated an acidic episode by shutting off flow from several alkaline wells. This reduced stream pH by about one unit and increased total dissolved Al to about 100 ug/L. More brown trout than brook trout moved downstream in response to this simulated episode. A few days later, a storm event produced an episode that was more severe than the simulated one. This second episode induced substantial downstream movement of the remaining brook trout.

Gagen et al. (1994) implanted miniature radio transmitters in adult, wild brook trout and monitored their locations for 35 days, during which time several severe episodes occurred. The first trial was conducted in spring 1989 in Linn Run, a low alkalinity stream, and in Baldwin Creek, which maintains good water quality during high flow events. On day 3 a storm event resulted in high streamflows and a large increase in concentrations of Al in Linn Run (Fig. 3). In response, brook trout began gradually moving downstream. Several other storms ensued and by the end of the 30-day trial, the mean net downstream displacement of surviving trout exceeded 400 m. A similar trial was conducted the following year in Benner Run and Stone Run. Though Al concentrations in Stone Run were not as high as in Linn Run, net downstream movement in Stone Run greatly exceeded that observed in Linn Run.

Investigators have frequently reported finding trout in stream microhabitats with better water quality (chemical refugia) than in the main stem during acidic episodes. For example, during episodes, Gagen et al. (1994) found brook trout near alkaline groundwater seeps, Dolte (1998) observed brook trout in alkaline tributaries, and Baker et al. (1996) reported that brook trout emigrated from an acidic stream into a lake. It is not clear if trout actively seek out chemical refugia during episodes or if they find these refugia by chance during passive downstream movements. Gagen et al. (1994) suggest that movement is passive, because trout oftentimes do not begin moving until toxic conditions have persisted for a day or more and after exposure to high concentrations of Al, trout do not readily respond to physical or visual stimuli. Regardless of whether trout move actively or passively in response to episodes, their use of chemical refugia allows them to survive otherwise lethal conditions. It is likely that chemical refugia help mitigate the effects of acidic episodes and facilitate recolonization of stream segments following the return of circumneutral conditions.

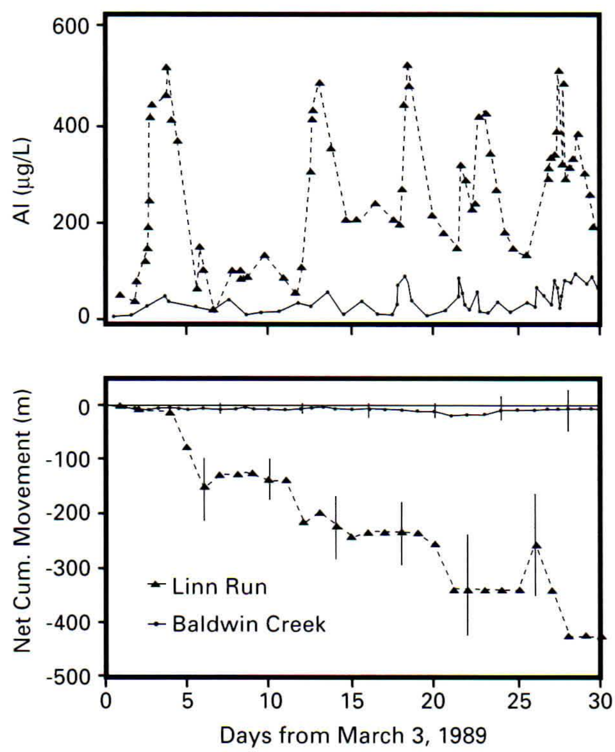

Fig. 3. Concentrations of total dissolved Al and mean net cumulative movement of brook trout in Linn Run and Baldwin Creek, spring 1989. From Gagen et al. (1994).

Population Responses

Among those stream systems that have been carefully examined, there seems to be a clear relation between densities of brook trout and water quality. Brook trout densities within the upper Linn Run drainage ranged from 1.7 to 180/0.1 ha in tributaries and the main stem, while mottled sculpin densities ranged from 0.2 to 227/0.1 ha (Carline et al., 1994). The lowest fish densities were found in the upper portion of the main stem, where Al concentrations were highest during storm events. The highest fish densities occurred in more alkaline tributaries, where Al concentrations were consistently low.

Among the five Pennsylvania streams included in the Episodic Response Project, brook trout density was closely correlated with the severity of acidic episodes (Carline et al., 1994). Baker et al. (1996) showed that both density and biomass of brook trout in ERP streams in Pennsylvania and New York were highly correlated with median weekly pH and Al_{im} (Fig. 4) and with median pH and Al_{im} during high streamflows. Given that acidic runoff events may produce conditions sufficiently toxic to kill all life stages of brook trout and induce downstream movement, it is not surprising that population density is directly related to episode severity.

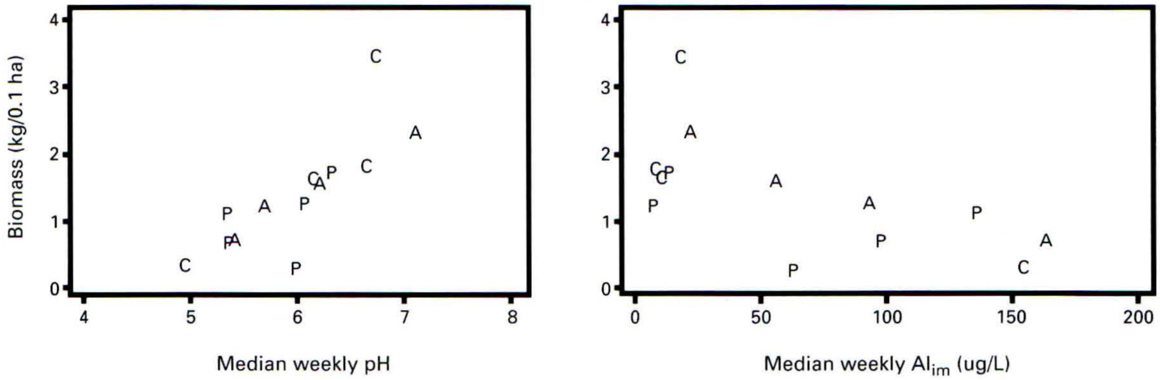

Fig. 4. Mean biomass of brook trout, 1988-1990, in relation to median weekly pH and median weekly Al_{im} in Adirondacks (A), Catskills (C), and Pennsylvania (P) streams. Figure from Baker et al. (1996).

Presumably, the relations between episode severity and sculpin density are similar to those for brook trout. Evaluating population-level responses of sculpins has been hampered because it is difficult to sample sculpins efficiently, hence, difficult to obtain precise estimates of population size. More often, investigators have relied on presence and absence data or catch-per-unit effort to assess sculpin abundance. The absence of sculpins in streams that have severe episodes (Sharpe et al., 1987) and the variation in sculpin abundance relative to water quality in the Linn Run basin (Carline et al., 1994) provide at least circumstantial evidence that sculpin densities reflect episode severity.

Communities

Unaltered headwater streams throughout Pennsylvania typically support fish communities consisting of just a few species. Streams subjected to acidification support even fewer species. Sharpe et al. (1987) surveyed 61 headwater streams in southwest Pennsylvania; of these, 49 were considered relatively uninfluenced by human disturbances. They found no fish in 10 streams that had the lowest pH and highest concentrations of total dissolved Al. Six streams supported remnant populations of brook trout and sculpins; these had intermediate values for pH and Al. Thirty-three streams—those that had the highest pH and lowest Al—all supported brook trout, most had sculpins, and one had blacknose dace.

Heard et al. (1997) provided rather strong circumstantial evidence that the reduction in species richness of low-alkalinity headwater streams was related to acidification. In 1994 and 1995 they sampled water quality and fish communities in 50 streams (1st-3rd order) on the Appalachian Plateau and 20 in the Valley and Ridge physiographic province and compared these data to those collected by E. Cooper (unpublished data, Pennsylvania State Fish Museum) in the same stream reaches during the period 1961-1971. The total number of species collected in Appalachian Plateau streams declined from 42 to 36 and from 25 to 21 in Valley and Ridge streams. Seventy-six percent of streams on the Appalachian Plateau and 65% of those in the Valley and Ridge province had fewer species in 1994-1995 compared to 1961-1971. In both regions, the mean number of species lost was about 3.5. Alkalinity and pH of streams that lost species were significantly lower in 1994-1995 than in 1961-1971, but there were no significant differences in these water quality variables for streams that did not lose species. Sampling during runoff events also showed poorer water quality in streams that lost species compared to those that did not. Heard et al. (1997) concluded that many low-alkalinity streams in Pennsylvania have had a reduction in fish diversity as a result of episodic acidification.

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