Evidence of Stock-recruit Relationships for Appalachian Brook Trout

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Abstract: Stock-recruit (SR) relationships have been reported for numerous stocks of trout and Pacific salmon, but despite the intuitive appeal, evidence of such relationships is lacking for brook trout (*Salvelinus fontinalis*). The relationship between number of adults spawning in a stream and the subsequent number of young produced can be used by management to predict year class strength. Disruptions of SR relationships (for species that exhibit strong relationships) can be indicative of environmental perturbations or habitat impairment. As part of a long-term study we have estimated brook trout abundance and measured habitat and water quality in 25 headwater streams in West Virginia since 2003. These streams span 4 geologies and include: Hampshire group, Mauch Chunk, Chemung, Pottsville, and Pottsville streams limed by the West Virginia Department of Environmental Protection. Strong SR relationships were detected for streams in the Hampshire group ($P < 0.01$) and the Pottsville group ($P < 0.05$). The relationship differed among years within the Hampshire groups suggesting the influence of annual variation in conditions such as stream discharge in structuring brook trout populations. Analysis aimed at identifying stream features (habitat, water quality, elevation, gradient, benthic macroinvertebrate community metrics, etc.) failed to detect any consistent variable related to strength of SR relationships in the streams. Although we were able to find a SR relationship for brook trout in some geologies, we were unable to find significant explanatory variables correlated with the relationship. This is likely due to different factors or combinations of factors weakening the underlying SR relationship in different streams. Further elucidation of factors affecting SR relationships will be possible with continued sampling of these streams.

Key words: brook trout, stock-recruit, headwater streams, population dynamics

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Seminal work by Beverton and Holt (1957), Ricker (1954), and Cushing (1981) has laid the foundation for the use of stock-recruit (SR) relationships and models to provide appropriate conservation end points for managing fish stocks. In theory, when adult stock size is low, compensatory mechanisms permit higher survival of young resulting in relatively higher stock size of young-of-year (YOY) fish (Ricker 1975). As the adult stock size increases, density-dependence may serve to reduce corresponding YOY abundance. For species in which spawning areas may be limiting, such as for stream-dwelling salmonids, YOY abundance could be further reduced at very high adult stock sizes as nests of earlier spawning fish are excavated by later-spawning fish or through antagonistic behavior that limits successful reproduction at high adult densities (Figure 1).

Stock-recruit relationships have been detected for many species of salmonids. Elliott (1994) and Langeland and Pedersen (2000) found strong SR relationships for brown trout (*Salmo trutta*) in Europe. In Pacific salmon, SR relationships are so commonly held that they are the basis for management of migratory stocks, using these relationships to manage for optimal escapement to the spawning grounds. In eastern North America, two species of salmonids are native: Atlantic salmon (*Salmo salar*) and brook

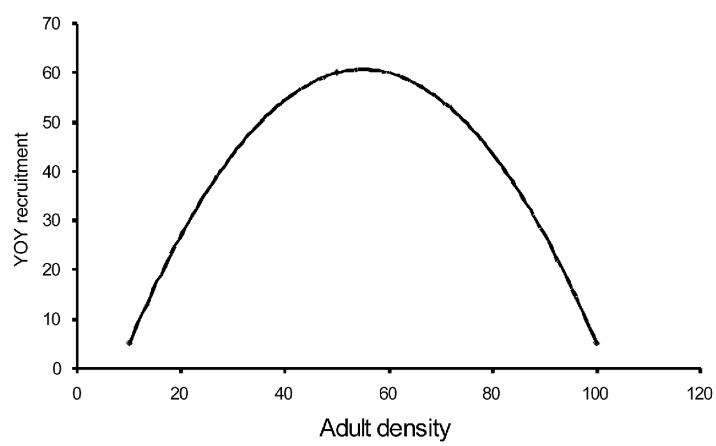

Figure 1. A hypothetical stock-recruitment relationship showing areas of compensation and density-independent recruitment at low adult stock size and depensation and density-dependence at high adult stock size.

trout (*Salvelinus fontinalis*). Stock-recruit relationships have been shown for Atlantic salmon (Chadwick and Randall 1986, Jonsson et al. 1998, Bagliniere et al. 2005), but SR relationships for brook trout have not been published.

The lack of published SR relationships for brook trout could be due to several factors. Many environmental and anthopogenic factors could obscure underlying SR relationships and studies failing to detect a relationship would likely be more difficult to publish than those that show one. In addition, few studies with brook trout have the temporal scale needed to detect such a relationship. We hypothesized that a SR relationship does exist for Appalachian brook trout. Data collected as part of a long-term study of brook trout populations in West Virginia provided the information necessary to test this hypothesis. Our objectives in this study were to (1) determine the presence of a SR relationship for Appalachian brook trout, and (2) examine variables that may affect SR relationships for Appalachian brook trout.

Study Site

In 2003 we began an ongoing, long-term study to evaluate population dynamics of brook trout in West Virginia. In the Appalachian Mountains in West Virginia headwater streams bearing brook trout originate in several different geological formations. These geologies differ in their alkalinity and also in their benthic macroinvertebrate production (McClurg 2004). Brook trout feed primarily on aquatic and terrestrial insects (Thonney and Gibson 1989, Thorne 2004, Utz and Hartman 2007, Sweka and Hartman 2008) and both benthic macroinvertebrate production and alkalinity are related to brook trout production (Clarke and Scruton 1999). Therefore, our study design included stratification of study streams across the common headwater trout stream geologies.

A total of 25 streams were selected for study in four different geologies (Table 1). Streams were classified as to geology based upon the predominant watershed geology from USGS geology maps for the region. The four geologies were the Hampshire group, Chemung group, Mauch Chunk group, and the Pottsville group. We included a fifth geological classification in this design (Pottsville-limed) to consider possible differences in brook trout population dynamics between streams treated with limestone sand and those that were not in the Pottsville geology. The West Virginia Department of Environmental Protection adds limestone sand to many of the headwater streams in the Pottsville group to

Table 1. The 25 study streams used in evaluating SR relationships in Appalachian brook trout. All streams are located in West Virginia. Streams are stratified by geological classification and mean water quality, habitat, landscape, and food web variables are listed. Here Mean SR is the r2 value for the mean SR relationship for a stream's geological classification; ALK is mean alkalinity; WVSCI is the benthic macroinvertebrate metric score (West Virginia Stream Condition Index); BMI is mean biomass of benthic macroinvertebrates; % forested is the percent of the watershed that is in forest cover type; and road density is a metric derived from dividing the length of roads within the riparian corridor to the length of stream in the study reach.

Stream name	Geology	Mean SR	Min pH	ALK	WVSCI	BMI	Gradient	Elevation (m)	Pool area	% Forested	Road density
Block Run	Chemung	0.12	5.43	3.00	82	0.269	0.054	1030	12.2	87.2	0.01
Clubhouse Run	Chemung	0.12	5.05	2.00	81	0.194	0.044	950	17.4	99.9	0.05
Elleber Run	Chemung	0.12	5.69	3.38	81	0.465	0.047	1147	5.4	88.1	0.47
Lick Run	Chemung	0.12	5.5	4.75	89	0.229	0.052	997	8.6	99.9	0.81
Poca Run	Chemung	0.12	5.25	2.38	79	0.510	0.092	1068	12.9	100.0	0.69
Big Run	Hampshire	0.60	5.46	4.63	78	0.116	0.042	1155	39.9	97.4	0.00
Elklick Run	Hampshire	0.60	5.85	17.38	77	0.285	0.034	603	23.5	98.8	0.58
Little Low Place	Hampshire	0.60	5.65	5.37	88	0.726	0.063	973	12.0	99.8	0.16
Seneca Creek	Hampshire	0.60	5.73	6.38	84	0.285	0.021	1138	51.9	98.1	0.00
Whites Run	Hampshire	0.60	6.12	22.25	83	0.596	0.064	733	12.6	85.6	0.22
Brushy Run	Mauch Chunk	0.00	5.8	13.88	87	0.409	0.064	716	14.0	94.6	0.36
Crooked Run	Mauch Chunk	0.00	6.25	10.00	77	0.132	0.040	1012	12.4	94.7	0.10
Long Run of Seneca	Mauch Chunk	0.00	5.78	11.00	80	0.276	0.028	701	20.6	98.5	0.15
Red Run	Mauch Chunk	0.00	4.1	7.25	73	0.026	0.044	955	11.8	98.2	0.16
Roaring Run	Mauch Chunk	0.00	5.79	8.88	76	0.183	0.082	766	21.0	97.5	0.20
Light Run	Pottsville	0.35	5.21	2.63	75	0.046	0.037	757	23.6	92.8	0.02
Little Branch	Pottsville	0.35	5.65	8.63	84	0.207	0.069	1073	12.6	99.6	0.00
North Fork of Panther Run	Pottsville	0.35	5.07	1.33	60	0.017	0.053	770	15.8	95.5	0.00
Sand Run	Pottsville	0.35	5.22	1.75	77	0.179	0.054	1065	12.6	99.8	0.00
Sugar Drain	Pottsville	0.35	5.65	7.88	85	0.065	0.077	872	15.8	97.1	0.00
Birch Run	Pottsville-unlimed	0.00	5.6	8.50	85	0.046	0.030	872	24.1	98.7	0.02
Long Run WERF	Pottsville-unlimed	0.00	5.88	3.83	72	0.027	0.053	757	20.3	86.7	0.14
Panther Run	Pottsville-unlimed	0.00	6.24	13.17	84	0.032	0.063	761	11.5	95.4	0.00
Rocky Run	Pottsville-unlimed	0.00	4.85	1.50	72	0.094	0.039	821	15.0	99.2	0.17
Schoolcraft Run	Pottsville-unlimed	0.00	5.32	8.25	85	0.046	0.026	742	25.6	90.7	0.08

buffer these watersheds against acid inputs from mines and atmospheric deposition (Clayton et al. 1998).

Methods

To evaluate possible SR relationships in brook trout, we first sampled brook trout populations (sampling methods described below) and then attempted to explain relationships using other attributes of each stream (habitat, water quality, watershed characteristics, and benthic macroinvertebrates). We conducted habitat assessments using a modification of the Basinwide Visual Estimation Technique (Dolloff et al. 1997). Each stream was sampled for habitat in the summer every two years from 2003 through 2006. In addition to habitat variables, we also collected water quality information (i.e., temperature, alkalinity, pH) at least twice a year. We remotely sensed landscape variables (e.g. watershed area, land cover types, road density) in 2006 using a GIS. We collected benthic macroinvertebrate collections in three replicate kick-net samples during spring 2006 at each stream section (see Stolarski 2007). We collected spawning sediment samples during fall fish sampling from 2003–2006, but these were not entirely processed for 2005 and 2006 at the time of this writing and, hence, despite the potential importance in explaining SR relationships (Hakala and Hartman 2006) these data could not be included in the analysis.

Brook trout spawn in September and October in West Virginia streams (Hakala 2000) and the young emerge from their gravel redd the following spring. Therefore, we sampled brook trout once per year during the spawning period to assess the density of adults spawning in each stream that year and the density of YOY fish produced by the previous year's spawning efforts. Our sampling of trout began in fall 2003 and continued through 2006, thus providing three pairs of adult density and corresponding YOY density for each stream. Sampling of brook trout was conducted on three representative 100-m reaches on each stream. We used a backpack electroshocker and three-pass removal to estimate the number of YOY and adult brook trout for each stream using Program MARK. Each fish was anesthetized in a clove oil solution (Anderson et al. 1997) and its total length and weight recorded. Fish were allowed to recover before being released into the stream following electrofishing sampling in that reach. Length-frequency analysis was used to partition YOY and adult fish abundance on each stream.

To test whether brook trout exhibited a SR relationship, we compared the density of adults (number per 300 m) with the corresponding density of YOY (number per 300 m) that they produced using ANOVA and an alpha level of 0.05. A hierarchical analysis was conducted looking first for any SR relationship across all streams and years, then looking within a geological classification. With only three complete measures of adult and YOY density on each stream we were unable to analyze each stream for a SR relationship so subsequent analysis was restricted to pooling streams within a geological classification. Each stream was assigned a value for strength of SR relationship using the correlation coefficient for the SR relationship in that stream's geology. Once we detected a significant relationship we used explanatory variables such as those described for water quality, habitat, food webs, and watersheds (Table 1) to attempt to explain the strength of SR relationship, or lack of a relationship across geologies, again using ANOVA and alpha = 0.05. The variables we used to explain the strength of SR relationships were those that have been shown to be important in describing brook trout abundance in previous studies (e.g., pH, alkalinity, pool area, elevation; Hakala and Hartman 2004, Almodovar et al. 2006, Rieman et al. 2006) as well as those that describe landscape attributes that are associated with sedimentation rates (percent forest cover, road density, and gradient; Hakala 2000, Sanders 2004) and those we considered reflective on food webs (West Virginia Stream Condition Index and benthic macroinvertebrate mean biomass). Bagliniere et al. (2005) reported differences in the strength of SR relationships in Atlantic salmon across years, so we also considered year-to-year differences in SR relations in our analysis.

Results

We found a significant relationship between adult brook trout density and subsequent YOY recruitment (74 d.f., $F = 5.47$, $P = 0.02$) when pooling data across streams and years (Figure 2). There was still considerable variation in the data and the linear regression model explained only 7% of the variation in the data across streams and years. This variability suggested that relationships for individual geologies or streams may either be lacking or different, so we examined the relationship within each geological classification.

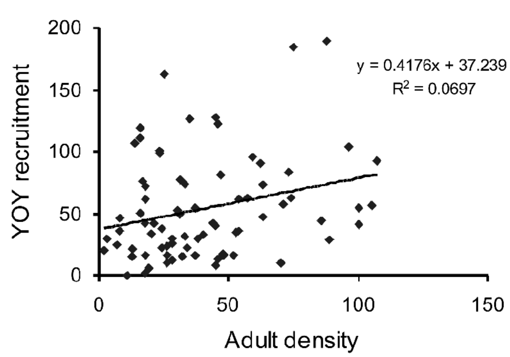

Figure 2. The brook trout stock-recruit relationship for data pooled across 25 study streams and four years (2003–2006). A weak relationship was detected between adult spawning stock density (t) and subsequent recruitment of YOY trout (t + 1). Units are number of adults or YOY per 300 m.

Some of the geological classifications had significant SR relations while others did not. A strong SR relationship was found in the Hampshire group (Figure 3) and in the Pottsville-unlimed classification (Figure 4) but not in the other geologies. Within these two geological classifications that produced SR relationships there were year-to-year differences in the strength and shape of the relations. Both classifications produced strongest SR relationships in 2004–05 (2005 year class produced by fall 2004 spawning) and weaker relationships in 2003–04 and 2005–06.

Correlation of individual stream variables (Table 1) with the presence of a significant SR relationship in a stream's geological classification failed to detect any water quality, habitat, or watershed variable that was related to SR relationships ($P > 0.05$). However, several variables were found to be significantly different across geologies. Alkalinity differed among geologies (4 d.f., $F = 2.93$, $P = 0.046$) being highest in the Hampshire group (11.2) and lowest in the Chemung group (3.1). Spring benthic macroinvertebrate biomass (BMIB) was also significantly different (4 d.f., $F = 4.93$, $P = 0.006$). The Hampshire group had the highest BMIB and was different than the Pottsville classifications. Lowest BMIB was in the Pottsville-limed classification, significantly lower than in the Hampshire and Chemung classifications.

Discussion

Previous studies have verified SR relationships for many species of trout and salmon (Solomon 1985, Chadwick and Randall 1986, Elliott 1994, Bagliniere et al. 2005). However, this paper presents the first evidence of a SR relationship for brook trout. This adds to the body of literature suggesting SR relationships exist for many salmonids and hints that SR relationships for stream-dwelling salmonids are probably the rule for most species. If SR relationships are the norm for stream-dwelling salmonids, then significant interest lies in exploring why they do not exist in some streams or why they vary across years.

Verification of a SR relationship for brook trout offers several important management implications. Most notably is the ability to use the SR relationship to predict recruitment in some streams based on adult spawning populations. Where strong SR relationships exist it is possible to predict population recovery times following environmental perturbations such as droughts or floods. Knowledge of the SR relationship in different streams or geologies could lead to management actions or fine-tuning of regulations to protect populations where recruitment is more strongly influenced by environmental conditions that adult stock size. Similarly

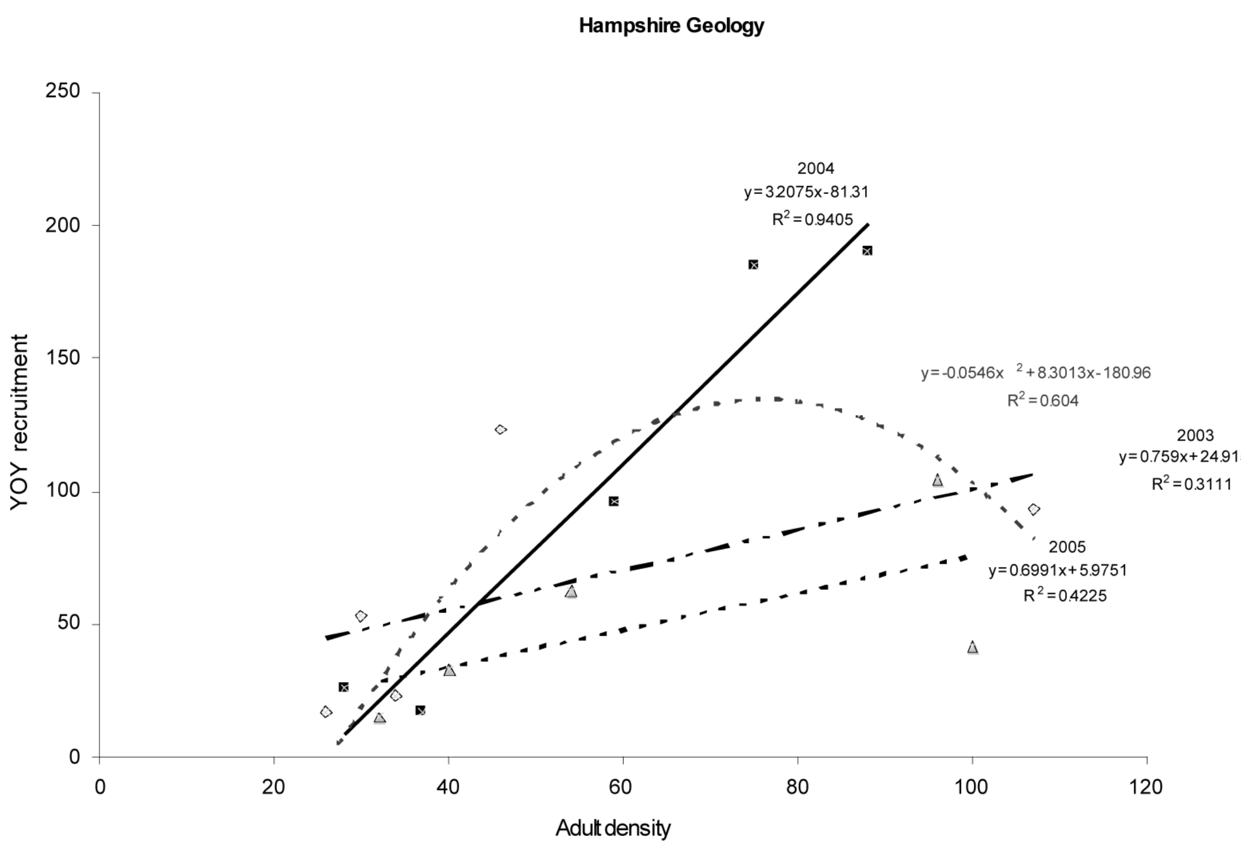

Figure 3. The stock recruit relationship for brook trout (number of trout per 300 m) in the Hampshire group geological classification shows a strong relationship overall ($r^2 = 0.60$). However, differences in the strength of the relationship occur between years (2003, diamonds; 2004, squares; 2005, triangles) suggesting other factors modify this relationship from year to year.

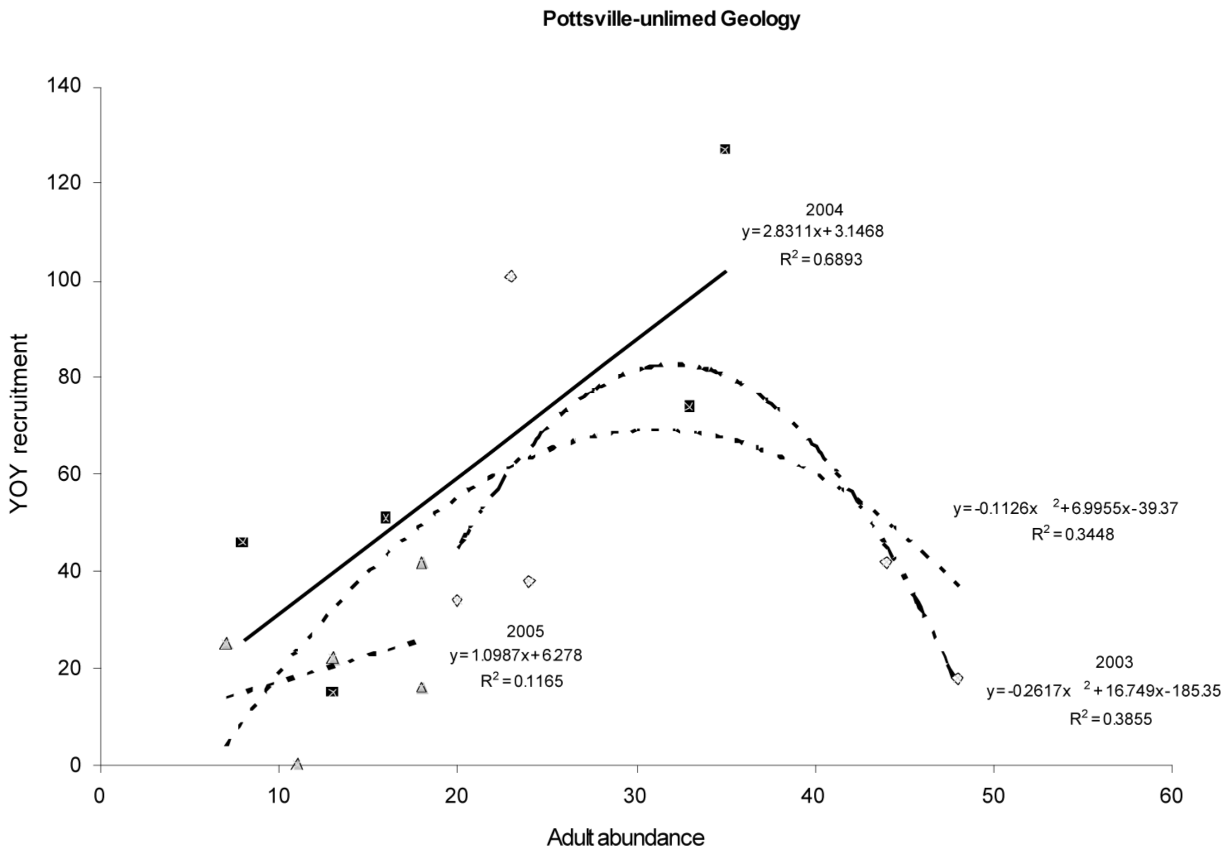

Figure 4. The stock recruit relationship for brook trout (number of trout per 300 m) in the Pottsville-unlimed geological classification shows a strong relationship overall ($r^2 = 0.35$). As with the Hampshire group (Figure 3), the relationship differs between years and was strongest in 2004. Here 2003 points are depicted by diamonds, 2004 points by squares, and 2005 points by triangles.

the SR relationship could be used to manage watersheds for optimal recruitment levels through harvest strategies that seek to maintain adult populations at the densities producing optimal recruitment. Essentially, differences in underlying SR relationships within a geology suggests a new context for "trout management units"—geological stream groups.

The SR relationship can also be used to define appropriate reference points to meet conservation goals. The presence of a SR relationship for brook trout means that each stream should theoretically have its own relationship. Lack of a relationship can be considered a measure of the role of abiotic factors in regulating that streams population (Sakuramoto 2005). Baglineare et al. (2005) found that factors such as fine sediment levels in spawning substrate was responsible for weakening SR relations in Atlantic salmon. Fine sediment levels (<0.063 mm) in spawning substrate exceeding 1% by weight have been found to negatively affect brook trout recruitment (Hartman and Hakala 2006) so these or other factors may be responsible for the lack of SR relations in some streams or geologies for brook trout.

We were unable to detect explanatory variables that were significantly related to SR relationships in brook trout in our streams. The reason for this is probably related to a lack of power relative to myriad explanatory variables and the fact that different factors or combinations of factors are likely responsible for disruption of SR relations in individual streams or geologies. Further, some streams maintained stable adult densities across the three complete years of SR data so that a sufficient range of adult densities were probably not present to detect a relationship. Further research is needed to elucidate which variables or combinations of variables are related to disruption of SR relationships for brook trout in these Appalachian headwater streams. Continuation of long-term stream studies such as the one initiated here represent our only hope for unlocking the population dynamics of brook trout.

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