2018 *NORTHEASTERN NATURALIST* 25(1):1–20

Changes in the Status of Native Brook Trout on Laurel Hill, Southwestern Pennsylvania

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Abstract - To evaluate the status of native *Salvelinus fontinalis* (Brook Trout) on Pennsylvania's Laurel Hill, we sampled fish, assessed habitat, and documented water quality from 20 non-randomly selected headwater streams of northwest- and southeast-facing slopes. In late spring and early summer of 2011 and 2014–2016, we sampled fish communities and measured specific conductance (µS/cm), total alkalinity (mg/l as $CaCO_3$), pH, and total dissolved aluminum (2011 and 2016). In addition, in 2015 we determined land-use patterns, riparian canopy, and substrate composition. Mean pH values among the streams recently assessed were significantly higher than historic values; however, all other water-quality parameters were similar. Native Brook Trout were present in all streams, and annual natural reproduction was evident in 90% of streams. Even though fish were present, we observed marked declines in total catch in both 0-age and adult trout; the overall reduction approached 60% when compared with those documented in 1983. We discuss possible causes for the observed declines, including acid deposition, introduction of nonnative/invasive species, water withdrawal, habitat fragmentation/alteration, predation, and climate change.

Introduction

Conservation of ecologically sensitive riverscapes and their attendant flora and fauna may require continued reassessments of established biological baselines. Anthropogenic activities such as landscape disturbance (Kelly et al. 1980, Kocovsky and Carline 2006), nonnative fish introductions (Larson and Moore 1985), and climate change (Argent and Kimmel 2013) may combine to alter ecosystems at local and regional levels (Hudy et al. 2008). Some states have long-term historical profiles of their aquatic resources that are temporal baselines against which current environmental perturbations can be measured. The New York Department of Environmental Conservation maintains one such example of an extensive database documenting ichthyofaunal assemblages of lotic and lentic waters over time (Carlson et al. 2016).

There is no such comprehensive monitoring and assessment program in Pennsylvania, and there are few historical accounts of the assemblage diversity and geographic distributions of its resident ichthyofauna. Data is particularly needed for the nearly 80,000 km of headwater streams in the state—less than half of which have ever been sampled (Argent et al. 2003)—and improved understanding of the fish assemblages in these waters is critical as emerging threats may irreversibly impact these fragile coldwater ecosystems where the native *Salvelinus fontinalis* (Mitchill) (Brook Trout) is a keystone species (Tzilkowski 2005).

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Manuscript Editor: Stuart Welsh

Hudy et al. (2008) examined historical accounts of native Brook Trout distribution in the eastern US. They reported that native Brook Trout were not detected and were possibly extirpated from 1760 (33%) of 5279 sub-watersheds. In Pennsylvania, anthropogenic impacts of immediate concern are natural-gas extraction from the Marcellus shale layer (Wagner et al. 2014, Weltman-Fahs and Taylor 2013), water withdrawal (EBTJV 2011), and climate change (Argent and Kimmel 2013). These 3 stressors threaten the ecological integrity of the Commonwealth's special protection waters, including those designated as High-Quality Coldwater Fishery and Exceptional Value (PADEP 2017).

Historically, sulfur dioxide emitted largely from coal-fired power plants in the Ohio Valley caused wet and dry acid deposition within the Laurel Highlands, resulting in high sulfate loads in forest soils. Spring runoff from melting snow and storm events produced acidic pulses and elevated dissolved aluminum in poorly buffered headwater streams (Sharpe et al. 1984). Concern about water quality and fish assemblages in this region prompted a study of 61 Laurel Hill streams in 1983 by Sharpe et al. (1987) as part of the National Acid Precipitation Assessment Program (NAPAP 1998). Specifically, Sharpe et al. (1987) evaluated impacts of acid deposition and provided the only historic comprehensive assessment of ichthyofaunal assemblages of Laurel Hill streams, herein identified as the historical baseline. Since this study, passage of The Clean Air Act Amendments of 1990 has resulted in declines of sulfur dioxide emissions and improving water quality in the northeastern US (Stoddard et al. 2003).

To assess the current status of historically self-sustaining populations of native Brook Trout on Laurel Hill, we compared results of our recent assessments (2011 and 2014–2016) with those of Sharpe et al. (1987). This region has been undersampled over the years and, therefore, represents a data gap in our understanding of Brook Trout distribution. Our objectives were to (1) compare the total catch of native Brook Trout from 1983 with contemporary collections, (2) document changes in fish-assemblage composition (e.g., shifts among resident species), and (3) discuss possible causations for the observed patterns.

Methods

Laurel Hill is a part of the Allegheny Mountain System of the Greater Appalachian Plateau Province of southwestern Pennsylvania. This 110-km anticlinal fold, located ~80 km southeast of Pittsburgh, is oriented along a northwest/southeast axis with an average elevation of 820 m (Shultz 1999). Laurel Hill lies in the mixed mesophytic forest region of Pennsylvania, and current canopy consists of 2nd and 3rd growth due to extensive logging in the late 1800s and early 1900s. At present, largely intact forests cover much of the area, which is protected from commercial development by substantial tracts of state parks, state forests, and state gamelands. Most recently, some state agencies have allocated leases for shale-gas development within public-land boundaries potentially resulting in habitat fragmentation and water withdrawal for hydraulic fracking (Weltman-Fahs and Taylor 2013).

We followed the methods of Sharpe et al. (1987) to classify streams based on the viability of their respective fish assemblages—fish present, fish absent, culturally impaired, and remnant fish population. We applied the fish present or culturally impaired designations to those streams harboring self-sustaining native Brook Trout populations that exhibited multiple year-class structures. Remnant populations consisted of a few adults only, with no evidence of stable year-class structure or reproduction.

For this study, we selected a total of 20 streams: 19 classified as having fish present and 1 deemed to be culturally impaired. Ten were on the NW and 10 on the SE slopes of Laurel Hill. These streams spanned the length of the anticline in approximately paired positions on each facing slope (Fig. 1). During the 1983 study, all 20 streams harbored native Brook Trout populations consisting of at least 3 age-classes, including 0-age fish. Sampling locations and Pennsylvania special protection designations (PADEP 2017) of Laurel Hill streams are summarized in Table 1. Eighteen of the 20 headwater streams and their attendant watersheds are designated high-quality coldwater fishery or exceptional value status, and are afforded the highest levels of protection by the PADEP (2017; Table 1).

The Laurel Hill streams are still bordered by largely intact riparian forest cover (PASDA 2013). Field notes taken in 1983 subjectively described benthic habitats as cobble, rubble, gravel, or sand, and provided species composition of canopy cover (W.E. Sharpe et al.,The Pennsylvania State University, University Park, PA, unpubl. field notes). To quantify substrate and riparian canopy-cover suitability for

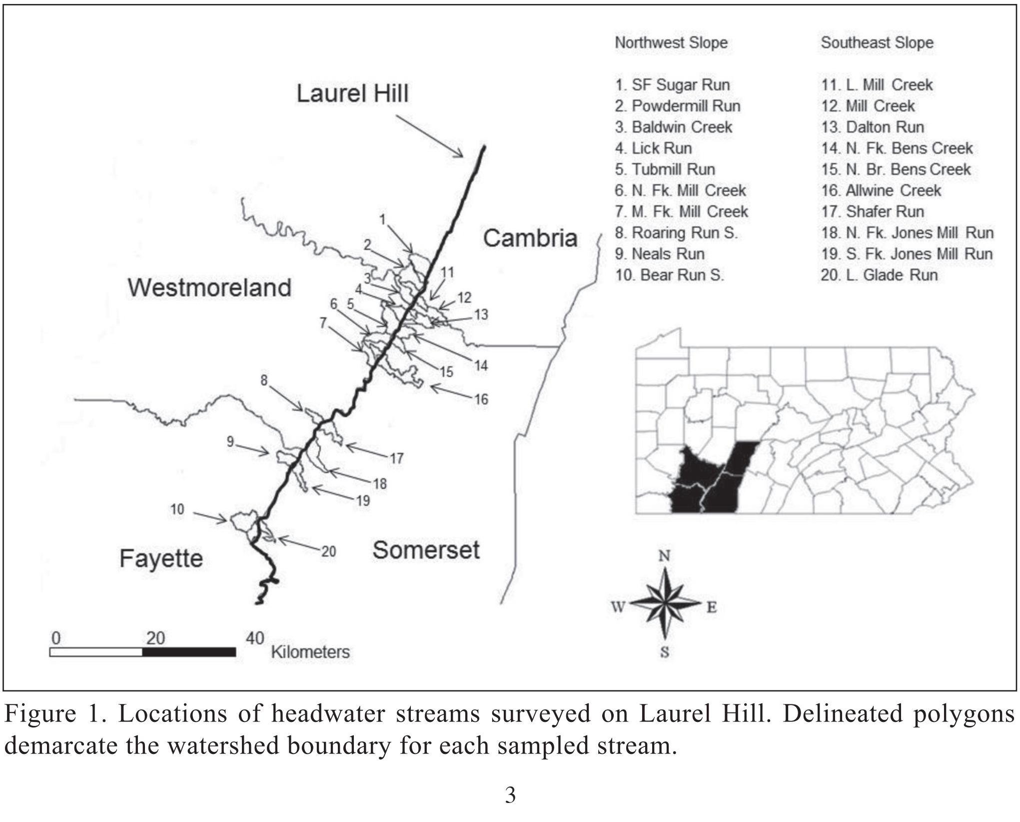


Figure 1. Locations of headwater streams surveyed on Laurel Hill. Delineated polygons demarcate the watershed boundary for each sampled stream.

native Brook Trout, we performed pebble counts using methods described by Bain and Stevenson (1999) and evaluated canopy cover using a densitometer (Johansson 1985) within each reach surveyed in 2015.

During May and June of 2011 and 2014–2016, we employed the methodology of Sharpe et al. (1987) to document water quality and sample fish assemblages of each stream. We conducted all sampling within 100-m reaches located at or near reaches identified in field notes from the historical survey. We surveyed each site for ~30 minutes. We recorded specific conductance (µS/cm), pH, and temperature (°C) on-site and collected a sample for measurement of total alkalinity (mg/l as $CaCO_3$) in the laboratory at California University of Pennsylvania. In 2011 and 2016, we took samples from each stream and sent them to H & H Water Controls Laboratory in Carmichaels, PA, for total dissolved aluminum (mg/l) analysis.

We employed 1-pass backpack electrofishing (Model LR-24 Smith-Root Shocker, Smith-Root, Inc., Vancouver, WA; 300–400 volts, and 30–40 Hz) to sample the fish assemblage of each stream. We measured total length (TL) of each native Brook Trout to the nearest mm, and classified those ≤75 mm as young-of-the-year (YOY). We categorized all larger trout as adults. We used our best professional judgment to differentiate native trout from those of hatchery origin using size, shape, and color as primary determinants. We identified, enumerated, and released all other captured fish, which primarily comprised *Cottus bairdii* (Girard) (Mottled Sculpin).

We used repeated-measures analysis of variance to test for differences in specific conductance (conductivity), alkalinity, pH, dissolved aluminum, and

Table 1. Locations, Pennsylvania State designated uses, and canopy-cover proportions of sampled streams on Laurel Hill. * CWF = cold water fishery, EV = exceptional value, and HQ-CWF = high quality-cold water fishery (PADEP 2001).

Stream name	Slope	Latitude (°N)	Longitude (°W)	Designated use	% canopy cover
Baldwin Run	NW	40.33639	79.05039	EV	95
Bear Run South	NW	39.89981	79.46442	EV	87
Lick Run	NW	40.31831	79.08051	EV	88
M Fork Mill Creek	NW	40.24911	79.14178	EV	78
Neals Run	NW	40.03382	79.34998	HQ-CWF	76
N Fork Mill Creek	NW	40.25198	79.14701	HQ-CWF	84
Powdermill Run N.	NW	40.36241	79.02843	EV	89
Roaring Run South	NW	40.06257	79.34493	EV	85
SF Sugar Run	NW	40.38551	79.02408	CWF	74
Tubmill Run	NW	40.31490	79.08909	EV	90
Allwine Creek	SE	40.28449	79.03439	EV	90
Dalton Run	SE	40.29488	79.01640	HQ-CWF	88
Little Glade Run	SE	39.86293	79.36250	HQ-CWF	77
Little Mill Creek	SE	40.31035	78.98829	EV	82
Mill Creek	SE	40.30928	78.98798	EV	92
N Branch Bens Creek	SE	40.23269	79.04709	EV	90
NF Bens Creek	SE	40.26630	79.02016	EV	84
NF Jones Mill Run	SE	40.02276	79.26656	EV	88
Shafer Run	SE	40.08263	79.23398	CWF	62
SF Jones Mill Run	SE	40.02212	79.26778	EV	77

adult Brook Trout catch among sampling periods (1983, 2011, and 2014–2016). To meet the assumption of normality and homoscedasticity for ANOVAs, we reciprocal-transformed pH, and log-transformed alkalinity, conductivity, and adult Brook Trout catch. We confirmed normality by examining quantile–quantile plots and examined homoscedasticity with Levine tests ($P > 0.05$ for all tests). We performed Mauchly's test to check the assumption of sphericity in our repeated-measures ANOVAs (all P-values > 0.05). If an ANOVA produced a significant result ($P < 0.05$), we ran Tukey's honestly significant difference tests to determine which time periods were different from one another for the response variable of interest. We did not analyze Mottled Sculpin and YOY Brook Trout abundance with ANOVAs because the assumption for normal distribution of residuals was not met. Instead, we employed non-parametric Friedman tests with repeated-measures. If a result from the Friedman test was significant, we ran post-hoc tests suggested by Hollander and Wolfe (1999:295) to determine which time periods were different from one another for the response variable of interest. To examine if there was a relationship between Mottled Sculpin and Brook Trout catches, we fitted a linear mixed-effects model with Brook Trout catch as the response variable, Mottled Sculpin catch as a fixed factor, and stream identity as a random factor. A simple linear regression was not possible for this analysis because we collected the catch data via repeated sampling of the 20 streams through time (i.e., all data points were not independent). We $\log_e$-transformed Mottled Sculpin abundance and $\log_{10}$-transformed adult and YOY Brook Trout abundances. We performed a likelihood ratio test in the lmtest package (Zeileis and Hothorn 2002) to determine the significance of our mixed-effects model in comparison with an intercept-only null model without predictors. We determined R^2 for the mixed-effects model according to Nakagawa and Schielzeth (2013), and calculated confidence intervals for predictions of the mixed-effects model using the bootMer function in the lme4 package (Bates et al. 2015). We conducted all analyses in the R programming language (Bliese 2016, R Core Team 2016).

Results

Our evaluation of water-quality parameters revealed no significant differences among sampling years for total alkalinity (Table 2, Fig. 2A). Specific conductance was consistent among years, with no clear trend over time (Table 2, Fig. 2B); pH values recorded after 1983 were significantly elevated between 2011 and 2015, but not in 2016 (Table 2, Fig. 2C). Although values of total dissolved aluminum for 2011 and 2016 were elevated in comparison with 1983 (Table 2, Fig. 2D), they were still far below the 200-µg/l toxicity threshold for Brook Trout and the historical threshold mean of 512 µg/l described for the fish absent category (Sharpe et al. 1987). Canopy cover varied from 62% to 95% (mean = 84%; Table 1) and a cumulative plot of substrate particle size among the 20 streams indicated that most stream substrates were 5–180 mm in diameter (Fig. 3). In summary, the physical habitat and water quality of sampled streams have remained relatively stable since 1983, with improving pH conditions.

Table 2. Results of repeated measures ANOVAs to compare water-quality parameters and adult Brook Trout catch among sampling periods in 20 streams.

Variable	Source	Degrees of freedom	Sum of squares	Mean sum of squares	*F*	*P*	Eta^2
pH	Year	4	0.0061	0.0015	29.7052	0.0000	0.4149
	Error	76	0.0039	5.1938x10-5			
Alkalinity	Year	4	0.3172	0.0793	1.3555	0.2573	0.0300
	Error	76	4.4462	0.0585			
Conductivity	Year	4	0.2877	0.0712	4.2748	0.0035	0.0888
	Error	76	1.2787	0.0168			
Dissolved Aluminum	Year	2	2.8439	1.4219	13.7191	0.0000	0.3755
	Error	30	3.1094	0.1036			
Adult Brook Trout	Year	4	5.7517	1.4379	24.2162	0.0000	0.4013
	Error	76	4.5128	0.0593			

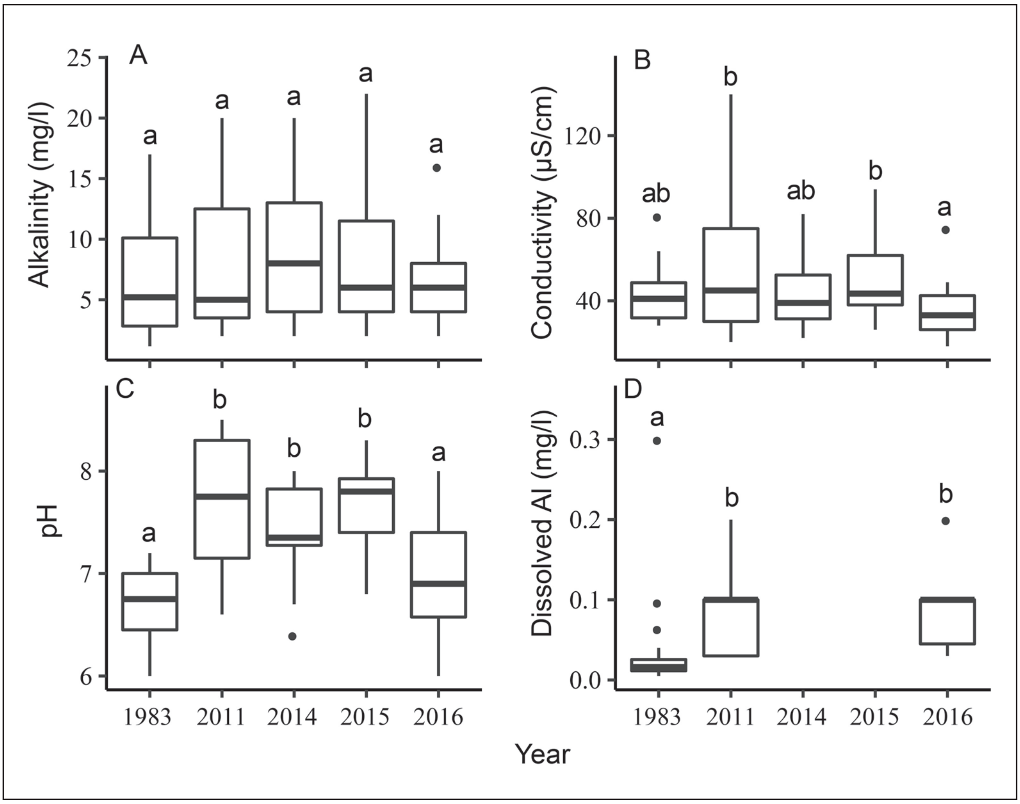


Figure 2. Water-quality summary. (A) Total alkalinity (mg/l), (B) specific conductance (µS/cm), (C) pH, and (D) total dissolved aluminum (mg/l). Lowercase letters above bars on the pH figure denote significant differences as determined by Tukey HSD tests. The dark line indicates the median, lower and upper hinges correspond to the 1st and 3rd quartiles, and the whiskers extend to the largest value no further than 1.5 times the interquartile range. The dots represent outlying data points.

In 1983, Sharpe et al. (1987) collected an average of about 35 native Brook Trout per stream. This total included 25 adult fish and 10 YOY per stream (Fig. 4). Although we found no data for surveys conducted between 1983 and 2011, comparisons with the data from 2011 and 2014–2016 reveal an overall decline in adult native Brook Trout of 64% from total catches reported in 1983 (Fig. 5, Appendix A). These declines were significant and relatively consistent between 2011 and 2014–2016 (Tukey test; $P < 0.001$). We collected Brook Trout of hatchery origin from the North Fork of Jones Mill Run, North Branch of Bens Creek, and Shafer Run along with several *Salmo trutta* L. (Brown Trout).

Overall, YOY native Brook Trout total catch showed highly variable recruitment rates among sampled streams, but we observed a general pattern of decline in comparison with 1983. Reductions of up to 50% were evident and significant between 1983 and 2011 and 1983 and 2016 (Friedman test with post-hoc analysis, $P < 0.05$; Fig. 4B, Appendix B), but not between 1983 and 2014 and 1983 and 2015 (Friedman test with post-hoc analysis, $P > 0.05$, Figure 4B). The increase in 0-Age fishes during 2014 can be attributed to 2 streams: Powdermill Run North and Allwine Creek, which yielded 39 and 65 YOY, respectively. These 2 streams accounted for 47% of the total YOY total catch reported for 2014. Except for 2014 (as noted above), recruitment of YOY native Brook Trout dramatically declined when compared with levels documented in 1983 (Fig. 6). Similarly, every age class over our multi-year study revealed declines at time of sampling. Age 5+ fish (>250 mm TL) were present only in 1983.

Of the 20 streams examined during our study, Sharpe et al. (1987) classified 19 streams as fish present and 1 as culturally impaired. We used the same historical criteria to reclassify the current status of these streams. We found that only 45% of those streams originally identified as fish present retained that classification during later surveys; 35% were re-classified as remnant fish (Table 3).

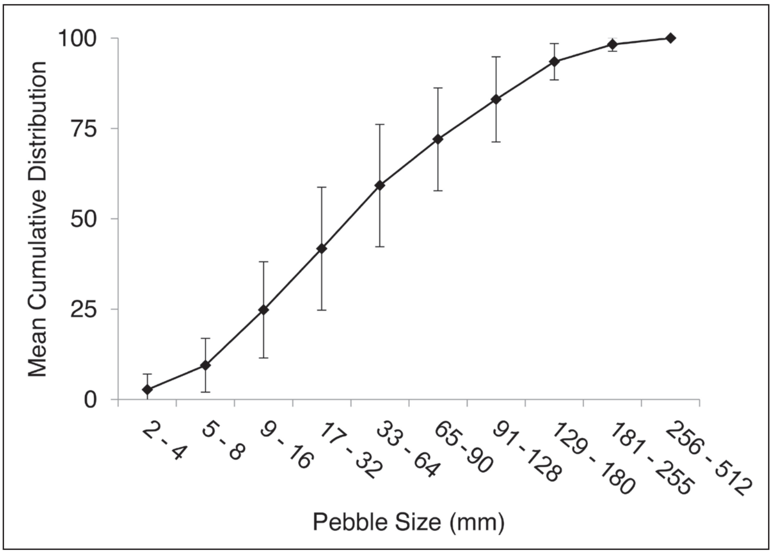


Figure 3. Cumulative plot of mean substrate-particle size among 20 Laurel Hill streams. Error bars denote 1 standard deviation.

Mottled Sculpin, commonly found in association with native Brook Trout in headwater streams at Laurel Hill, were present in 13 of the 20 streams sampled. Unlike the native Brook Trout, they appear to have increased at a relatively steady pace since 2011. The Mottled Sculpin catch was greater than in 1983, but the difference between historic and current catches was not significant (P = 0.072; Fig. 4C, Appendix C). Our linear mixed-effects model demonstrated that there was a significant, but weak negative relationship between Brook Trout catch and Mottled Sculpin catch (P-value compared to null model = 0.003, R^2 = 0.10, Fig. 7).

Discussion

Native Brook Trout populations in headwater streams are known to fluctuate widely in response to changing local abiotic characteristics of these inherently

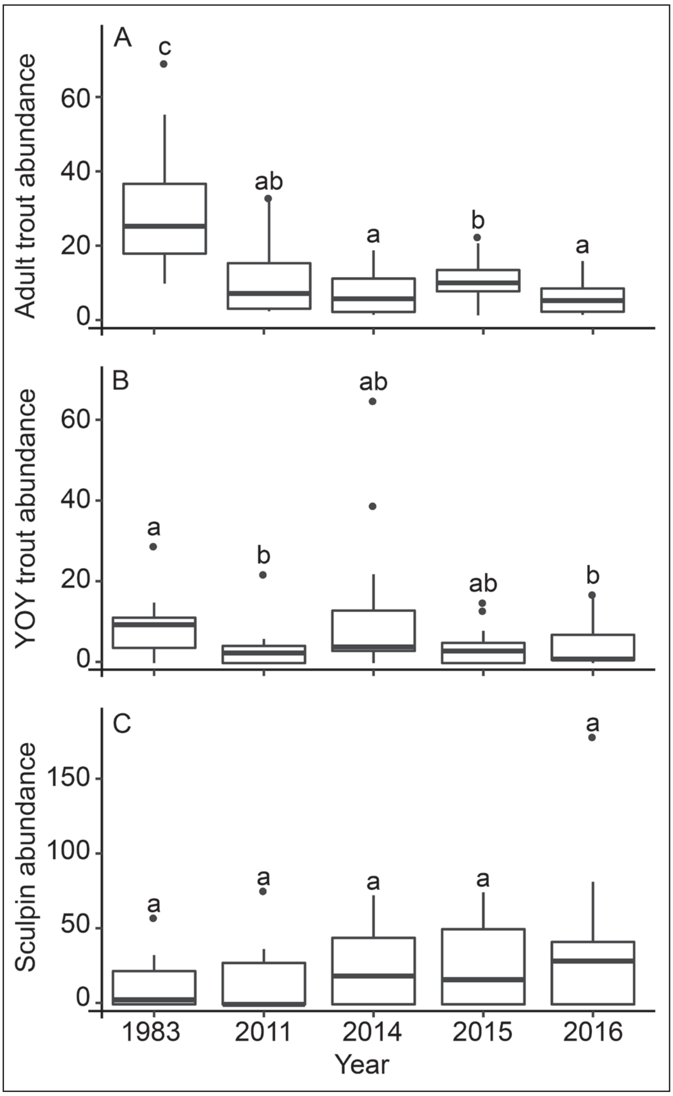


Figure 4. (A) Mean catch by stream of adult native Brook Trout, (B) YOY Brook Trout and (C) Mottled Sculpin among years in 20 Laurel Hill streams. See Figure 2 caption for information on formatting of the box plot. Lowercase letters above bars denote significant differences among years as determined by the Tukey HSD test (Adult Brook Trout) or Post-hoc tests following a Friedman test (YOY Brook Trout and Mottled Sculpin).

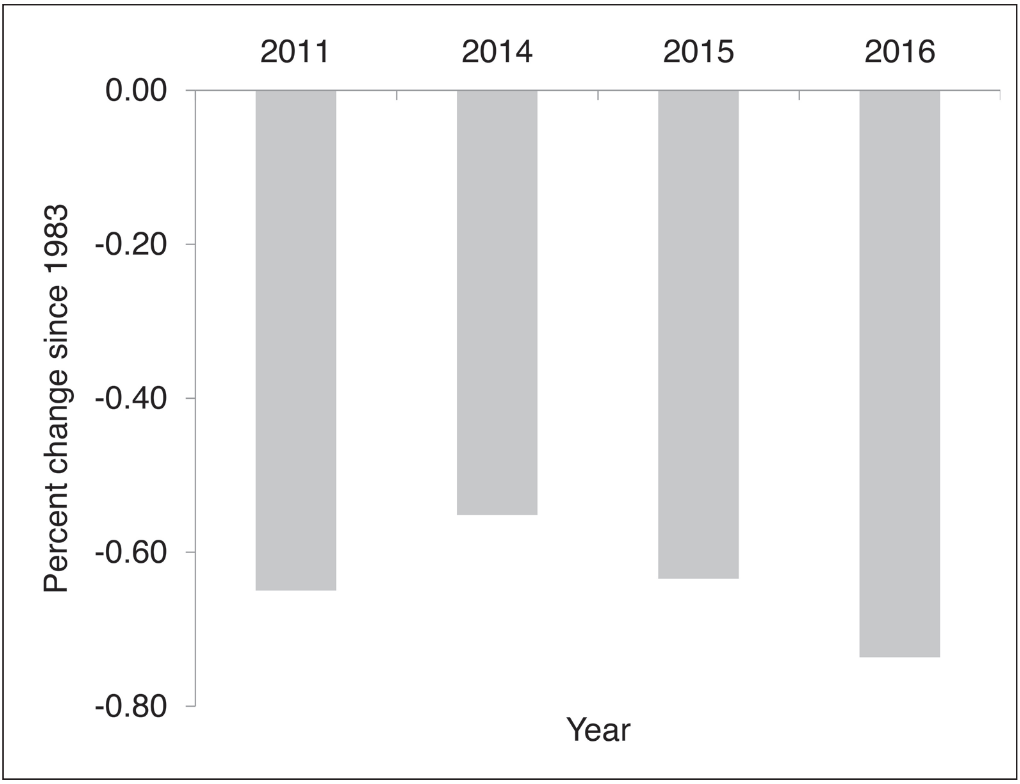
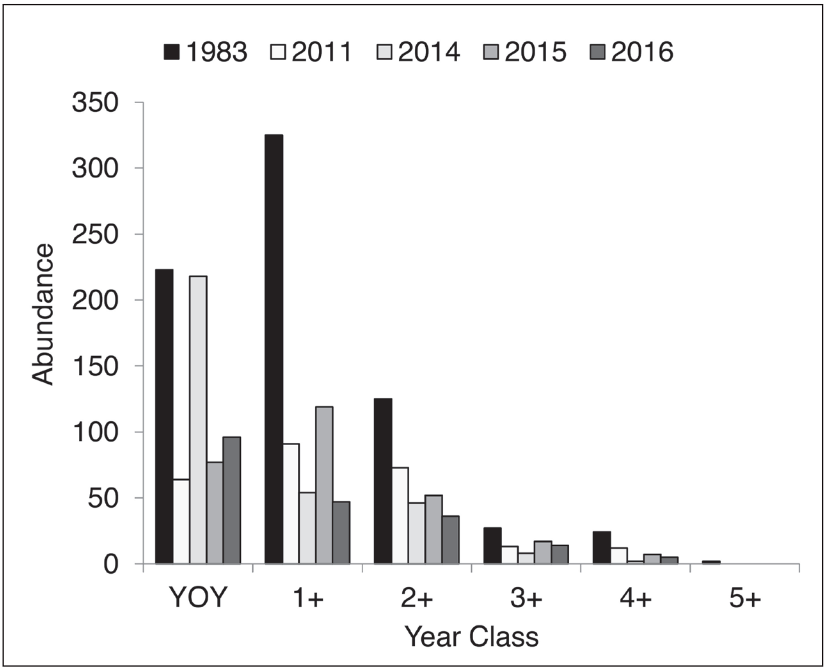


Figure 5. Percent change in catch of native Brook Trout (all age classes) from 1983 levels.

Figure 6. Year-class structure of native Brook Trout collected from 20 Laurel Hill streams comparing 1983 and 2011, and 2014–2016.



unstable environments (Hall and Knight 1981, Roghair et al. 2002). Anthropogenic factors may compound, mask, or exacerbate natural fluctuations. The EBTJV (2011) recognized the following as threats to native Brook Trout: climate change, acid deposition, rise in water temperature, urbanization, modification of hydrologic regime, dewatering events, invasive species, habitat degradation, fragmentation, and runoff from abandoned mine lands. Our comparisons of the results of surveys made over 24 years apart indicate a precipitous decline in Brook Trout numbers followed by a period of relative stability, suggesting a new baseline for this species on Laurel Hill. In the discussion below, we describe and speculate on possible impacts of historical and contemporary anthropogenic stressors on native Brook Trout populations in this geographic area, such as acid deposition, introduced/invasive species, competition, fishing pressure, water withdrawal, habitat fragmentation, and climate change.

Acid deposition since the Sharpe et al. (1987) study appears to be an unlikely driver (Stoddard et al. 2003) of native Brook Trout declines on Laurel Hill. Although the area received high levels of sulfate deposition during the mid- to late 1980s and many streams showed fish declines due to episodic acidification, none of the 20 streams selected for our survey were identified as impacted by Sharpe et al. (1987). Buffering capacity of these streams prevented or reduced pH declines sufficient to mobilize soluble aluminum from forest soils. Total alkalinity and levels of total dissolved aluminum did not differ from historic values, which indicates retention of buffering capacity among the 20 streams over time. Further, wet sulfate deposition has been declining across the Northeast since the passage of the Clean Air Act Amendments of 1990, and surface waters have responded positively

Table 3. An updated classification of Laurel Hill streams using criteria developed from the 1983 survey.

Stream name	1983 Classification	Contemporary classification
Allwine Creek	Culturally impacted	Culturally impacted
Baldwin Run	Fish present	Fish present
Bear Run South	Fish present	Fish present
Dalton Run	Fish present	Fish present
Lick Run	Fish present	Remnant fish
Little Glade Run	Fish present	Remnant fish
Little Mill Creek	Fish present	Fish present
M Ford Mill Creek	Fish present	Remnant fish
Mill Creek	Fish present	Fish present
N Branch Bens Creek	Fish present	Remnant fish
N Fork Mill Creek	Fish present	Remnant fish
Neals Run	Fish present	Fish present
NF Bens Creek	Fish present	Fish present
NF Jones Mill Run	Fish present	Fish absent
Powdermill Run N.	Fish present	Fish present
Roaring Run South	Fish present	Remnant fish
SF Jones Mill Run	Fish present	Remnant fish
SF Sugar Run	Fish present	Fish absent
Shafer Run	Fish present	Fish absent
Tubmill Run	Fish present	Fish present

(Stoddard et al. 2003). The significant increase in overall stream pH values may be a response to enhanced regulation of sulfur dioxide emissions and seems to have benefitted native Brook Trout populations on Laurel Hill.

Interspecific and intraspecific competition for resources can influence growth rates, fecundity, and survival of native Brook Trout (Marchand and Boisclair 1997, Marschall and Crowder 1996). Several studies have documented the ability of non-native Brown Trout to (1) depress local densities of native Brook Trout, and

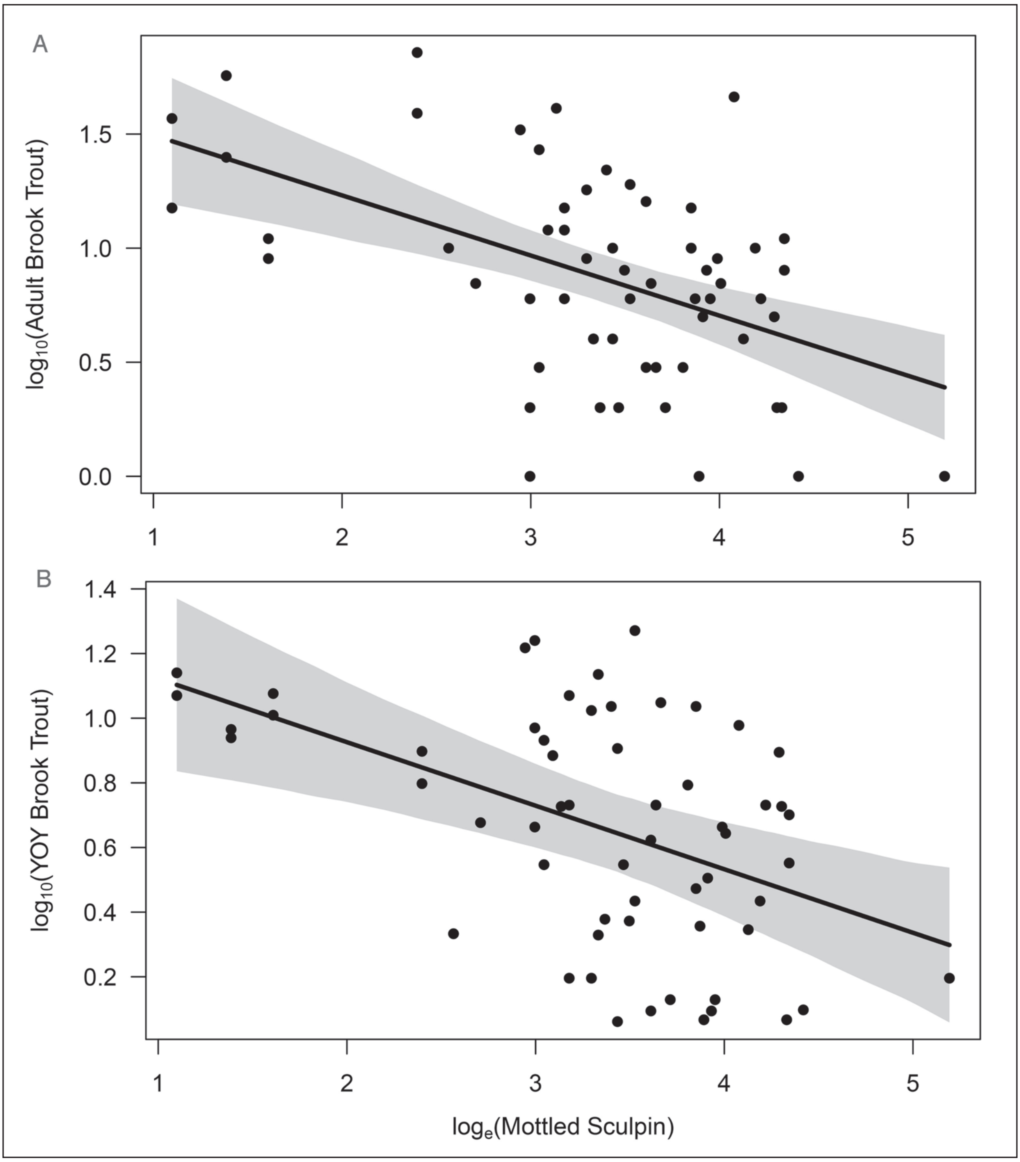


Figure 7. (A) Relationship between Mottled Sculpin and native Brook Trout adult total catch among Laurel Hill streams. (B) Relationship between Mottled Sculpin and YOY native Brook Trout total catches. The shaded area represents the 95% confidence interval of the model predictions.

(2) exclude native Brook Trout from preferred habitat (DeWald and Wilzbach 1992, Fausch 1988, Fausch and White 1981). We found a few introduced (stocked) salmonids in several streams, but due to the relative isolation of the Laurel Hill collective, it seems unlikely that exotic species or fishing pressure (Marschall and Crowder 1996) played a major role in native Brook Trout population dynamics.

The increase in Mottled Sculpin abundance may be associated with declines in native Brook Trout. Native Brook Trout and either Mottled Sculpin or *Cottus cognatus* Richardson (Slimy Sculpin) typically co-dominate the ichthyofaunal assemblages of many Pennsylvania headwater streams (Cooper 1983); hence, native Brook Trout and Mottled Sculpin have a long history of coexistence. Moreover, no studies have documented interspecific competition between native Brook Trout and sculpins at a level negatively impacting either species (Zimmerman and Vondracek 2006). However, a decline in native Brook Trout numbers may allow sculpins to increase, or perhaps some aspects of sculpin behavior may be a cause of or contributor to the observed decline of Brook Trout populations. For example, several studies have documented that some sculpin species in the genus *Cottus* are egg predators of salmonids (Biga et al. 2008, Fitzsimons et al. 2006, Marsden and Tobi 2014, Mirza and Chivers 2002). Additional studies are needed to determine if consumption of trout eggs by Mottled Sculpin may affect the native Brook Trout populations of Laurel Hill. Additionally, Mottled Sculpins may forage on other early life-stages of native Brook Trout, which could lead to a decline in recruitment of native Brook Trout. We did not detect Mottled Sculpin from Allwine Creek or Powdermill Run North; both streams experienced spikes in native Brook Trout recruitment.

Recently, requests for water-withdrawal permits from surface and ground waters on Laurel Hill have been on the rise in support of a variety of development projects in the area. Water withdrawals effectively remove a portion of the streamflow with no return until late winter or spring when snowpack melts (Cunjak 1996). Competition for water resources has emerged as a contentious public issue on Laurel Hill among developers of recreational residences (American Rivers 2009), municipalities, and 2 large ski resorts. In addition, pending and realized gas extraction may further exacerbate conflicts among stakeholders. However, there is no documentation of historical or recent declines in stream discharge among the 20 Laurel Hill streams we surveyed.

Several studies have focused on the effects of habitat fragmentation on fish populations including such factors as persistence, dispersal, growth, expression of life-history stages, and impediments to gene flow (Fahrig 2003, Letcher et al. 2007, Morita and Yamamoto 2002, Roberts et al. 2013). Fragmentation resulting in population isolation can occur because of a number of anthropogenic factors including pollution, road and dam construction, water diversion, climate change, and, most recently on Laurel Hill, shale-gas development (Hansbarger et al. 2010, Weltman-Fahs and Taylor 2013).

Fragmentation can strongly influence population persistence and expression of life-history strategies in spatially structured populations. Letcher et al. (2007)

reported that, in naturally isolated tributaries, native Brook Trout persistence was associated with higher early juvenile survival (~45% greater), shorter generation time, and strong selection against large body size. Moreover, barriers to upstream migration caused rapid (2–6 generations) local extirpation.

Although our quantitative measures of substrate and riparian canopy are not directly comparable to historical data, they do indicate the presence of suitable native Brook Trout spawning substrates and cover for YOY (Fig. 3). Raleigh (1982) described suitable spawning substrate for native Brook Trout as gravel 3–8 cm in diameter and ≤5% fines, criteria met among streams sampled on Laurel Hill. In addition, canopy cover varied from 62% to 95% (mean = 84%; Table 1), suggesting that streams were well shaded and stream banks were largely intact. Shafer Run, identified earlier in this paper as receiving Brook Trout of hatchery origin, maintains the lowest proportion of canopy cover. From these observations and comparative measures of water quality parameters, we concluded that habitat suitability for trout remained largely unchanged over the >24-year interval between our study and that of Sharpe et al. (1987).

It would thus seem unlikely that the decline in Laurel Hill native Brook Trout populations can be attributed to a singular large-scale physical habitat change. However, climate change can also result in habitat fragmentation because elevated temperatures may restrict connectivity of watershed tributary networks (Hansbarger et al. 2010, Letcher et al. 2007, Meisner 1990), reduce fish survival (Xu et al. 2010a), and reduce fish growth (Xu et al. 2010b). Fragmentation of such habitats may ultimately lead to reductions in genetic variation among and within such isolated resident fish populations (Whiteley et al. 2013).

Argent and Kimmel (2013) described the potential effects of climate change on Laurel Hill native Brook Trout populations, and documented varying patterns of air/instream temperature relationships (thermal sensitivity [r]) in 6 (3 on each slope) of the 20 Laurel Hill streams described here. We documented largely intact riparian cover in the surveyed reaches; thus, it seems likely that the major factor controlling r would be variation in groundwater input. Canopy cover and groundwater input have both been documented as important factors in predicting r (Kelleher et al. 2012) and native Brook Trout occurrence (Kanno et al. 2015a, 2015b). In-stream/air temperature profiles from the respective NW- and SE-slope receiving streams, suggest that avenues of tributary connectivity may be temporally constricted by elevated temperatures (Argent and Kimmel 2013). While speculative, the climate-change scenario is worthy of note and may impact streams exhibiting reductions in canopy cover. Further, in-stream temperature change may influence species-assemblage dynamics. For example, Mottled Sculpins exhibit a greater maximum threshold-temperature tolerance (24.3 °C) than native Brook Trout (22.4 °C) (Eaton and Scheller 1996), and may experience an advantage if water temperatures increase in streams of Laurel Hill (Argent and Kimmel 2012).

The similarity of water quality and habitat conditions documented between the historic and recent Laurel Hill surveys and the scope of the overall native Brook Trout population declines seem to rule out the aforementioned stressors acting independently or in concert at the local level. Natural-gas extraction (Weltman-Fahs and Taylor 2013) may play a role in both water withdrawal and habitat fragmentation in the near future, but there is no available evidence of widespread historical impacts from such activities at this time.

We recognize the large time gap between sampling periods (24+ years), but assert this comparison provides the only means for a much needed reassessment of the historical baseline. Moreover, we realize that native Brook Trout often experience unpredictable shifts in population structure (Hall and Knight 1981; Kanno et al. 2015b, 2016; Roghair et al. 2002), which explains why we extended our study to include 4 years of data. We believe that the longer sample period adds strength to our findings and provides a basis in which we establish a new contemporary baseline.

In summary, it is not possible at this time to identify single or multiple causes for fish-assemblage changes in Laurel Hill streams. The literature provides some indication as to what might be happening, but a definitive reason for the nearly 60% decline since 1983 remains unknown. Companion studies in Maryland identify 5 reasons for native Brook Trout decline: high water temperature, agriculture, urbanization, non-native species invasions, and poor riparian habitat (Heft 2006). Based on our study, urbanization, agriculture, non-native species, and poor-quality riparian habitat seem unlikely causative agents for the observed decline in native Brook Trout populations among the Laurel Hill collective.

Given the observed decline in resident stream-dwelling native Brook Trout populations on Laurel Hill, researchers and natural resource managers should consider further investigations on the reasons for decline, which could include systematic, temporal, and comprehensive surveys. The decline in resident native Brook Trout populations in Laurel Hill streams underscores the importance of biomonitoring and assessment of aquatic communities facing anthropogenic changes that may create new baselines of community diversity and structure. This study establishes a new baseline for native Brook Trout populations on Laurel Hill for the assessment of current and future anthropogenic stressors. Understanding of the limitations of adaptability and resilience (Adger and Kelly 2000) in these fish assemblages is crucial to their conservation, and a future program of dedicated monitoring may provide the necessary data to accomplish this goal.

Acknowledgments

We thank the Wild Resources Conservation Fund (Contract # WRCP – 10371) for providing financial support for this project. Jeff Ambrose, Chris Warden, Justin Peel, Benjamin Trask, Nathan Backenstose, and Austin Hess provided assistance with field collections, and Pat Suschak, Paul Knupp, Barry Zaffuto, and Lee Miller enabled access to various sampling sites. Lastly, we acknowledge the comments provided by 2 reviewers and the contributions of Manuscript Editor Dr. Stuart Welsh to improve this paper.

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Appendix A. Numbers of adult Brook Trout captured in 1983, 2011, and 2014–2016.

Stream Name	Slope	1983	2011	2014	2015	2016
Baldwin Run	NW	19	15	4	17	7
Bear Run South	NW	35	6	10	8	8
Lick Run	NW	71	32	5	9	1
M Fork Mill Creek	NW	11	6	5	5	3
N Fork Mill Creek	NW	40	3	1	4	3
Neals Run	NW	17	2	1	6	7
Powdermill Run N.	NW	34	33	18	20	6
Roaring Run South	NW	45	10	3	9	2
SF Sugar Run	NW	31	4	0	2	0
Tubmill Run	NW	36	9	0	8	7
Allwine Creek	SE	17	2	10	22	3
Dalton Run	SE	19	27	17	12	13
Little Glade Run	SE	9	1	0	9	1
Little Mill Creek	SE	31	7	10	11	15
Mill Creek	SE	56	14	14	14	8
N Branch Bens Creek	SE	21	5	14	9	1
NF Bens Creek	SE	10	16	7	17	14
NF Jones Mill Run	SE	24	2	2	7	5
SF Jones Mill Run	SE	38	5	4	8	0
Shaffer Run	SE	18	1	0	1	0
Total		582	200	125	198	104

Appendix B. Numbers of YOY Brook Trout captured in 1983, 2011, and 2014–2016.

Stream Name	Slope	1983	2011	2014	2015	2016
Baldwin Run	NW	5	2	0	4	1
Bear Run South	NW	9	1	3	4	7
Lick Run	NW	10	22	12	2	13
SF Sugar Run	NW	14	3	0	3	0
M Fork Mill Creek	NW	3	3	3	0	1
N Fork Mill Creek	NW	4	1	4	2	1
Neals Run	NW	11	3	3	4	6
Powdermill Run N.	NW	2	3	39	8	7
Roaring Run South	NW	15	5	22	4	16
Tubmill Run	NW	11	6	3	3	1
Allwine Creek	SE	7	4	65	0	0
Dalton Run	SE	1	6	3	15	17
Little Glade Run	SE	29	0	0	0	1
Little Mill Creek	SE	11	0	11	8	4
Mill Creek	SE	10	0	13	13	13
N Branch Bens Creek	SE	15	3	15	3	1
NF Bens Creek	SE	0	5	13	8	7
NF Jones Mill Run	SE	6	0	4	0	1
SF Jones Mill Run	SE	3	0	4	0	0
Shaffer Run	SE	15	0	0	0	0
Total		181	67	217	81	97

Appendix C. Numbers of Mottled Sculpin captured in 1983, 2011, and 2014–2016.

Stream Name	Slope	1983	2011	2014	2015	2016
Baldwin Run	NW	0	0	0	0	0
Bear Run South	NW	0	0	0	0	0
Lick Run	NW	10	18	19	12	19
SF Sugar Run	NW	0	27	22	45	0
M Fork Mill Creek	NW	23	37	67	51	61
N Fork Mill Creek	NW	22	27	73	49	30
Neals Run	NW	26	20	31	54	76
Powdermill Run N.	NW	0	0	0	0	0
Roaring Run South	NW	58	76	27	46	38
Tubmill Run	NW	2	30	19	53	32
Allwine Creek	SE	0	0	0	0	0
Dalton Run	SE	0	0	0	0	0
Little Glade Run	SE	0	0	0	0	0
Little Mill Creek	SE	0	0	4	21	36
Mill Creek	SE	3	0	23	2	4
N Branch Bens Creek	SE	29	33	46	65	0
NF Bens Creek	SE	0	0	0	0	0
NF Jones Mill Run	SE	3	36	44	50	47
SF Jones Mill Run	SE	10	23	72	26	82
Shaffer Run	SE	33	0	48	75	179
Total		219	327	495	549	604