Transactions of the American Fisheries Society 132:166–171, 2003

Influences of Logging History and Stream pH on Brook Trout Abundance in First-Order Streams in New Hampshire

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Abstract.—In New England streams, both logging and acidification may influence native populations of brook trout *Salvelinus fontinalis*. We assessed the relationship between these factors and brook trout abundance in 16 first-order streams that had been logged 6 to more than 30 years prior; we quantitatively sampled fishes and collected habitat and water chemistry data from these streams. Logging history (years since harvest) was negatively correlated with substrate embeddedness, suggesting that this aspect of physical habitat quality improves with forest recovery. Brook trout density and biomass, however, were negatively correlated to years since logging. In contrast, stream pH (ranged from <6 to >7 during low-flow conditions in August) was positively correlated with trout density and biomass. These results suggest that forest recovery alone may not result in across-the-board increases in brook trout abundance and that among-site variation in stream chemistry needs to be accounted for when assessing the effects of land-use on trout populations in the New England region.

The New England region (USA) has a complex land-use history involving multiple anthropogenic stresses to stream ecosystems. Chief among these are intensive timber harvest, both historical (Foster 1992) and present-day (Miller et al. 1998), and stream-water acidification and base cation depletion (Driscoll et al. 2001). Although many studies have addressed the influences of these stresses on resident trout growth, survival, and reproduction in other ecoregions (Reeves et al. 1993; Baker et al. 1996), we know little about their association with native brook trout abundance in New England. Moreover, previous studies are inconclusive as to whether logging has negative (Reeves et al. 1993; Hauer et al. 1999) or positive (Bisson and Sedell 1984; Wilzbach 1985) effects and are divided as to the relative influence of logging versus effects of stream-water chemistry on trout populations (Hesthagen et al. 1999; Baldigo and Lawrence 2000). Given these uncertainties, region-specific studies are critically needed to develop effective conservation, management, and forestry practices. In this study, we surveyed populations and habitats of wild resident brook trout *Salvelinus fontinalis* in first-order streams throughout New Hampshire. Streams were located in drainages varying widely in the time since they had last been logged (6 to >30 years). Our goal was to provide an initial assessment of the relationship between brook trout abundance and logging history, selected habitat features, and stream-water chemistry (pH) in northern New England streams. We used survey data to test whether the density, biomass, and condition of brook trout was lower in streams in drainages that have been logged more recently and lower in streams with low pH.

Methods

Study sites.—In August 2000, we sampled the physical habitat, water chemistry, and brook trout in 16 first-order streams in New Hampshire that were in and adjacent to the White Mountain National Forest (Table 1). All streams were less than 1 km in total length, less than 2 km^2 in drainage area, and had not been stocked with brook trout in recent years. The general terrain of these drainages was moderately to steeply sloped. Forest type was approximately 25% hardwood forest, 25% softwood forest, and 50% mixed forest. The primary hardwood species included sugar maple *Acer saccharum*, yellow birch *Betula alleghaniensis*, beech *Fagus grandifolia*, American white birch *Betula papyrifera*, and quaking aspen *Populus tremuloides*. The softwood component was primarily composed of red spruce *Picea rubens* and balsam fir *Abies balsamea*. The small size of these first-order streams provided two important study design

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Received January 14, 2002; accepted June 25, 2002

TABLE 1.—Summary of brook trout study sites, including habitat and water characteristics of 16 first-order streams in New Hampshire sampled in August 2000. Values for large woody debris (LWD), gravel, cobble, and boulder are the proportional coverages of the total substrate area measured along sampling transects. Embeddedness was a visual estimate of objects partially embedded in the bottom.

Stream	Latitude (degrees)	Longitude (degrees)	Elevation (m)	Years since harvest	Embeddedness	Proportion of total substrate: LWD	Gravel	Cobble	Boulder	Other	pH
Spillman	44.0	71.8	637	6	0.55	0.03	0.28	0.63	0.03	0.03	7.5
Alder, East	45.0	71.2	404	8	0.37	0.00	0.47	0.31	0.13	0.09	5.7
Johnson	45.0	71.2	472	9	0.62	0.01	0.16	0.4	0.28	0.15	6.8
Wheeler, North	43.0	72.0	322	10	0.65	0.05	0.11	0.69	0.05	0.1	7.1
Cone Pond	43.9	71.5	311	14	0.24	0.01	0	0.76	0.15	0.08	6.5
Hazelton, North	44.0	71.6	401	15	0.77	0.03	0.19	0.27	0.47	0.04	7.1
Hazelton, South	44.0	71.6	416	17	0.33	0.13	0.32	0.23	0.18	0.14	6.8
Washburn	45.0	71.1	418	24	0.68	0.03	0.3	0.35	0.13	0.19	6.9
Alder, West	45.0	71.2	392	30	0.17	0.01	0.48	0.4	0.07	0.04	7.1
Black, East	44.1	71.7	554	30	0.29	0.04	0.48	0.44	0.06	0	5.7
Black, West	44.1	71.7	554	30	0.27	0.03	0	0.69	0.14	0.14	6.4
Horne	45.0	71.1	445	30	0.33	0.04	0.1	0.37	0.38	0.11	7.1
Jeffers	44.0	71.8	621	30	0.08	0.07	0.39	0.44	0.05	0.05	7.1
Merrill	45.0	71.1	430	30	0.14	0.11	0.16	0.42	0.33	0	5.7
Taves	43.0	72.0	302	30	0.51	0.03	0.43	0.34	0.12	0.08	5.7
Wheeler, South	43.0	72.0	318	30	0.31	0.04	0.33	0.4	0.03	0.2	5.2

advantages: (1) they could be considered independent replicates for statistical analysis, and (2) it is reasonable to assume that within-watershed spatial variation in logging intensity was minimal (due to smallness of the watersheds) and that no riparian buffer strips were left. This assumption was corroborated by interviews with district and private foresters and by site inspections.

Habitat surveys.—Habitat and logging history assessments followed the methods of Lowe and Bolger (2002). Our measure of logging history in each of the study drainages was the number of years since the last harvest activity. Drainages for which there was no record of harvest and no evidence of harvest, based on site inspections, were assigned a value of 30 years since last harvest, the value of the drainage with the earliest recorded harvest date. To characterize specific physical habitat conditions likely to be affected by logging activities, we collected data on large woody debris (LWD; >10-cm diameter at breast height and >30 cm long) and substrate embeddedness in all of the survey streams (Table 1). In each stream, embeddedness and LWD were measured at six randomly placed habitat transects that were 50–100 m apart. Transects were 1 m wide and extended between bank-full channel edges (i.e., edges at high-flow conditions, as indicated by evidence of scour). The proportion of LWD cover and the proportion of embedded cover within each transect were estimated visually (Hankin and Reeves 1988; U.S. Forest Service 1996). Embedded cover objects were those having visible vertical surfaces that were buried in either silt or sand (modified from Welsh et al. 1997). Stream pH was determined in the field with a portable pH meter (Oakton, Inc., Vernon Hills, Illinois).

Fish sampling.—We sampled brook trout in the 16 streams during a 1-week period in late August 2000. In each stream, a 100-m study section was established in representative habitat. Electrofishing surveys involved 3-pass removals using a Smith-Root BP-12 backpack electroshocker set to 500V DC. Block nets were used to prevent movement in and out of the study section during electrofishing samples. Upon capture, each fish was anesthetized using MS-222, weighed and measured, then returned to the stream. A modified Zippin maximum likelihood method was used to estimate population size (McMenemy 1995). Mortalities were low (three fish total), and catchability estimates high (77–98%) over the course of the study.

Data analysis.—We used stepwise multiple regression to test whether variation in years since logging, physical habitat, and pH predicted variation in brook trout density, biomass, and relative condition factor among the study streams. Because fishless streams might be the result of migration barriers, we ran analyses using (1) the entire data set (N = 16), and (2) only fish-containing streams (N = 12). Stepwise regression was performed using a backwards-elimination procedure in which predictor variables were iteratively discarded from the model based on a cutoff alpha-value of 0.150 (Kleinbaum et al. 1998). Before entering predictor

TABLE 2.—Summary of brook trout surveys from 16 first-order streams in New Hampshire sampled in August 2000. Age-class designations were based on size-frequency distributions. Condition factors were relative measures for individual streams based on an overall length–weight relation for all streams combined.

Stream	Total	Age 0	Overyearling	Biomass (g)	Mean weight (g)	Mean length (cm)	Condition factor
Spillman	94	25	64	1,002.48	92.51	11.04	−0.048
Alder, East	30	17	11	224.54	81.75	8.31	0.051
Johnson	53	12	40	430.47	88.23	8.02	−0.041
Wheeler, North	37	23	20	360.77	88.32	10.99	0.115
Cone Pond	47	27	17	297.41	75.91	6.95	0.021
Hazelton, North	90	26	62	766.30	86.44	8.23	0.002
Hazelton, South	43	3	40	476.37	97.88	10.51	0.014
Washburn	43	23	19	366.27	83.26	8.68	−0.030
Alder, West	34	7	25	344.67	95.09	10.74	−0.008
Black, East	0			0.00			
Black, West	0			0.00			
Horne	25	5	20	320.19	99.96	13.09	0.010
Jeffers	14	4	10	141.17	92.64	10.19	0.015
Merrill	0			0.00			
Taves	0			0.00			
Wheeler, South	3	0	3	52.86	118.33	18.72	0.065

variables into the regression analysis, we tested for significant correlations to understand both the potential causal relationships among these variables and to eliminate redundant variables from the stepwise regression. All data were tested for normality and appropriately transformed before analysis. To determine relative condition factor, we calculated the $\log_e$length–$\log_e$weight relationship, pooling all individuals across all study streams, along with residuals for each individual fish. Negative residuals indicated fish having weights at length that were lower than predicted for the general population (low relative condition factor); positive residuals indicated weights at length that were higher than predicted (high relative condition factor). Mean relative condition factor for each stream therefore reflected fish condition relative to the other streams.

Results

Habitat

Most streams were dominated by large substrates (cobbles and boulder), and riffles and cascades were the predominant channel type. Substrate embeddedness ranged from 0.08 to 0.68, LWD cover from 0.0 to 0.13, and stream pH from 5.2 to 7.2 (Table 1). Years since logging was significantly and negatively correlated with embeddedness ($r = -0.56$, $P < 0.05$) because streams that were logged most recently had the highest levels of substrate embeddedness. There was no significant correlation between logging history and percentage LWD cover ($r = 0.24$, $P = 0.37$). Stream pH was not significantly correlated with any of the other variables.

Brook Trout Density and Biomass

Brook trout were found in 12 of 16 streams surveyed, and a total of 498 individuals were captured (Table 2). The number of brook trout per 100-m stream section ranged from 0 to 94, fish sizes ranging from 31 to 180 mm fork length and from 0.51 to 63.6 g wet weight. Based on length–weight frequency distributions, age-0 fish were readily distinguishable from overyearling fish. In all but 1 of the 12 fish-bearing streams, both age-0 and overyearling fish were present. Based on visual characteristics (fin shape, coloration), we had no indication that any fish were of hatchery origin.

Factors Associated with Brook Trout Density and Biomass

Because of the significant correlation between logging history and stream embeddedness, we confined our regression analysis to three variables: logging history (years since harvest), stream pH, and LWD cover. We found significant correlations between brook trout abundance (density and biomass) and stream characteristics, accounting for 63–78% of the variation in the data set (Table 3). Logging history and stream pH accounted for approximately equal proportions of the total variation in trout density and trout biomass. In all analyses, density and biomass were negatively correlated with years since logging, the highest density of brook trout being found in streams that had been most recently logged (Figure 1). In contrast, brook

TABLE 3.—Summary of results of stepwise regression of brook trout density and biomass using stream variables (logging history, pH, and large woody debris) for 16 New Hampshire study streams sampled in 2000. Large woody debris was not a significant predictor and was eliminated by the stepwise procedure.

	Comparison	Effect	Coefficient	R^2	F	t	P
Density	All 16 sites	Model		0.78	22.75		<0.0001
(number per section)		Logging history	−0.581			−4.15	<0.005
		pH	0.487			3.48	<0.005
	Sites with fish (12)	Model		0.66	8.53		<0.01
		Logging history	−0.592			−3.01	<0.05
		pH	0.496			2.52	<0.05
Biomass	All 16 sites	Model		0.76	20.28		<0.0001
(grams per section)		Logging history	−0.496			−3.392	<0.01
		pH	0.559			3.82	<0.005
	Sites with fish (12)	Model		0.63	7.87		<0.05
		Logging history	−0.497			−2.45	<0.05
		pH	0.575			2.84	<0.05

trout density and biomass were positively correlated with stream pH in all analyses. Streams with pH lower than 6 at summer base-flow conditions had low numbers of trout (Figure 1). Trout density and biomass were not correlated with LWD cover in any of the analyses. We found no correlations between relative trout condition factor and stream characteristics or between condition factor and trout density.

Discussion

We found that that two important anthropogenic stresses to New England streams, logging and acidification, were significantly associated with brook trout density and biomass. Although these stresses have been shown to strongly influence resident trout populations in other regions, these are some of the first data from the northern New England region to address these issues. Our results are particularly relevant given the overall trajectory of forest recovery in the region. Reforestation, forest succession, and changes in forest practices are likely to result in reestablishment of mature and more diverse forests throughout northern New England, particularly in protected riparian buffer zones. Our results suggest that forest recovery may not result in across-the-board increases in brook trout abundance. However, we recognize the inherent limitations of this short-term correlative study and underscore the need for further research on these important issues.

Consistent with a number of previous studies, we found higher abundances of resident trout in streams that had been most recently logged (Bisson and Sedell 1984; Wilzbach 1985). Forest removal may have a range of enhancement effects on resident trout, including increased light penetration as related to primary and secondary productivity (Hawkins et al. 1982) and increased foraging success (Wilzbach 1985). Our results conflict, however, with a number of studies indicating negative effects of logging on resident trout populations (Reeves et al. 1993; Hauer et al. 1999). One explanation for this conflict may involve the timescale of logging effects. Several studies have shown that in old-growth forests the density of LWD is positively correlated with salmonid productivity and that LWD is reduced in logged drainages (Murphy and Koski 1989; Hauer et al. 1999). Although this relationship may apply in New England, it could be obscured by the extent of human alteration of forests in this region. Probably, all of our study sites were logged within the last 50–100 years. Consequently, even for sites not exposed to logging in the last 30 years, the new forests may not have matured to the point that LWD stores are sufficient to influence stream habitat and positively affect trout populations.

In contrast to logging history, stream pH was positively correlated to brook trout abundance. Although we recognize the limitations of a single pH measurement, given substantial seasonal variability in stream pH, our results are consistent with the general finding of negative effects of low pH on resident trout populations (Baker et al. 1996; Baldigo and Lawrence 2000). We found that summer low-flow pH was generally within the acceptable range for brook trout (i.e., not low enough to cause mortality) in all 16 streams (Baker et al. 1996). Therefore, further investigation is required to determine if negative effects of lower pH were due to correlation between low-flow pH and episodic acidification during spring runoff (Baker et al. 1996) or due to negative effects of low pH on

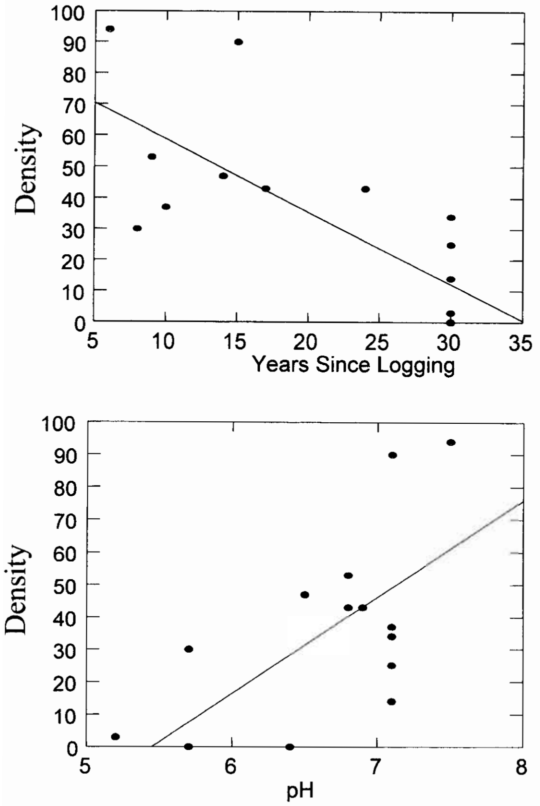

FIGURE 1.—Brook trout density (total number of individuals per 100 m^2 stream length) versus **(top panel)** logging history (years since logging) and **(bottom panel)** stream pH (some data points are obscured by overlying points; sample size = 16).

overall stream productivity (Cada et al. 1987; Kwak and Waters 1997). Greater positive effects of higher pH compared with negative effects of higher embeddedness is consistent with the findings of a field study of brown trout in Norway (Hesthagen et al. 1999) and a modeling study of brook trout in southern Appalachian streams (Marschall and Crowder 1996). In contrast, Baldigo and Lawrence (2000) found that physical habitat effects on brook trout abundance appear to have a stronger influence than water chemistry in the Neversink River in the northeastern USA.

In general, upland headwater streams in this part of New England are naturally low in pH as a result of cation-deficient soils and underlying bedrock (Driscoll et al. 2001). Our results indicate that observed variation in the pH of these systems can have measurable effects on brook trout abundance. Given the large number of streams in northern New England currently affected by atmospheric deposition, base cation depletion, and associated acidic water conditions and because of the potential for changes in these conditions resulting from air and water quality regulations, understanding this source of variation is critical for effective management of wild trout populations in the region. In addition, taking underlying variation in stream pH into account is clearly necessary when assessing the effects of forestry practices on stream salmonids in New England.

Acknowledgments

We would like to thank H. Fassnacht, B. Golden, C. Glastris, and D. Hogan for field help and R. DeGraaf and two anonymous reviewers for comments on the manuscript.

References

Baker, J. P., J. Van Sickle, C. J. Gagen, D. R. De Walle, W. E. Sharpe, R. F. Carline, B. P. Baldigo, P. S. Murdoch, D. W. Bath, W. A. Kretser, H. A. Simonin, and P. J. Wigington. 1996. Episodic acidification of small streams in the northeastern United States: effects on fish populations. Ecological Applications 6:422–437.

Baldigo, B. P., and G. B. Lawrence. 2000. Composition of fish communities in relation to stream acidification and habitat in the Neversink River, New York. Transactions of the American Fisheries Society 129:60–76.

Bisson, P., and J. R. Sedell. 1984. Salmonid populations in streams in clearcut vs. old-growth forests in western Washington. *In* W. R. Meehan, T. R. Merrell, Jr., and T. A. Hanley, editors. Proceedings, fish and wildlife relationships in old-growth forests symposium. American Institute of Fishery Research Biologists, Asheville, North Carolina.

Cada, G. F., J. M. Loar, and M. J. Sale. 1987. Evidence of food limitation of rainbow and brown trout in southern Appalachian soft-water streams. Transactions of the American Fisheries Society 116:692–702.

Driscoll, C. T., G. B. Lawrence, A. J. Bulger, T. J. Butler, C. S. Cronan, C. Eagar, K. F. Lambert, G. E. Likens, J. L. Stoddard, and K. C. Weathers. 2001. Acidic deposition in the Northeastern U.S.: sources and inputs, ecosystem effects, and management strategies. BioScience 51:3.

Foster, D. 1992. Land use history (1730–1990) and vegetation dynamics in central New England, USA. Journal of Ecology 80:253–772.

Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Canadian Journal of Fisheries and Aquatic Sciences 45:834–844.

Hauer, F. R., G. C. Poole, J. T. Gangemi, and C. V. Baxter. 1999. Large woody debris in bull trout spawning streams of logged and wilderness watersheds in northwest Montana. Canadian Journal of Fisheries and Aquatic Sciences 56:915–924.

Hawkins, C. P., L. Murphy, and N. H. Anderson. 1982. Effects of canopy, substrate composition, and gradient on the structure of macroinvertebrate communities in Cascade Range streams. Ecology 63: 1840–1856.

Hesthagen, T., J. Heggenes, B. M. Larsen, H. M. Berger, and T. Forseth. 1999. Effects of water chemistry and habitat on the density of young brown trout *Salmo trutta* in acidic streams. Water Air and Soil Pollution 112:85–106.

Kleinbaum, D. G., L. L. Kupper, K. E. Muller, and A. Nizham. 1998. Applied regression analysis and other multivariable methods. Duxbury Press, Pacific Grove, California.

Kwak, T. J., and T. F. Waters. 1997. Trout production dynamics and water quality in Minnesota streams. Transactions of the American Fisheries Society 126: 35–48.

Lowe, W. H., and D. T. Bolger. 2002. Local and landscape-scale predictors of salamander abundance in New Hampshire headwater streams. Conservation Biology 16:183–193.

Marschall, E. A., and L. B. Crowder. 1996. Assessing population responses to multiple anthropogenic effects: a case study with brook trout. Ecological Applications 6:152–167.

McMenemy, J. R. 1995. Survival of Atlantic salmon fry stocked at low density in the West River, Vermont. North American Journal of Fisheries Management 15:366–374.

Miller, A. B., E. S. Bryant, and R. W. Birnie. 1998. An analysis of land cover changes in the northern forest of New England using multitemporal landsat mss data. International Journal of Remote Sensing 19: 245–265.

Murphy, M. L., and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal of Fisheries Management 9:427–436.

Reeves, G. H., F. H. Everest, and J. R. Sedell. 1993. Diversity of juvenile anadromous salmonid assemblages in coastal Oregon basins with different levels of timber harvest. Transactions of the American Fisheries Society 122:309–317.

U.S. Forest Service. 1996. Stream inventory handbook, Level 1 and 2, Pacific Northwest Region, version 9.5. U.S. Forest Service, Washington, D.C.

Welsh, H. H., L. M. Ollivier, and D. G. Hankin. 1997. A habitat-based design for sampling and monitoring stream amphibians with an illustration from Redwood National Park. Northwestern Naturalist 78:1–16.

Wilzbach, M. A. 1985. Relative roles of food and cover in determining the habitat distribution of stream-dwelling cutthroat trout. Canadian Journal of Fisheries and Aquatic Sciences 42:1668–1672.