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ARTICLE

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Abstract
In 2004, the Pennsylvania Fish and Boat Commission implemented catch-and-release (CR) regulations on headwater stream systems to determine if eliminating angler harvest would result in an increase in the number of adult (≥100 mm) or large (≥175 mm) Brook Trout *Salvelinus fontinalis*. Under the CR regulations, angling was permitted on a year-round basis, no Brook Trout could be harvested at any time, and there were no tackle restrictions. A before-after–control-impact design was used to evaluate the experimental regulations. Brook Trout populations were monitored in 16 treatment (CR regulations) and 7 control streams (statewide regulations) using backpack electrofishing gear periodically for up to 15 years (from 1990 to 2003 or 2004) before the implementation of the CR regulations and over a 7–8-year period (from 2004 or 2005 to 2011) after implementation. We used Poisson mixed models to evaluate whether electrofishing catch per effort (CPE; catch/100 m^2) of adult (≥100 mm) or large (≥175 mm) Brook Trout increased in treatment streams as a result of implementing CR regulations. Brook Trout CPE varied among sites and among years, and there was no significant effect (increase or decrease) of CR regulations on the CPE of adult or large Brook Trout. Results of our evaluation suggest that CR regulations were not effective at improving the CPE of adult or large Brook Trout in Pennsylvania streams. Low angler use, high voluntary catch and release, and slow growth rates in infertile headwater streams are likely the primary reasons for the lack of response.

Brook Trout *Salvelinus fontinalis* are the only stream-dwelling salmonid native to Pennsylvania streams and are considered indicators of cold, clean water. They primarily occur in watersheds that contain large tracts of forest land and are important to the history and angling heritage of the state (Detar 2007; PFBC 2010). Because of this legacy and the availability of over 20,000 km of wild trout streams, anglers spend more time fishing for trout, including Brook Trout, than any other species group in Pennsylvania (USFWS 2007). In addition, wild trout angling contributes over US$7 million annually to Pennsylvania's economy; thus, Brook Trout are considered an important socioeconomic species (Greene et al. 2005; Sweka et al. 2012). Over the past century, Brook Trout distribution has been drastically reduced and their abundance has declined due to habitat loss, introduction of exotic species, atmospheric deposition of acidic compounds, overexploitation, and other anthropogenic influences (Detar 2007; Hudy et al. 2008; Risley and Zydlewski 2010; McKenna and Johnson 2011; Wagner et al. 2013).

Brook Trout primarily inhabit headwater stream systems in Pennsylvania, and fishing for them provides a unique angling experience as populations are usually found in forested watersheds with limited development. Brook Trout are more vulnerable

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to angling than most other trout species, especially Brown Trout *Salmo trutta,* with overharvest potentially leading to reduced densities of adult and larger fish (Cooper 1953; Alexander and Nuhfer 1993; Risley and Zydlewski 2010). Nuhfer and Alexander (1994) found that the intensity of angler exploitation over time may alter the potential for growth and angler catchability of Brook Trout, with the resulting population age–size structure tending toward a static state of young, slow-growing individuals with high annual mortality rates. In an attempt to conserve Brook Trout resources and limit the potential negative effects associated with high angler harvest, a number of regulations that limit angler harvest and reduce angling mortality have been implemented or modeled with varying degrees of success in Pennsylvania and elsewhere. These special regulations include increased minimum size limits, protected slot limits, decreased creel limits, and gear and season restrictions (Hunt 1970; Marcinko et al. 1988; Power and Power 1996). More recently, with catch and release becoming a greater component of personal philosophy and common practice among trout anglers, catch-and-release regulations have become more socially acceptable and have grown substantially in popularity as a fishery management tool (Barnhart 1989; Casselman 2005; Duda et al. 2008).

During 2002, the Pennsylvania Fish and Boat Commission (PFBC) hosted a "Trout Summit" conference to obtain public input on trout management. The results indicated strong public support for developing a catch-and-release regulation program to protect and attempt to enhance wild Brook Trout populations by increasing the number of adult (≥100 mm) and larger (≥175 mm) Brook Trout in headwater streams. Thus, to explore whether angler harvest was limiting wild Brook Trout populations, the PFBC implemented experimental catch-and-release (CR) regulations in 2004 and 2005 on a subset of streams. The management goal was to increase the abundance of adult (≥100 mm) and larger (≥175 mm) wild Brook Trout. Under the experimental CR regulations, angling was permitted on a year-round basis, no Brook Trout could be harvested at any time, and there were no tackle restrictions. Statewide regulations (178-mm minimum length limit and five trout/d creel limit from the opening day of trout season [first Saturday after April 11] through Labor Day, with no harvest for the remainder of the year) applied to Brown Trout.

METHODS

Study area.—Initially, 140 km of the upper Kettle Creek watershed was placed under the CR regulations in 2004. In 2005, eight additional watersheds or portions of watersheds were added to the program, providing an additional 155 km of CR waters. Sixteen streams were monitored within the nine treatment watersheds (Figure 1; Table 1). Seven additional streams were selected as controls (statewide regulations) and were similar in size and character to the treatment waters (Figure 1; Table 1). To ensure similar environmental conditions, the control streams were located within the same larger watershed as the treatment streams or in a nearby watershed; all were within 24 km of treatment streams. Study stream watersheds were forested, varied in size from 2nd to 4th order, ranged in average width from 2.7 to 10.8 m, and had productivity levels, as measured by total alkalinity, ranging from 0 to 33 mg/l (Table 1). Study streams were also comprised of those with road access and those requiring a walk-in. We considered streams to have road access if they were located within 300 m of a public road. There were three control streams with road access and four that required a walk-in and seven and nine treatment streams with and without road access, respectively (Table 1). All treatment and control streams were managed for wild trout with no stocking, and all were open to public angling. Study streams contained either allopatric Brook Trout populations ($n = 8$) or sympatric Brook Trout and Brown Trout populations ($n = 15$) that were Brook Trout dominant (mean total trout catch per effort [CPE] was 95% Brook Trout; range, 58–99%).

Brook Trout monitoring.—To evaluate the effects of CR regulations on the numbers of adult (≥100 mm) and larger (≥175 mm) wild Brook Trout, we used a before-after–control-impact design that was replicated temporally and spatially. Replication in time consisted of sampling control and treatment waters for up to 15 years (from 1990 to 2003 or 2004) before the implementation of the CR regulations (although not all streams were sampled in all years) and over a 7–8-year period (from 2004 or 2005 to 2011) after implementation. The 15-year preimplementation period was not necessarily by design but encompassed historical, routine stream assessments. We also analyzed the data using a 10- and 7-year preimplementation period; however, results did not change and thus we present the analysis using the 15-year preimplementation period. The 7–8-year postimplementation sampling period was chosen to allow for 1–2 cohorts of Brook Trout to move through the population, assuming a maximum age of 3–6 years. Based on back-calculated length-at-age data for Brook Trout in 48 Pennsylvania headwater streams from 1978 to 1990, average length at age 3 was 165 mm, at age 4 was 184 mm, at age 5 was 201 mm, and at age 6 was 215 mm (PFBC, unpublished). Replication in space was accomplished by using treatment waters ($n = 16$) managed under the CR regulations and control waters ($n = 7$) managed under statewide regulations to account for changes in fish populations not associated with changes in harvest regulations (Figure 1).

Brook Trout were sampled during summer and early-fall base flows (mid-June through the first week in October) using backpack electrofishing gear at fixed sampling stations. The larger study streams (Kettle Creek, Camp Run, Shaeffer Run, and Roaring Run) each had two to three sample sites, while all other waters had one sample site. Sample sites averaged 306 m in length (range, 200–456 m). We measured the total length of all Brook Trout captured during electrofishing and enumerated catches by 25-mm length-groups. A combination of depletion and mark–recapture techniques were used to sample fish populations. Because different techniques

TABLE 1. Description of treatment and control streams used for the evaluation of catch-and-release regulations on Brook Trout in Pennsylvania. Strahler stream order and drainage area were calculated at the sample reach for Kettle Creek and Sherman Creek because Brook Trout are only located in the upper reaches of these larger streams. Mean catch per effort (CPE) reflects the mean first-pass electrofishing catch of Brook Trout/100 m^2 throughout the study period.

Stream	River km of sample site	Strahler stream order	Drainage area (km^2)	Stream length (km)	Year regulation began	Sample occasions before	Sample occasions after	Total alkalinity (mg/l)	pH (SU)	Site length (m)	Mean site width (m)	Mean ± SD Brook Trout ≥100 mm CPE (fish/100 m^2)	Mean ± SD Brook Trout ≥175 mm CPE (fish/100 m^2)
Billings Branch	1.8	2	8.0	4.0	2004	1	1	5	6.4	300	3.1	8.0 ± 3.7	0.5 ± 0.1
Germania Branch[a]	1.3	3	25.0	3.8	2004	2	4	18–25	7.0–7.1	300	6.5	3.7 ± 1.8	0.8 ± 0.5
Indian Run	1.8	2	4.9	4.0	2004	2	4	6–7	6.4–6.8	300	3.1	4.9 ± 1.5	0.4 ± 0.4
Kettle Creek	58.6	4	113.1	12.8	2004	3	4	10–19	6.8–7.1	340	10.8	0.8 ± 0.6	0.3 ± 0.1
Kettle Creek[a]	64.0	4	113.1	12.8	2004	2	4	11–15	6.8–7.1	325	6.9	6.0 ± 4.3	1.1 ± 0.7
Kettle Creek[a]	67.4	3	113.1	12.8	2004	2	4	8–12	6.6–6.9	360	5.4	7.0 ± 3.7	0.7 ± 0.3
Long Run	1.2	3	15.6	7.9	2004	1	4	11–17	6.8–7.2	311	3.9	8.8 ± 3.6	1.4 ± 0.7
Sliders Branch	2.3	3	14.4	6.3	2004	2	3	13–18	6.8–7.1	300	3.5	10.8 ± 6.0	1.0 ± 0.5
Birch Run	3.2	2	16.2	8.5	2005	1	4	12–12	6.8–7.1	300	3.9	6.4 ± 3.3	1.7 ± 0.9
Camp Run[a]	0.4	2	8.0	6.6	2005	4	4	13–28	6.9–7.3	310	4.4	2.1 ± 0.2	0.3 ± 0.0
Camp Run[a]	2.0	2	8.0	6.6	2005	4	4	17–33	7.1–7.3	300	4.0	2.4 ± 0.2	0.3 ± 0.0
Jeans Run	3.4	2	10.7	4.1	2005	3	4	1–4	5.8–6.3	300	4.5	6.1 ± 2.1	0.2 ± 0.2
Kistler Run[a]	0.6	2	5.3	2.6	2005	2	4	0–4	6.0–6.0	300	4.4	4.9 ± 1.2	0.9 ± 0.6
Lyman Run[a]	8.2	3	41.6	6.2	2005	3	4	12–17	6.8–7.1	300	4.8	4.8 ± 2.7	0.8 ± 0.4
Minister Creek	2.1	3	28.3	8.0	2005	2	7	2–8	6.3–6.8	288	7.1	1.5 ± 1.1	0.3 ± 0.1
Shaeffer Run[a]	5.2	2	14.9	7.7	2005	6	3	7–10	6.6–6.8	308	5.1	4.4 ± 1.6	0.6 ± 0.3
Shaeffer Run[a]	6.9	2	14.9	7.7	2005	6	3	6–10	6.1–6.6	298	5.1	4.6 ± 1.2	0.4 ± 0.1
Shaeffer Run[a]	9.8	2	14.9	7.7	2005	4	3	6–10	6.4–6.4	300	3.7	6.9 ± 2.4	0.4 ± 0.2
UNT Minister Creek (1)[b]	0.1	2	8.3	6.8	2005	1	7	1–8	5.6–6.5	315	5.1	3.1 ± 1.3	0.2 ± 0.2
UNT Minister Creek (2)[b]	0.1	2	4.4	4.3	2005	1	7	1–8	6.1–6.4	302	3.9	5.1 ± 2.0	0.1 ± 0.1
Wolf Swamp Run[a]	0.3	2	5.8	3.2	2005	2	4	4–6	6.2–6.8	301	2.8	6.0 ± 2.9	0.4 ± 0.2
Devils Hole Creek	5.3	2	6.5	2.4	Control	5	3	6–14	6.4–7.0	305	4.9	17.4 ± 5.7	1.9 ± 0.7
Roaring Run[a]	2.5	3	24.6	3.1	Control	2	4	8–23	6.9–7.1	200	5.8	3.2 ± 1.3	0.5 ± 0.5
Roaring Run	3.2	2	9.9	5.6	Control	1	4	10–25	7.0–7.2	200	5.5	4.0 ± 1.5	0.4 ± 0.3
Sawmill Run	1.8	2	5.3	3.7	Control	1	4	4–14	6.4–6.9	305	2.7	9.6 ± 6.2	1.1 ± 0.9
Sherman Creek[a]	83.1	3	33.2	5.3	Control	2	3	4–6	6.3–6.6	323	4.8	4.9 ± 1.4	0.8 ± 0.4
Sunken Branch[a]	1.7	3	15.8	2.8	Control	2	4	10–12	6.7–7.0	307	3.1	10.7 ± 5.4	1.9 ± 0.6
Trout Run[a]	2.1	3	32.1	4.0	Control	2	2	7–17	6.8–7.0	326	4.7	4.9 ± 1.3	0.7 ± 0.2
Tubbs Run	4.7	2	19.1	5.1	Control	2	5	4–8	5.9–6.6	456	4.4	4.2 ± 1.3	0.3 ± 0.2

[a]Indicates road access to stream (public road located within 300 m of sample site).
[b]The abbreviation UNT = unnamed tributary to.

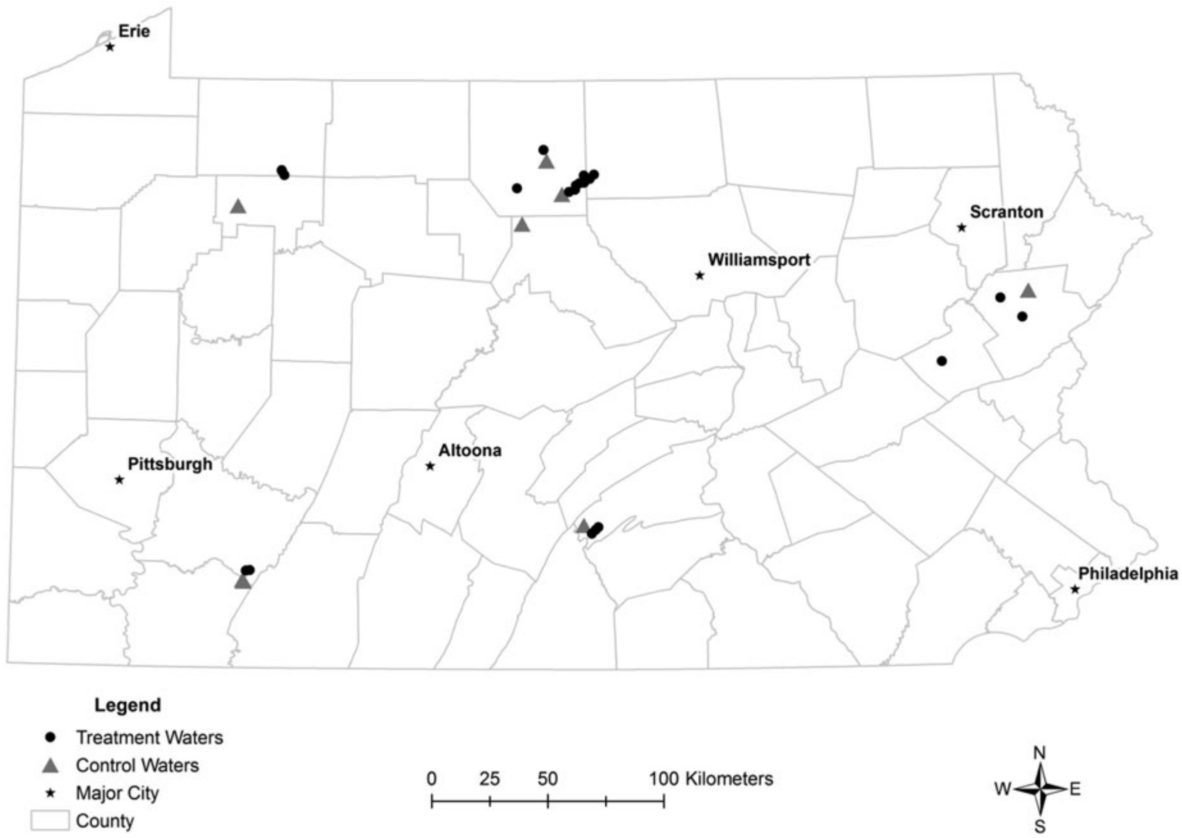

FIGURE 1. Location of 16 treatment (circle) and 7 control (triangle) streams used for evaluating catch-and-release regulations in Pennsylvania.

were used to sample study streams, and thus different abundance estimators were used, we chose to use first-pass electrofishing CPE (catch/100 m^2) as the primary metric to evaluate the experimental regulations. We also used abundance-derived density estimates as a secondary metric to compare the experimental regulations, despite the high correlations between first-pass electrofishing CPE and abundance estimates ($r^2 = 0.93$ and 0.88 for depletion estimates of $\geq$100-mm and $\geq$175-mm fish, respectively, and $r^2 = 0.90$ and 0.90 for mark–recapture estimates of $\geq$100-mm and $\geq$175-mm fish, respectively).

Statistical analysis.—Although we examined both CPE and abundance-derived density estimates, we report the statistical analysis for the case of CPE because this was our primary metric and the basic model was the same for both metrics. We fitted Poisson mixed models to examine whether or not CR regulations achieved the management goals of increasing the CPE of Brook Trout $\geq$100 mm and $\geq$175 mm in total length in treatment streams compared with control streams. Accordingly, the response variables were the number of Brook Trout $\geq$100 mm and the number of Brook Trout $\geq$175 mm total length caught during single-pass electrofishing [i.e., we assumed the number of fish caught on sample occasion i (y_i) was $y_i \sim \text{Poisson}(\lambda_i)$]. Fixed effects included stream type (whether a stream had CR regulations implemented or whether it was a control stream), time period (before or after CR regulation implementation), and the interaction between stream type and time period. Stream and year were treated as random effects. The statistical model was as follows:

$$\log_e(\lambda_i) = \log_e(A_i) + \alpha_{lm(i)} \times \text{stream type}_i \times \text{time period}_i + \gamma_{j(i)} + \delta_{k(i)},$$

where A_i is the stream area (m^2) sampled, α_{lm} is the mean $\log_e$(catch/100 m^2) for stream type l in time period m, γ_j is a random effect for stream j, independent and identically distributed as $\gamma_j \sim N(0, \sigma^2_{\text{site}})$, and δ_k is a random effect for year k, independent and identically distributed as $\delta_k \sim N(0, \sigma^2_{\text{year}})$. In addition to examining whether or not the effects of the experimental regulations were influenced by road access, we also fitted models with an additional categorical effect: whether or not a stream had road access. Specifically, a three-way interaction between stream type, pre- versus postregulation, and road access was estimated.

Bayesian estimation was used to estimate all parameters. Noninformative uniform priors were used for σ^2_{site} and σ^2_{year}(i.e., unif [0, 50]), while noninformative normal priors were used for all other parameters (i.e., N [0, 0.001]; note that the precision

$1/\sigma^2$ is used in place of the variance for normal priors). All analyses were performed using the programming environment R and JAGS (Plummer 2011; R Development Core Team 2011). Three parallel chains were run with different initial values in JAGS to generate 50,000 samples from the posterior distributions for each analysis, after discarding the first 10,000 samples. We retained every third sample. The posterior mean and 80% and 95% credible intervals were calculated. We examined the Gelman–Rubin convergence statistic, chain histories, and posterior density plots to assess convergence. Significant changes in the CPE of Brook Trout ≥100 mm and ≥175 mm were based on evaluating for nonoverlapping credible intervals.

RESULTS

There were a total of 186 samples across 29 sites from the 23 streams used in this study. The number of times a stream was sampled ranged from one to six occasions before regulations were implemented and one to seven occasions in the posttreatment evaluation period (Table 1). Brook Trout CPE varied considerably temporally and spatially in both treatment and control waters. First-pass catches of adult Brook Trout ranged from 0.2 to 25.3/100 m^2 (mean ± SD, 5.5 ± 4.3) and from 0.0 to 3.1/100 m^2 (0.7 ± 0.6) for larger fish (Figure 2).

Because results were similar and inferences did not change based on whether or not CPE or abundance-derived density estimates were used for the evaluation, we only present results for

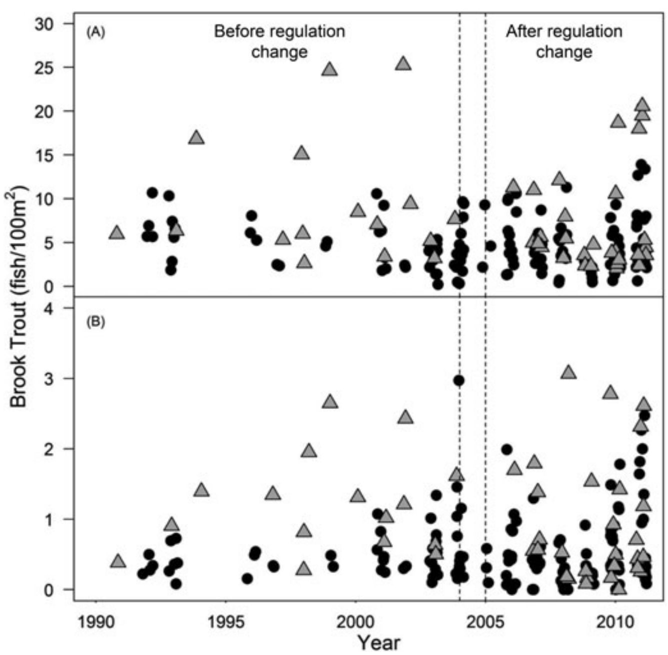

FIGURE 2. First-pass electrofishing catch/100 m^2 of Brook Trout **(A)** ≥100 mm and **(B)** ≥175 mm from 1990 to 2011 in 23 Pennsylvania streams. Circles are treatment streams and triangles are control streams. Dashed vertical lines indicate the time period (2004 and 2005) when treatment streams were placed under catch-and-release regulations.

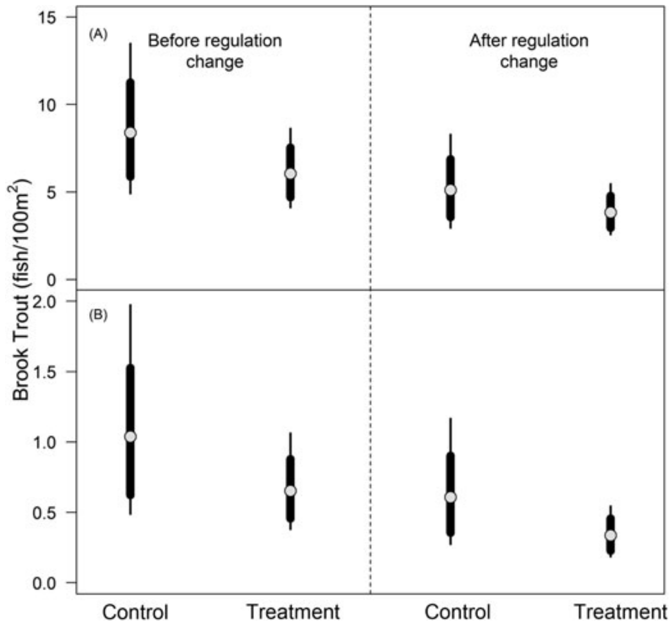

FIGURE 3. Estimated posterior mean catch/100 m^2 of Brook Trout **(A)** ≥100 mm and **(B)** ≥175 mm in control and treatment streams before and after catch-and-release regulations. Circles are posterior means and thick lines are 80% credible intervals and thin lines are 95% credible intervals.

the CPE analysis. Based on overlapping 80% and 95% credible intervals, we found that there were no changes in the mean CPE of Brook Trout ≥100 mm or ≥175 mm from before to after experimental CR regulation implementation for treatment or control streams (Table 2; Figure 3). We also found that there were no differences in mean Brook Trout/100 m^2 ≥100 mm or ≥175 mm between treatment and control streams during any time period (Table 2; Figure 3). In addition, although there were some differences in mean CPE between streams with and without road access (e.g., treatment stream posterior means [95% credible intervals] before the regulation change for those with and without road access were 2.4 Brook Trout/100 m^2 [1.2–4.3] and 18.8 Brook Trout/100 m^2 [9.3–33.9], respectively), there were no differences after the regulation change when compared with before the regulation change for control or treatment streams regardless of access category (Figure 4).

DISCUSSION

We used a controlled and replicated design to evaluate the effects of CR regulations on Brook Trout over a broad geographical range of streams and a relatively long time frame (up to 15 years before and 7–8 years after regulation implementation), and regulations were applied to watersheds rather than individual streams or stream reaches. We included both streams with road access (e.g., public roads within 300 m of the stream) as well as streams that required walk-in access. The mean first-pass catch of adult (≥100 mm) Brook Trout was 5.5 fish/100 m^2 (range, 0.2–25.3), which was similar to the average abundance of adult Brook Trout throughout the state (5.7 fish/100 m^2; T.

TABLE 2. Parameter estimates and 95% credible intervals (in parentheses) from a Poisson mixed model used to evaluate catch-and-release (CR) regulations in Pennsylvania streams.

Brook Trout size-class (TL)	Before CR regulations		After CR regulations			
	Control ($\hat{\alpha}_{lm}$)	Treatment ($\hat{\alpha}_{lm}$)	Control ($\hat{\alpha}_{lm}$)	Treatment ($\hat{\alpha}_{lm}$)	$\hat{\sigma}_{\text{site}}$	$\hat{\sigma}_{\text{year}}$
≥ 100 mm	–3.28 (–3.66, –2.91)	–2.82 (–3.19, –2.45)	–3.00 (–3.52, –2.49)	–2.51 (–3.01, –2.00)	0.61 (0.45, 0.85)	0.43 (0.30, 0.61)
≥ 175 mm	–5.73 (–6.29, –5.55)	–5.07 (–5.57, –4.90)	–5.17 (–5.90, –4.45)	–4.63 (–5.32, –4.40)	0.84 (0.60, 1.18)	0.46 (0.27, 0.75)

Wagner, unpublished), suggesting that these streams were representative of Pennsylvania's Brook Trout resource as a whole. Results of our evaluation suggest that CR regulations were not effective at increasing the abundance of adult (≥100 mm) or large (≥175 mm) Brook Trout in Pennsylvania streams. These findings are consistent with other evaluation and modeling studies that have shown no detectable effect of CR or other harvest regulations for improving size structure or abundance of adult or larger Brook Trout in waters where natural mortality rates were high, CR rates were high before regulations were implemented, angler harvest represented an insignificant portion of total mortality, or stream productivity was low (Barnhart 1989;

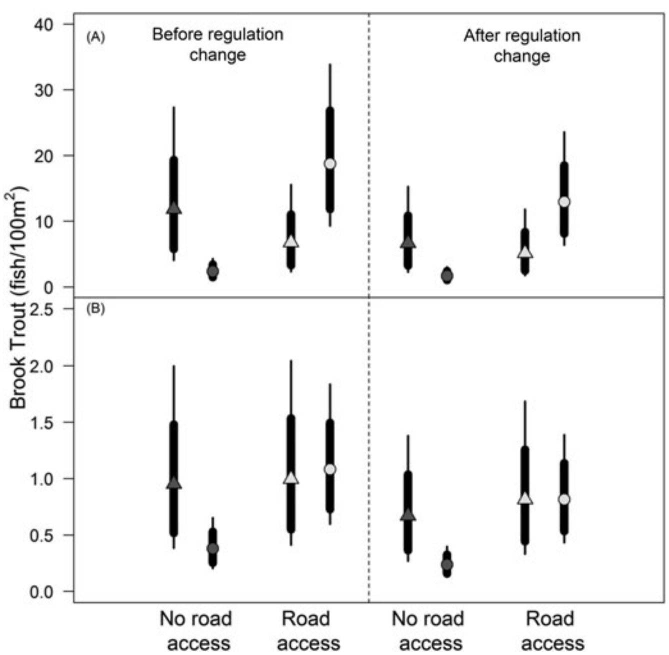

FIGURE 4. Estimated posterior mean catch/100 m^2 of Brook Trout **(A)** ≥100 mm and **(B)** ≥175 mm in control (triangles) and treatment (circles) streams before and after implementing catch-and-release regulations. Streams were classified into two categories: those with vehicle road access (light grey symbols) and those without road access (dark grey symbols). Symbols are posterior means and thick lines are 80% credible intervals and thin lines are 95% credible intervals.

Clark and Alexander 1992; Alexander and Nuhfer 1993; Habera and Strange 1993; Risley and Zydlewski 2010).

Numerous studies have consistently shown that Brook Trout populations in headwater streams in the Eastern United States, including Pennsylvania, exhibit slow growth, are short lived (maximum age, 3–6 years), and have annual mortality rates which often exceed 70% or more (Cooper 1953, 1962; Bridges and Mullan 1958; Zorn and Nuhfer 2007; PFBC, unpublished). Pennsylvania headwater stream systems have low productivity and often experience extreme environmental conditions. These conditions can be difficult to overcome when trying to improve Brook Trout populations with more restrictive angling regulations, especially in the presence of high voluntary CR and low angler use. For example, a statewide survey of trout anglers conducted in 1991 indicated that the majority (61%) of respondents felt that keeping a limit of wild trout was important to them (Hummon 1992). However, Duda et al. (2008) found that 88% of Pennsylvania trout anglers practiced CR at least half of the time. In addition, an angler survey on 200 wild trout streams in Pennsylvania during 2004 found that anglers released 93% of their total catch and exploitation of legal-size trout was estimated at 8% for Brook Trout (Greene et al. 2005). These results show a shift in CR similar to the growing trend of anglers practicing CR for trout elsewhere, which can result in low exploitation (e.g., Casselman 2005; Schill et al. 2007).

Besides the increasing trend of voluntary CR documented in Pennsylvania's wild trout fisheries, angler pressure on small wild trout streams is generally low. Greene et al. (2005) reported angler use ranged from 45 to 123 angler-h/ha on small (<6 m wide) Pennsylvania wild trout streams during 2004. Similarly, an angler-use evaluation during 2012 on three CR regulation streams and one control stream estimated angler use at 64 angler-h/ha (Kristine 2012). Thus, these data show angler use was low at both the onset and completion of the CR regulation evaluation period and was well below the range of angling pressure of 160–300 angler-h/ha reported by Risley and Zydlewski (2010), when even modest increases in angling mortality would be expected to cause a decline in the density of older or larger Brook Trout. Angler use on small Pennsylvania wild trout streams was also much lower than the more intensive angling pressure of 371–1,065 angler-h/ha which Nuhfer and Alexander (1994) postulated could result in Brook Trout populations exhibiting slower growth and lower angler catchability. High angler catch rates of 1.8 wild Brook Trout/h on small wild trout streams in Pennsylvania suggests that wild Brook Trout fisheries are not experiencing levels of depressed angler catchability (Greene et al. 2005).

In small Pennsylvania streams where angling pressure is low, factors other than angling mortality are most likely driving the overall abundance and size structure of wild Brook Trout populations. Mason (2009) found mean wetted width, gradient, and pools per kilometer to be the limiting factors for Brook Trout densities in an evaluation of habitat features found in 28 headwater streams in central Pennsylvania. Zorn and Nuhfer (2007) and Grossman et al. (2010, 2012) found density-dependent processes and year-class strength to be primary forces determining population size and growth in Brook Trout populations. The importance of protecting habitat and providing fish passage to maintaining quality Brook Trout populations is further highlighted by Mollenhauer et al. (2013) and Petty et al. (2005, 2012), who documented that some larger adult Brook Trout in Pennsylvania and West Virginia have been shown to move long distances (>1 km) within a watershed system. While managers need to evaluate all aspects of wild Brook Trout populations and fisheries, including angler use and harvest, these studies underscore the importance of maintaining high-quality habitat, access to thermal refugia, and population connectivity as critical to maximizing Brook Trout population productivity at the watershed scale.

The CR regulations program was designed to evaluate the effects of angler harvest on adult (≥100 mm) or large (≥175 mm) Brook Trout in Pennsylvania streams. While the regulation restricted harvest, it permitted the use of all tackle, including natural bait. However, it is unlikely that restricting tackle to artificial lures or flies would have changed the outcome because of low angler use prior to and after regulation implementation and because the majority (57–61%) of anglers were already using artificial lures or fly fishing gear (Greene et al. 2005; Kristine 2012). Even if we assumed high hooking mortality (35%) by all anglers, at 123 angler-h/ha (maximum angler use on small trout streams documented by Greene et al. [2005]) and an average catch rate of 1.8 Brook Trout/h (Greene et al. 2005), there would be a loss of about 14% of the average estimated density of adult Brook Trout in our study streams to hooking mortality. This is likely a relatively small portion of the total annual mortality, considering total annual mortality averaged 70% (range, 24–96%) for age-1 and older Brook Trout in 48 headwater streams from 1978 to 1990 (PFBC, unpublished).

Angling regulations play an important role in fisheries management. However, applying more restrictive angling regulations will likely not have the desired results of increased abundance of larger fish if voluntary CR is high prior to regulation implementation, angler use is low, and thus together, angling mortality is low and does not comprise a considerable portion of the total annual mortality. We conclude that factors other than angler harvest are most likely driving the abundance of adult and larger wild Brook Trout. If low angler use and high voluntary CR continue into the future, protecting habitat and population connectivity in these systems will be a more effective tool for conserving and managing Brook Trout than applying more restrictive angling regulations. Because angler sentiment could shift back toward higher levels of harvest, maintaining up-to-date fishery monitoring and angler-use and harvest data are critical for helping managers make decisions that are most likely to have a population-level benefit.

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