This article was downloaded by: [Bradley B. Shepard]
On: 28 September 2014, At: 12:29
Publisher: Taylor & Francis
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

North American Journal of Fisheries Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujfm20

Factors Influencing Successful Eradication of Nonnative Brook Trout from Four Small Rocky Mountain Streams Using Electrofishing

Bradley B. Shepard[ab], Lee M. Nelson[c], Mark L. Taper[d] & Alexander V. Zale[e]

[a] Department of Ecology, Montana State University, Montana Department of Fish, Wildlife and Parks, Bozeman, Montana 59717, USA

[b] Wildlife Conservation Society, 301 North Willson Avenue. 59715, Bozeman, Montana, USA

[c] Montana Department of Fish, Wildlife and Parks, 39 Centerville Road. 59644, Townsend, Montana, USA

[d] Department of Ecology, Montana State University, 59717, Bozeman, Montana, USA

[e] U.S. Geological Survey, Montana Cooperative Fishery Research Unit, Montana State University, 59717, Bozeman, Montana, USA

Published online: 10 Sep 2014.

To cite this article: Bradley B. Shepard, Lee M. Nelson, Mark L. Taper & Alexander V. Zale (2014) Factors Influencing Successful Eradication of Nonnative Brook Trout from Four Small Rocky Mountain Streams Using Electrofishing, North American Journal of Fisheries Management, 34:5, 988-997

To link to this article: http://dx.doi.org/10.1080/02755947.2014.942042

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

North American Journal of Fisheries Management 34:988–997, 2014
© American Fisheries Society 2014
ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2014.942042

ARTICLE

Factors Influencing Successful Eradication of Nonnative Brook Trout from Four Small Rocky Mountain Streams Using Electrofishing

Bradley B. Shepard*
Department of Ecology, Montana State University, Montana Department of Fish, Wildlife and Parks, Bozeman, Montana 59717, USA; and Wildlife Conservation Society, 301 North Willson Avenue, Bozeman, Montana 59715, USA

Lee M. Nelson
Montana Department of Fish, Wildlife and Parks, 39 Centerville Road, Townsend, Montana 59644, USA

Mark L. Taper
Department of Ecology, Montana State University, Bozeman, Montana 59717, USA

Alexander V. Zale
U.S. Geological Survey, Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana 59717, USA

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

Abstract
We successfully eradicated nonnative Brook Trout *Salvelinus fontinalis* by electrofishing from 2.4- to 3.0-km treatment reaches of four Rocky Mountain streams in Montana to conserve sympatric populations of native Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi*. At least 6, and as many as 14, removal treatments of two to four electrofishing passes per treatment were required to successfully eradicate Brook Trout from these treatment reaches. We increased success by modifying our treatment efforts during this study from single annual treatments to several treatments a year to take advantage of autumn spawning and winter aggregating behavior. Eradication by electrofishing cost US$3,500 to $5,500 per kilometer where no riparian vegetation or woody debris clearing was necessary, increasing to $8,000 to $9,000 per kilometer where clearing was needed. Treatment costs without stream clearing were similar to costs of eradication using piscicides. Eradication by electrofishing may be preferable where native fish occur in sympatry with nonnative fish in smaller streams (base flow wetted widths <3.0 m) because native fish can be salvaged during removal efforts and because electrofishing may be more acceptable to the public than use of piscicides.

Westslope Cutthroat Trout *Oncorhynchus clarkii lewisi* (hereafter WCT) have experienced severe declines in distribution and abundance throughout most of their historical range (Liknes and Graham 1988; Behnke 1992; McIntyre and Rieman 1995; Van Eimeren 1996; Shepard et al. 1997, 2005). Shepard et al. (2005) estimated that WCT occupy about 59% of their historical habitats in the USA, and genetically tested populations with no evidence of introgression occupy about 10% of currently occupied habitats. Factors associated with this decline include introductions of nonnative fishes, habitat changes, and overexploitation (Hanzel 1959; Liknes and Graham 1988; Behnke 1992; McIntyre and Rieman 1995). Genetic introgression with introduced Rainbow Trout *O. mykiss* and Yellowstone Cutthroat Trout *O. c. bouvieri* also represents a

*Corresponding author: bshepard@wcs.org
Received December 16,2013; accepted June 9,2014

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

serious threat to WCT throughout their range (Allendorf and Leary 1988). Because of the high amount of genetic variability observed among WCT populations, Allendorf and Leary (1988) recommended the conservation of as many populations throughout the historical range as possible to conserve that genetic diversity.

Shepard et al. (1997) estimated that genetically tested WCT populations in which no evidence of introgression was found occupied about 5% of their historical range within the upper Missouri basin of Montana and their population viability assessments for these remaining WCT populations indicated that most had relatively low probabilities of persistence for the next century unless conservation measures were implemented. However, more recent analyses by Peterson et al. (in press) indicated that persistence of WCT populations isolated above fish barriers for the past 50–100 years was related to quality and length of available habitat, but not time of isolation. Montana, which has a long history of WCT conservation, formalized a collaborative statewide conservation agreement with federal land management agencies and many private organizations in 1999 that was updated in 2007 (Montana Department of Fish, Wildlife and Parks 2007). A primary objective of this conservation agreement is to protect and expand existing populations.

Many historical habitats formerly occupied by WCT now contain populations of nonnative trout, which in many cases have totally replaced WCT (MacPhee 1966; Griffith 1972; Liknes and Graham 1988; Behnke 1992; McIntyre and Rieman 1995). A large proportion of historical WCT habitat in the upper Missouri basin is now occupied by nonnative Brook Trout *Salvelinus fontinalis,* which were introduced during the early half of the 20th century (Shepard et al. 1997).

Mechanisms by which Brook Trout might replace or displace WCT are varied. Griffith (1972) documented dietary overlap between Brook Trout and WCT and suggested that although Brook Trout could replace WCT through competition for food or space or both, replacement of Cutthroat Trout by Brook Trout probably occurred only after habitat degradation had already reduced or eliminated Cutthroat Trout. Thomas (1996) observed that young Brook Trout inhibited the foraging efficiency of juvenile Colorado River Cutthroat Trout *O. c. pleuriticus* in a controlled laboratory setting. She suggested that this inhibition might be the mechanism responsible for the decreased growth rates of Cutthroat Trout she documented in the wild. Juvenile Brook Trout excluded juvenile Greenback Cutthroat Trout *O. c. stomias* from more profitable stream positions (Cummings 1987). Fecundities of Brook Trout and Cutthroat Trout that typically inhabit small headwater streams are similar (e.g., Rounsefell 1957; Wydoski and Cooper 1966; Downs et al. 1997; Adams 1999); however, female Brook Trout in headwater streams can mature at smaller sizes than WCT (e.g., Downs et al. 1997; Kennedy et al. 2003).

When Brook Trout were physically removed from a reach of stream in Montana, WCT abundance increased rapidly, apparently because of increased survival of young, primarily age-0 WCT (Shepard et al. 2002). A similar response by Colorado River Cutthroat Trout occurred in four mountain streams in Colorado (Peterson et al. 2004a). Both Shepard et al. (2002) and Peterson et al. (2004a) suggested that earlier emergence by Brook Trout probably provided a competitive size advantage and allowed them to out-compete age-0 Cutthroat Trout.

Removal of nonnative fish has been recommended as part of numerous native fish conservation plans (e.g., Cowley 1987; Propst et al. 1992; Langlois et al. 1994) and is usually accomplished using the piscicides rotenone or antimycin (e.g., Marking et al. 1983; Gresswell 1988; Behnke 1992; Knight et al. 1999; Finlayson et al. 2000; Hepworth et al. 2002). However, public concern regarding the use of piscicides (Goodrich and Buskirk 1995; Finlayson et al. 2002; McClay 2005) and loss of sympatric native fish during treatment with piscicides have focused attention on the potential for using electrofishing to remove unwanted nonnative fish from specific waters.

Electrofishing removal of nonnative Rainbow Trout has been successful in some streams in Great Smoky Mountains National Park (Moore et al. 1986; West et al. 1990); however, Thompson and Rahel (1996) and Meyer et al. (2006) were unsuccessful in removing Brook Trout from Rocky Mountain streams. Carmona-Catot et al. (2010) suggested that Brook Trout might be successfully removed by electrofishing from a tributary to Eagle Lake, California, to conserve the native Rainbow Trout, and Buktenica et al. (2013) used electrofishing to remove Brook Trout from a small Sun Creek tributary in Crater Lakes National Park, Oregon, to conserve Bull Trout *Salvelinus confluentus*. Caudron and Champigneulle (2011) reduced, but did not eradicate, nonnative Atlantic Salmon *Salmo salar* from a stream that supported native Brown Trout *Salmo trutta*.

The variability in success or failure of these eradication projects suggests that certain measurable factors, such as stream characteristics or total effort, may contribute to whether eradication can or cannot be achieved. To provide guidance on types of streams where this technique may be feasible and desirable, we evaluated whether backpack electrofishing could successfully eradicate Brook Trout from headwater reaches of several Northern Rocky Mountain streams that also supported WCT. We estimate costs associated with these eradication efforts and describe procedures we found to be most effective, given our experiences during these removals.

STUDY AREA

We initially selected six study streams located throughout the upper Missouri River basin in Montana, based on recommendations of local biologists (Table 1). We estimated elevations and channel gradients of these streams and our treatment reaches using 1:100,000 stream hydrography (http://nhd.usgs.gov/data.html) and digital elevation model layers (30-m resolution) within ArcView (version 3.2; ESRI 1999). We measured three to five stream widths per 100 m of stream

TABLE 1. Physical characteristics of six Rocky Mountain streams where Brook Trout removals were conducted from 1993 through 2005.

	Stream					
Parameter	Cottonwood	Craver[a]	Muskrat	Spring[a]	Staubach	Whites
Latitude (N)	47.44469	44.68639	46.29663	45.28308	46.47506	46.61870
Longitude (W)	110.47702	113.00383	112.03632	112.37472	111.72489	111.48500
Elevation range of entire stream (m)	970–1,830	2,200–2,800	1,480–2,350	1,470–2,320	1,500–1,840	1,200–1,870
Elevation range of treatment reach (m)	1,590–1,780	2,300–2,400	1,920–2,110	1,880–2,120	1,500–1,730	1,600–1,790
Length of stream (km)	31.1	5.8	33.9	24.0	11.4	25.5
Treatment length (km)	3.0	2.8	2.4	1.7	2.5	2.9
Wetted width (m)	2.4	1.2	2.6	1.7	1.6	2.0
Channel order[b]	3rd	2nd	3rd	3rd	2nd	3rd
Channel gradient (%)	6	3	6	5	11	3
Riparian vegetation (density and predominant types)	Sparse willow, aspen	Dense willow, alder	Moderate conifer, alder	Dense willow, alder	Moderate conifer, alder	Moderate to dense willow, alder[c]
Late summer discharge (m^3/s)	0.10	0.05	0.17	0.07	0.06	0.08
July and August water temperatures (°C)	12–17	5–20	6–16	9–20	10–19	8–10
Conductivity (μmho)	88	44	72	230	60	660
pH	8.7	8.2	8.4	8.9	7.9	8.2

[a]Craver and Spring creeks were excluded from the study because electrofishing efficiencies in the treatment reaches of these streams were so poor that eradication of Brook Trout was deemed impossible.

[b]Strahler (1957) stream order classification from 1:24,000 scale maps.

[c]Areas of dense riparian vegetation along and within Whites Creek were cleared before removal efforts were conducted.

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

length throughout the treatment reaches, the total length of each treatment reach, water temperatures, water conductivity, and pH during sampling. Wetted stream width was averaged over treatment reaches.

Study streams were relatively small, cold, neutral to alkaline, and had low to moderate conductivities (Table 1). Treatment reaches were located in the headwater portions of each stream, and elevations, channel gradients, and densities and types of riparian communities of treatment reaches varied (Table 1). After initial site visits that included attempts to conduct electrofishing removals, we dropped Craver and Spring creeks as study streams. Dense woody vegetation and debris choked stream channels in both these streams and, along with numerous beaver ponds in Craver Creek, made it nearly impossible to effectively electrofish in these streams.

Barriers to upstream fish movement were constructed at the lower boundary of each treatment reach. Two barriers were constructed of wooden cribs, one was made of concrete and rock, and one was a modified culvert. Barriers had vertical drops of from 1.5 to 3.0 m onto hardened splash pads constructed immediately below each barrier that prevented pools from forming. These barriers prevented upstream invasion by nonnative fish by creating vertical or horizontal water velocity migration barriers and by eliminating the formation of a pool at the downstream side of the barrier from which fish could jump.

METHODS

Electrofishing was used to remove Brook Trout and their abundance was estimated with removal estimators (Van Deventer and Platts 1989). Fish were captured using Smith-Root BP-15, BP-12, and SR-24 backpack electrofishers operated at voltages in the range of 100–600 V, frequencies of 30–50 Hz, and pulse widths of 1–2 μs to maximize the number of fish captured while minimizing injury to fish caused by the shock (Dwyer et al. 2001).

An electrofishing crew consisted of either two or three people. One crewmember wore the backpack shocker and shocked using a wand anode while dragging a cable cathode. A second crewmember followed the shocker netting all stunned fish. When available, a third crewmember held a dip net in the stream channel below the two other crewmembers and carried a mesh bucket for transporting captured fish. Block nets or fencing material (6.5-mm mesh) were installed between sample sections during most sampling and removal events. The assumption of population closure for treatment reaches was met because Brook Trout populations within each treatment reach were isolated at their lower bound by a fish barrier and the entire Brook Trout population was sampled during most treatments. Closure for each subsection was met by (1) the use of either block fences or nets at the upper and lower ends of all sample sections or, in some cases, locating sections so that shallow riffles or partial velocity barriers were present at their upper and lower boundaries; (2) the presence of a second netter during most sampling to prevent fish from moving downstream; and (3) the relatively short time it took to complete all sample passes (White et al. 1982).

Two to four electrofishing passes were made in an upstream direction during each removal treatment, except for a few treatments in Staubach and Whites creeks, where only one pass was made (Table 2). All electrofishing passes were generally conducted within 4 h, except for some sections in Muskrat Creek during 2002 and 2003 and in Staubach Creek from 2002 to 2006, where subsequent passes were done the following day. The entire length of each treatment reach was usually shocked during each removal treatment; however, in some cases less area was covered during later treatments to concentrate removals within those portions of the reach where Brook Trout predominated and to reduce potential electroshock effects on WCT (Table 2). Brook Trout were considered to be eradicated from a treatment reach when none were captured during a sampling effort that consisted of at least two electrofishing passes conducted throughout the reach. After no Brook Trout were captured, we subsequently sampled some or all of each treatment reach from four to six times to confirm that no Brook Trout remained.

Lengths (total length in mm), species, and pass number were recorded for all captured fish. All captured Brook Trout were removed. From 40% to 60% of captured Brook Trout were marked by removing their adipose fin and then moved below constructed fish barriers to evaluate the effectiveness of these barriers.

Brook Trout removed during each treatment were classified as age 0 or age 1 and older based on their lengths. Brook Trout 100 mm and smaller were assumed to be age 0, based on length frequency information from these streams and aging of Brook Trout using otoliths from a similar type of mountain stream in Idaho (Meyer et al. 2006). Brook Trout 101 mm and longer were classified as age 1 and older.

Abundance estimates of all Brook Trout 75 mm and longer were calculated with removal estimators (Van Deventer and Platts 1989). Removal estimators generally underestimate true abundances, especially when only two passes are made and capture probabilities are less than 0.9 (Riley and Fausch 1992; Habera et al. 2010; Meyer and High 2011; Shepard et al. 2013). White et al. (1982) recommended that three or more passes be made unless the capture probability is 0.8 or higher. Three or more passes reduce estimate bias (Riley and Fausch 1992). Shepard et al. (2013) provided simulations demonstrating that when captured fish make up at least 70% of the estimated abundance, bias was usually less than 25% and this bias declines as the proportion of fish captured increases. Of the 204 valid removal estimates we made in the subsections, 141 were two-pass estimates, 57 were three-pass estimates, and six required four or more passes to obtain valid estimates. Estimated probabilities of capture were at least 0.7 for 82% and 0.8 or higher for 63% of the two-pass estimates. Ratios of total catch to estimated numbers were over 0.7 for 96%, over 0.8 for 92%, and over 0.9 for 84% of all two-pass estimates, indicating that underestimation bias was probably relatively low (<25%) for most of the two-pass estimates.

Abundances of Brook Trout 75 mm and longer, and their associated variances, were estimated by sample section and pooled among these sample sections for each treatment period. Abundance estimates and their 95% confidence intervals are reported for each treatment period by stream.

Costs of conducting removals were based on U.S. dollars in 2005 (US$), an hourly rate of $10/h, a workday of 10 h, and State of Montana daily per diem rates ($36/d). Travel costs were reduced because we camped on-site at each treatment reach during each week of removal treatments, except in Staubach Creek, which was located relatively close (54 km round-trip) to a field station. We included all costs associated with conducting the removals but not the costs of constructing barriers to prevent upstream invasion by nonnative fish nor costs associated with preparing environmental assessments for these projects because these activities would be necessary for any eradication project, including those with piscicides. Channel and bank-clearing costs were included for Whites Creek, where they were necessary to accomplish removals. However, channel clearing was necessary only in the lower portion of this treatment reach.

RESULTS

Brook Trout were successfully eradicated over a period of 4 to 8 years from all four treatment reaches totaling about 10.8 km (Tables 1 and 2). At least 6, and as many as 14, multiple-pass electrofishing removal treatments (two or more passes per treatment), or from 13 to 29 electrofishing passes, were necessary to eradicate Brook Trout from these treatment reaches (Table 2). The total number of Brook Trout removed from each treatment reach ranged from 1,627 in Staubach Creek to 7,936 in Muskrat Creek (651–3,307/km; Table 2 and Figure 1). During this project we adapted our efforts by increasing the number of treatments per year and focusing on removing adults before concentrating on age-0 fish to successfully eradicate Brook Trout (Figure 2).

The total person-days needed to successfully eradicate Brook Trout from the four treatment reaches ranged from 64 (21.3 person-days/km) in Cottonwood Creek to 171 (71.3 person-days/km) in Muskrat Creek (Table 3). Eradication of Brook Trout using electrofishing in the two smaller streams that did not require channel clearing (Cottonwood and Staubach creeks) cost about $3,500 to $5,500 per kilometer of stream (Table 3). Costs were higher for the larger stream (Muskrat Creek) because the single annual removal efforts for 4 years (1997–2000) were relatively ineffective. Where extensive channel clearing was necessary, as in Whites Creek, eradication costs rose to an estimated $8,000 to $9,000 per kilometer.

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

TABLE 2. Number of treatments, number of removal passes, distance treated, and number of Brook Trout removed by year and stream, and total number removed per kilometer during removal treatments conducted in Montana streams from 1993 through 2005.

Stream	Year	Number of times treated	Total number of passes	Distance treated (km)	Brook Trout removed
Cottonwood Creek	1998[a]	1	1	0.5	494
	2001	2	4	1.6	1,574
	2002	2	5	3.0	130
	2003	2	3	2.3	8
	2004	1	2	2.3	0
	2005	1	1	1.6	0
Total[b] (number/km)		7	13	3.0	2,206 (735)
Muskrat Creek	1997	1	2	2.4	1,933
	1998	1	2	2.4	1,443
	1999	1	2	2.4	1,090
	2000	1	3	2.4	1,095
	2001	2	5	2.4	1,768
	2002	5	10	2.4	589
	2003	2	5	2.4	18
	2004	1	2	2.4	0
	2005	1	2	0.7	0
Total[b] (number/km)		13	29	2.4	7,936 (3,307)
Staubach Creek	2000	3	1–7	2.5	1,394
	2001	4	2–12	2.5	146
	2002	3	2–6	2.5	70
	2003	3	2–6	2.5	16
	2004	1	1–2	2.5	1
	2005	1	2	2.0	0
	2006	1	2	2.5	0
Total (number/km)		14	8–24	2.5	1,627 (651)
Whites Creek	1993	1	1 or 2	1.4	111
	1994	1	1 or 2	1.1	33
	1995[c]	1	1–3	3.0	4,271
	1996	1	1 or 2	1.9	144
	1997	1	1 or 2	2.1	135
	1998	1	1 or 2	2.8	238
	1999	1	2 or 3	2.7	91
	2000	1	2 or 3	1.8	4
	2001	1	2	1.8	0
	2002	1	2	0.5	0
Total[b] (number/km)		8	10–19	2.9	5,027 (1,733)

[a]In 1998 a pilot removal treatment was conducted in a portion of Cottonwood Creek.
[b]Total numbers of treatments and electrofishing passes include only those that captured Brook Trout.
[c]Total includes a total of 2,750 Brook Trout that were removed using raft-mounted electrofishing from old mining settling ponds as well as after these ponds were dewatered during a mining reclamation project conducted during 1995.

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

No adipose-clipped Brook Trout were recaptured above any of the constructed barriers, indicating that the barriers were effective. A few unmarked adult Brook Trout were found above constructed barriers in Whites and Muskrat creeks 5 and 7 years after eradication, respectively. We suspect that these Brook Trout had been moved above the barriers by members of the public because these barriers were located near public access roads. These Brook Trout were again eradicated with two additional years of moderate removal efforts.

DISCUSSION

Our findings that it took from 6 to 10 multiple-pass electrofishing removal treatments (2 or more passes per treatment) to eradicate Brook Trout from our treatment reaches are

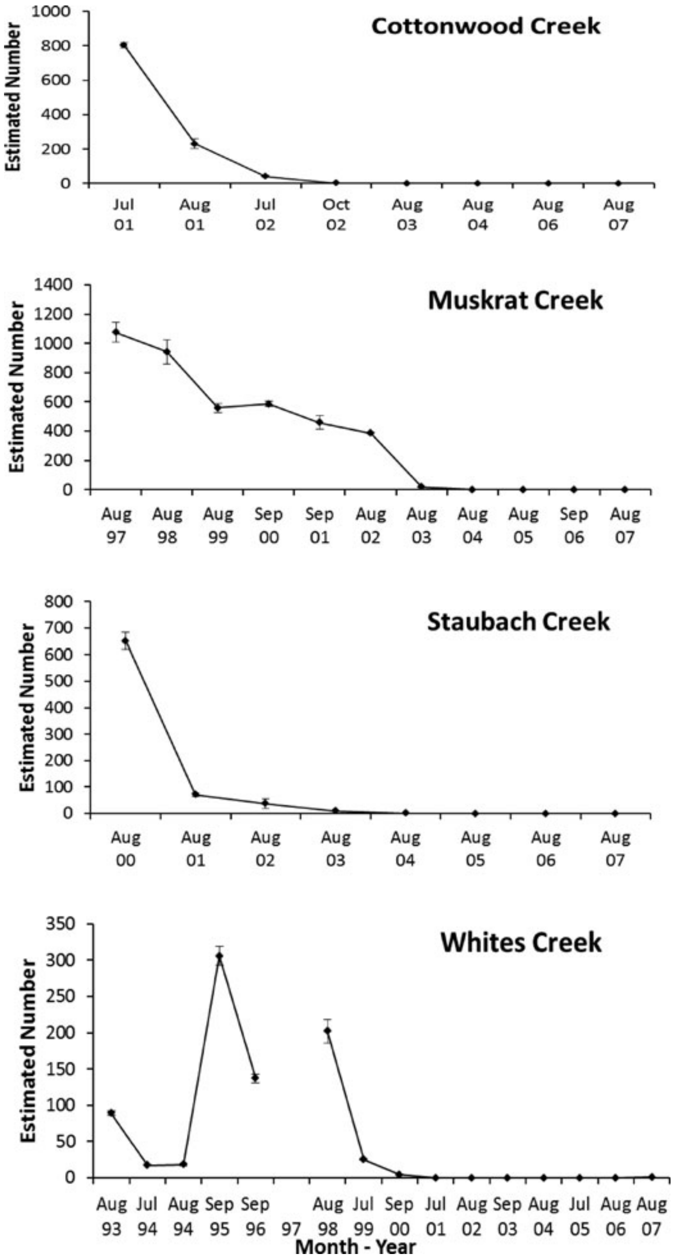

FIGURE 1. Estimated abundances (±95% confidence intervals) of Brook Trout 75 mm and longer in treatment sections of four Montana streams by month and year. No estimate was done in Whites Creek during 1997.

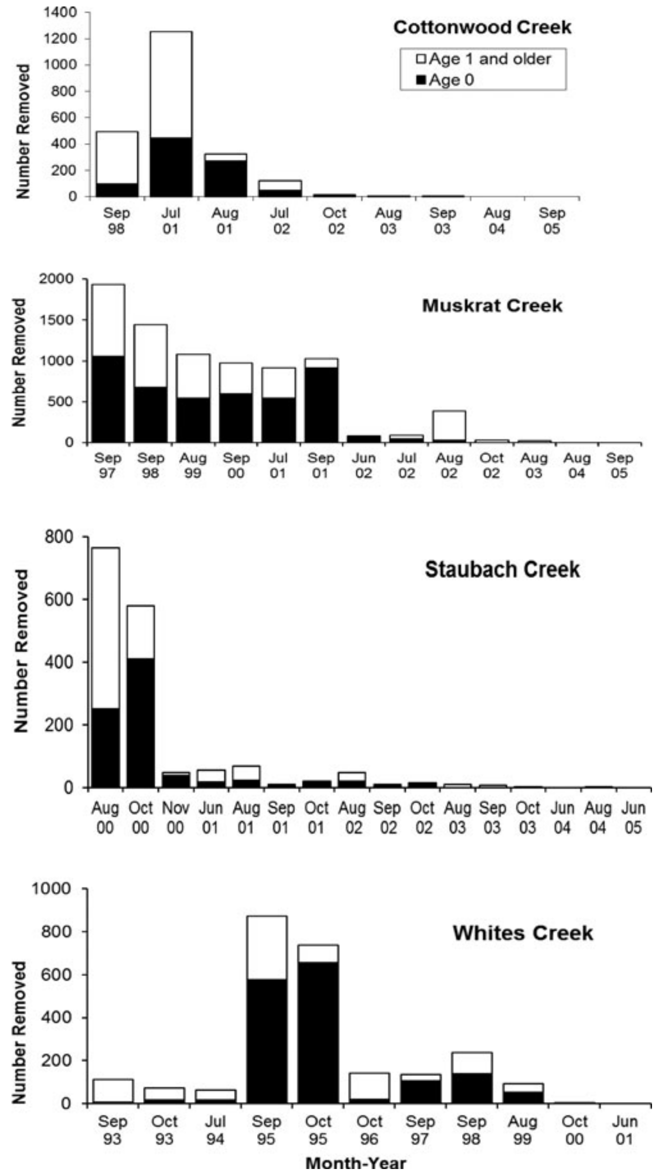

FIGURE 2. Number of age-0 or age-1 and older Brook Trout removed by electrofishing during each time period (month and year) in the treatment reaches of four Montana streams. Only partial removals were done in Whites Creek in 1993 and in 1998.

concordant with studies where eradication either was achieved by electrofishing (Larson et al. 1986; Kulp and Moore 2000) or was not achieved due to a lower total effort (Thompson and Rahel 1996; Meyer et al. 2006; Carmona-Catot et al. 2010). We observed that it was more effective to concentrate removal treatments within a shorter time period (i.e., 3 to 4 years) than to conduct single annual removal treatments over 6 or more years, similar to findings reported by Kulp and Moore (2000) on their efforts to eradicate nonnative Rainbow Trout in streams of Great Smoky Mountains National Park to conserve native Brook Trout. We were unable to eradicate, or even effectively reduce, Brook Trout from Muskrat Creek until we began conducting multiple removal treatments each year, suggesting that this might be the only viable treatment strategy for moderate-sized (i.e., 2–3-m wide), higher-gradient streams (>5%) with boulder substrates and moderate to high amounts of instream cover (Table 2).

We successfully eradicated Brook Trout from four treatment headwater reaches in Rocky Mountain streams, but Meyer et al. (2006) were unsuccessful in a relatively large stream in Idaho and Carmona-Catot et al. (2010) were unsuccessful in a small spring creek in California. We suggest that the relatively large

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

TABLE 3. Effort (person-days) and costs (US$ in 2005) to successfully eradicate Brook Trout from the headwater portions of four Northern Rocky Mountain streams.

Item	Cottonwood	Muskrat	Staubach	Whites
Total person-days	64	171	100	95
Personnel on site	$6,400	$17,100	$10,000	$9,500
Personnel travel time	$600	$3,100		$1,000
Per diem	$2,304	$6,156	$600	$1,800
Mileage	$875	$630	$616	$1,085
Supplies	$400	$775	$2,500	$2,375
Channel clearing				$7,500
Total	$10,579	$27,761	$13,716	$23,260
Km treated	3.0	2.4	2.5	2.9
Person-days per km	21.3	71.3	40.0	32.8
Cost per km	$3,527	$11,567	$5,486	$8,020

size of Meyer et al.'s (2006) treatment stream (wetted width of 2.8 m and treatment length of 7.8 km), their lower number of treatments (only 4 treatments compared with our 6 to 14 treatments), and the fact that they conducted treatments only once a year, might have contributed to their lack of success. Carmona-Catot et al. (2010) dramatically reduced, but did not eradicate, Brook Trout from their treatment stream after three electrofishing removal treatments (three passes for each treatment). We suggest with a few more removal treatments and an effective barrier near the mouth of this stream they could have eradicated Brook Trout, especially because there appeared to be some limited immigration of large adult Brook Trout into their treatment stream.

Studies of backpack electrofishing efficiencies for salmonids in streams have indicated that electrofishing efficiencies (i.e., capture probabilities) were negatively related to stream size and amounts of cover, particularly undercut banks and instream woody debris, and positively related to proportion of cobble substrate (Habera et al. 1992, 2010; Thompson and Rahel 1996; Peterson et al. 2004b; Rosenberger and Dunham 2005; Meyer and High 2011). This appeared to be the case for our electrofishing efforts within portions of our treatment reaches, but we did not have detailed data to estimate these physical variables within entire treatment reaches. We found no significant relationships between pooled estimates of these variables over our treatment reaches and the effort required to eradicate Brook Trout.

We were able to take advantage of the aggregating behavior of Brook Trout during their autumn spawning season and winter (Bustard and Narver 1975; Cunjak and Power 1986; Brown and Mackay 1995; Jakober et al. 1998; Muhlfeld et al. 2001; Roni and Quinn 2001; Dare and Hubert 2002). By initially targeting adult Brook Trout before and during spawning, we reduced their subsequent recruitment. We could then focus on capturing juvenile fish in subsequent years as they grew to sizes that were more vulnerable to electrofishing. Thompson and Rahel (1996) found that an electrofishing treatment conducted the year following their initial treatment further reduced Brook Trout numbers, especially of age-1 fish that were not captured at age 0 in the previous year. Early winter treatments took advantage of aggregations of Brook Trout in pool habitats during this time, which made them more vulnerable to electrofishing.

Trampling and electrofishing over trout redds reduces embryo survival (Roberts and White 1992; Dwyer et al. 1993). Consequently, we avoided electrofishing over WCT spawning areas during their incubation period (late June to early August in our streams) but did target Brook Trout spawning areas during autumn and early winter treatments in Muskrat Creek. Unfortunately, we did not quantitatively evaluate the effectiveness of this approach. We suggest this might be a fruitful area for future research, particularly with recent advances in the potential use of electrofishing grids to reduce survival of Lake Trout *Salvelinus namaycush* embryos (P. Brown, Montana Cooperative Fishery Research Unit, personal communication).

Thompson and Rahel (1996) reported that "removing young fish from beaver ponds is complicated because the ponds are difficult to wade and remain turbid after the first electrofishing pass, and fish can avoid the electrofishing gear." We found this to be true in beaver ponds located in Craver Creek, one of the streams we eliminated from the study, even after we removed most of the dams from several of these ponds. Because Brook Trout have been found to select beaver pond habitats when they are available, these ponds are probably important sources of Brook Trout in stream systems (Thompson and Rahel 1996; Benjamin et al. 2007). Treatment with piscicides is probably the only viable alternative for eradicating Brook Trout in streams where large beaver ponds are present.

We spent less time (64–161 person-days or 21.3–71.3 person-days/km; Table 3) to successfully eradicate Brook Trout from four stream reaches than either Meyer et al. (2006; 217 person-days or 27.8 d/km) or Carmona-Catot et al. (2010; 205 person-days or 73 person-days/km) expended in their unsuccessful attempts to eradicate Brook Trout from 7.8 km of a stream in Idaho and a 2.8-km reach of Bogard Spring Creek, California, respectively. In contrast to the two electrofishing crews that Meyer et al. (2006) used for each of their electrofishing treatments, we used a single electrofishing crew of two to three people. Carmona-Catot et al.'s (2010) crews drove back and forth to the project site each day (96 km), whereas our crews mostly camped on-site.

Our costs to successfully eradicate Brook Trout from treatment reaches where no channel clearing was necessary ($3,500 to $5,500 per km) were also lower than costs incurred by Carmona-Catot et al. (2010; $10,000/km) and Meyer et al. (2006; $7,486/km). Meyer et al. (2006) included $15,000 of barrier cost in their estimates, but we did not. Carmona-Catot et al.'s (2010) travel and per diem costs were higher than our costs. Our costs almost doubled where channel clearing was needed ($8,000/km), becoming similar to those of Carmona-Catot et al. (2010) and Meyer et al. (2006).

Costs of electrofishing removal where no channel clearing was necessary were lower than estimated costs of two antimycin treatments (about $5,000 to $7,000 per km) and higher than those of two rotenone treatments (about $3,000 to $5,000 per km) in Montana (Lee Nelson, unpublished data; Pat Clancey and Dave Moser, Montana Fish, Wildlife and Parks, personal communications). We suggest that treatments with piscicides, especially rotenone, might be more economical than electrofishing eradication in longer stream reaches, especially in streams with dense cover, situations where costs per kilometer differences accumulate.

Our cost estimates did not include barrier construction, environmental assessments, and public involvement, all which must precede eradication treatments using either electrofishing or piscicides. Eradication by piscicides often requires greater levels of environmental assessment and public involvement than electrofishing treatments (Finlayson et al. 2000); thus, treatment costs for piscicides may be similar to or higher than costs of electrofishing removals if environmental assessment and public involvement costs are included.

Removal of nonnative fish using electrofishing is a viable alternative to using piscicides in small streams, especially where extant populations of native fish are sympatric with nonnative fish, because electrofishing allows for the collection and preservation of the native fish. Even when an attempt is made to salvage native species before treatment with piscicides, only a small proportion of the native population is usually saved, and holding these salvaged fish increases costs and project complexity (Buktenica et al. 2013). We think this electrofishing eradication method could be applied to any stream with similar characteristics (Table 1) and similar-sized fish. However, treatments with piscicides may be the only viable alternative for large streams (base flow wetted widths >3 m) or in any stream where dense stands of woody vegetation or beaver ponds make electrofishing difficult or impossible. Electrofishing eradication may be possible in larger streams (base flow wetted widths >3 m) by simultaneous electrofishing by two or more crews (at increased cost), but this needs to be further evaluated (see Meyer et al. 2006).

A barrier to upstream fish movement at the lower boundary of any removal project is necessary to ensure that nonnative species do not move upstream to recolonize habitats reclaimed for native fish (Moore et al. 1983; Hepworth et al. 2001; Shepard et al. 2002; Peterson et al. 2004a). The importance of barriers to prevent competition and hybridization with nonnative trout species is recognized in many Cutthroat Trout recovery plans (e.g., Langlois et al. 1994). Natural waterfalls are ideal barriers and should be used where available. However, where no waterfalls exist, barriers will need to be constructed. Many Greenback Cutthroat Trout restoration attempts failed because of competition with nonnative salmonids (Harig et al. 2000). Many of these failures were caused by incomplete removal efforts, but in some cases nonnative trout were able to recolonize over constructed barriers. Constructed barriers are not as effective as natural waterfalls and members of the public are more likely to move nonnative fish over constructed barriers (Harig et al. 2000), especially when constructed barriers are located near public roads. We think this contributed to Brook Trout being moved over barriers into our treatment reaches in Whites and Muskrat creeks. Postproject monitoring, particularly in lower portions of treatment reaches immediately above barriers, is critical for evaluating the success of these projects and for discovering and eradicating nonnative fish that may have moved (either naturally or by human intervention) into the treatment reach.

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

ACKNOWLEDGMENTS

The Future Fisheries Improvement and Native Fish programs of Montana Fish, Wildlife and Parks, and Challenge Cost-Share and Bring Back the Natives grants from the U.S. Department of the Interior Bureau of Land Management (USDI BLM) and U.S. Department of Agriculture (USDA) Forest Service, provided funding to conduct the fieldwork and prepare initial reports. B.B.S. was supported by the Wild Fish Habitat Initiative through the Montana University System Water Center and thanks Gretchen Rupp and the staff at the Water Center for their support. B.B.S. and M.L.T. also received support from the National Science Foundation (DEB 0717456). Ron Spoon of Montana Fish, Wildlife and Parks, helped conduct many of the Brook Trout removal efforts in Muskrat and Staubach creeks. We also thank K. McDonald, D. Oswald, D. Kampwerth, J. Roscoe, S. Sovey, B. Sanborn, J. Brammer, M. Enk, A. Tews, and S. LaMar for their assistance. Numerous fieldworkers and volunteers from Montana State University, Montana Fish, Wildlife and Parks, the USDA Forest Service, USDI BLM, Montana Conservation Corps, and the American Fisheries Society Hutton Scholarship program assisted with fieldwork. D. Goodman, R. Gresswell, D. Skaar, S. Cherry, L. Thompson, K. Meyer, and two anonymous reviewers reviewed and improved the manuscript. The Montana Cooperative Fishery Research Unit is jointly sponsored by the U.S. Geological Survey, Montana Fish, Wildlife and Parks, Montana State University, and the U.S. Fish and Wildlife Service. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. or Montana State Government. This research was done as part of B.B.S.'s PhD dissertation (Shepard 2010).

REFERENCES

Adams, S. B. 1999. Mechanisms limiting a vertebrate invasion: Brook Trout in mountain streams of the northwestern USA. Doctoral dissertation. University of Montana, Missoula.

Allendorf, F. W., and R. F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species, the Cutthroat Trout. Conservation Biology 2:170–184.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society, Monograph 6, Bethesda, Maryland.

Benjamin, J. R., J. B. Dunham, and M. R. Dare. 2007. Invasion by nonnative Brook Trout in Panther Creek, Idaho: roles of local habitat quality, biotic

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

resistance, and connectivity to source habitats. Transactions of the American Fisheries Society 136:875–888.

Brown, R. S., and W. C. Mackay. 1995. Fall and winter movements of and habitat use by Cutthroat Trout in the Ram River, Alberta. Transactions of the American Fisheries Society 124:873–885.

Bustard, D. R., and D. W. Narver. 1975. Preferences of juvenile Coho Salmon (*Oncorhynchus kisutch*) and Cutthroat Trout (*Salmo clarki*) relative to simulated alteration of winter habitat. Journal of the Fisheries Research Board of Canada 32:681–687.

Buktenica, M. W., D. K. Hering, S. F. Girdner, B. D. Mahoney, and B. D. Rosenlund. 2013. Eradication of nonnative Brook Trout with electrofishing and antimycin-A and the response of a remnant Bull Trout population. North American Journal of Fisheries Management 33:117–129.

Carmona-Catot, G., P. B. Moyle, E. Aparicio, P. K. Crain, L. C. Thompson, and E. Garcia-Berthou. 2010. Brook Trout removal as a conservation tool to restore Eagle Lake Rainbow Trout. North American Journal of Fisheries Management 30:1315–1323.

Caudron, A., and A. Champigneulle. 2011. Multiple electrofishing as a mitigate tool for removing nonnative Atlantic Brown Trout (*Salmo trutta* L.) threatening a native Mediterranean Brown Trout population. European Journal of Wildlife Research 57:575–583.

Cowley, P. C. 1987. Potential for increasing abundance of cutthroat in streams by stocking fry and removal of Brook Trout. Master's thesis. University of Idaho, Moscow.

Cummings, T. R. 1987. Brook Trout competition with greenback Cutthroat Trout in Hidden Valley Creek, Colorado. Master's thesis. Colorado State University, Fort Collins.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization by stream resident Brook Trout (*Salvelinus fontinalis*) and Brown Trout (*Salmo trutta*). Canadian Journal of Fisheries and Aquatic Sciences 43:1970–1981.

Dare, M. R., and W. A. Hubert. 2002. Changes in habitat availability and habitat use and movements by two trout species in response to declining discharge in a regulated river during winter. North American Journal of Fisheries Management 22:917–928.

Downs, C. C., R. G. White, and B. B. Shepard. 1997. Age at sexual maturity, sex ratio, fecundity, and longevity of isolated headwater populations of Westslope Cutthroat Trout. North American Journal of Fisheries Management 17:85–92.

Dwyer, W. P., W. Fredenberg, and D. A. Erdahl. 1993. Influence of electroshock and mechanical shock on survival of trout eggs. North American Journal of Fisheries Management 13:839–843.

Dwyer, W. P., B. B. Shepard, and R. G. White. 2001. Effect of backpack electroshock on Westslope Cutthroat Trout injury and growth 110 and 250 days posttreatment. North American Journal of Fisheries Management 21:646–650.

ESRI (Environmental Systems Research Institute). 1999. ARC/VIEW, version 3.2. ESRI, Redlands, California.

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, and C. W. Thompson. 2002. Assessment of antimycin A use in fisheries and its potential for re-registration. Fisheries 27(6):10–18.

Finlayson, B. J., R. A. Schnick, R. L. Cailteux, L. DeMong, W. D. Horton, W. McClay, C. W. Thompson, and G. J. Tichacek. 2000. Rotenone use in fisheries management: administrative and technical guidelines manual. American Fisheries Society, Bethesda, Maryland.

Goodrich, J. M., and S. W. Buskirk. 1995. Control of abundant native vertebrates for conservation of endangered species. Conservation Biology 9:1357–1364.

Gresswell, R. E. 1988. Status and management of interior stocks of Cutthroat Trout. American Fisheries Society, Symposium 4, Bethesda, Maryland.

Griffith, J. S. Jr. 1972. Comparative behavior and habitat utilization of Brook Trout (*Salvelinus fontinalis*) and Cutthroat Trout (*Salmo clarki)* in small streams in northern Idaho. Journal of the Fisheries Research Board of Canada 29:265–273.

Habera, J. W., M. A. Kulp, S. E. Moore, and T. B. Henry. 2010. Three-pass depletion sampling accuracy of two electric fields for estimating trout abundance in a low-conductivity stream with limited habitat complexity. North American Journal of Fisheries Management 30:757–766.

Habera, J. W., R. J. Strange, and S. E. Moore. 1992. Stream morphology affects trout capture efficiency of an AC backpack electrofisher. Journal of the Tennessee Academy of Science 67:55–58.

Hanzel, D. A. 1959. The distribution of the Cutthroat Trout (*Salmo clarki*) in Montana. Proceedings of the Montana Academy of Sciences 19:32–71.

Harig, A. L., K. D. Fausch, and M. K. Young. 2000. Factors influencing success of Greenback Cutthroat Trout translocations. North American Journal of Fisheries Management 20:994–1004.

Hepworth, D. K., M. J. Ottenbacher, and C. B. Chamberlain. 2001. Occurrence of native Colorado River Cutthroat Trout (*Oncorhynchus clarki pleuriticus*) in the Escalante River drainage, Utah. Western North American Naturalist 61:129–138.

Hepworth, D. K., M. J. Otterbacher, and C. B. Chamberlain. 2002. A review of a quarter century of native trout conservation in southern Utah. Intermountain Journal of Sciences 8:125–142.

Jakober, M. J., T. E. McMahon, R. F. Thurow, and C. G. Clancy. 1998. Role of stream ice on fall and winter movements and habitat use by Bull Trout and Cutthroat Trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223–235.

Kennedy, B. M., D. P. Peterson, and K. D. Fausch. 2003. Different life histories of Brook Trout populations invading mid-elevation and high-elevation Cutthroat Trout streams in Colorado. Western North American Naturalist 63:215–223.

Knight, C. A., R. W. Orme, and D. A. Beauchamp. 1999. Growth, survival, and migration patterns of juvenile adfluvial Bonneville Cutthroat Trout in tributaries of Strawberry Reservoir, Utah. Transactions of the American Fisheries Society 128:553–563.

Kulp, M. A., and S. E. Moore. 2000. Multiple electrofishing removals for eliminating Rainbow Trout in a small southern Appalachian stream. North American Journal of Fisheries Management 20:259–266.

Langlois, D., J. Cameron, D. Smith, M. Japhet, C. S. Hutchinson, and J. Castellano. 1994. Colorado River Cutthroat Trout conservation strategy for southwestern Colorado. Colorado Division of Wildlife and U.S. Forest Service, Montrose.

Larson, G. L., S. E. Moore, and D. C. Lee. 1986. Angling and electrofishing for removing nonnative Rainbow Trout from a stream in a national park. North American Journal of Fisheries Management 6:580–585.

Liknes, G. A., and P. J. Graham. 1988. Westslope Cutthroat Trout in Montana: life history, status and management. Pages 53–60 in R. E. Gresswell, editor. Status and management of interior stocks of Cutthroat Trout. American Fisheries Society, Symposium 4, Bethesda, Maryland.

MacPhee, C. 1966. Influence of differential angling mortality and stream gradient on fish abundance in a trout–sculpin biotope. Transactions of the American Fisheries Society 95:381–387.

Marking, L. L., T. D. Bills, J. J. Rach, and S. J. Grabowski. 1983. Chemical control of fish and fish eggs in the Garrison Diversion Unit, North Dakota. North American Journal of Fisheries Management 3:410–418.

McClay, W. 2005. Rotenone use in North America (1988–2002). Fisheries 30(4):29–31.

McIntyre, J. D., and B. E. Rieman. 1995. Westslope Cutthroat Trout. U.S. Forest Service General Technical Report RM-256:1–15.

Meyer, K. A., and B. High. 2011. Accuracy of removal electrofishing estimates of trout abundance in Rocky Mountain streams. North American Journal of Fisheries Management 31:923–933.

Meyer, K. A., J. A. Lamansky, and D. J. Schill. 2006. Evaluation of an unsuccessful Brook Trout electrofishing removal project in a small Rocky Mountain stream. North American Journal of Fisheries Management 26:849–860.

Montana Department of Fish, Wildlife and Parks. 2007. Memorandum of understanding and conservation agreement for Westslope Cutthroat Trout and Yellowstone Cutthroat Trout in Montana. Montana Department of Fish, Wildlife and Parks, Helena.

Downloaded by [Bradley B. Shepard] at 12:29 28 September 2014

Moore, S. E., G. L. Larson, and B. L. Ridley. 1986. Population control of exotic Rainbow Trout in streams of a natural area park. Environmental Management 10:215–219.

Moore, S. E., B. Ridley, and G. L. Larson. 1983. Standing crops of Brook Trout concurrent with removal of Rainbow Trout from selected streams in Great Smoky Mountains National Park. North American Journal of Fisheries Management 3:72–80.

Muhlfeld, C. C., D. H. Bennett, and B. Marotz. 2001. Fall and winter habitat use and movement by Columbia River redband trout in a small stream in Montana. North American Journal of Fisheries Management 21:170–177.

Peterson, D. P., K. D. Fausch, and G. C. White. 2004a. Population ecology of an invasion: effects of Brook Trout on native Cutthroat Trout. Ecological Applications 14:754–772.

Peterson, D. P., B. E. Rieman, D. L. Horan, and M. K. Young. In press. Patch size but not short-term isolation influences occurrence of Westslope Cutthroat Trout above human-made barriers. Ecology of Freshwater Fish. DOI: 10.1111/eff.12108.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004b. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 133:462–475.

Propst, D. L., J. A. Stefferud, and P. R. Turner. 1992. Conservation and status of Gila Trout, *Oncorhynchus gilae*. Southwestern Naturalist 37:117–125.

Riley, S. C., and K. D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768–776.

Roberts, B. C., and R. G. White. 1992. Effects of angler wading on survival of trout eggs and pre-emergent fry. North American Journal of Fisheries Management 12:450–459.

Roni, P., and T. P. Quinn. 2001. Density and size of juvenile salmonids in response to placement of large woody debris in western Oregon and Washington streams. Canadian Journal of Fisheries and Aquatic Sciences 58:282–292.

Rosenberger, A. E., and J. B. Dunham. 2005. Validation of abundance estimates from mark-recapture and removal techniques for Rainbow Trout captured by electrofishing in small streams. North American Journal of Fisheries Management 25:1395–1410.

Rounsefell, G. A. 1957. Fecundity of North American Salmonidae. U.S. Fish and Wildlife Service Fishery Bulletin 57:451–468.

Shepard, B. B. 2010. Evidence of niche similarity between Cutthroat Trout (*Oncorhynchus clarkii*) and Brook Trout (*Salvelinus fontinalis*): implications for displacement of native Cutthroat Trout by nonnative Brook Trout. Doctoral dissertation. Montana State University, Bozeman.

Shepard, B. B., B. E. May, and W. Urie. 2005. Status and conservation of Westslope Cutthroat Trout within the western United States. North American Journal of Fisheries Management 25:1426–1440.

Shepard, B. B., B. Sanborn, L. Ulmer, and D. C. Lee. 1997. Status and risk of extinction for Westslope Cutthroat Trout in the upper Missouri River basin. North American Journal of Fisheries Management 17:1158–1172.

Shepard, B. B., R. Spoon, and L. Nelson. 2002. A native Westslope Cutthroat Trout population responds positively after Brook Trout removal and habitat restoration. Intermountain Journal of Sciences 8:193–214.

Shepard, B. B., M. L. Taper, and A. V. Zale. 2013. Improved variance estimates of biomass for stream-dwelling fish calculated using removal estimators. Transactions of the American Fisheries Society 142:841–853.

Strahler, A. N. 1957. Quantitative analysis of watershed geomorphology. Transactions of the American Geophysical Union 38:913–920.

Thomas, H. M. 1996. Competitive interactions between a native and exotic trout species in high mountain streams. Master's thesis. Utah State University, Logan.

Thompson, P. D., and F. J. Rahel. 1996. Evaluation of depletion-removal electrofishing of Brook Trout in small Rocky Mountain streams. North American Journal of Fisheries Management 16:332–339.

Van Deventer, J. S., and W. S. Platts. 1989. Microcomputer software system for generating population statistics from electrofishing data—user's guide for Microfish 3.0. U.S. Forest Service General Technical Report INT-254.

Van Eimeren, P. 1996. Westslope Cutthroat Trout *Oncorhynchus clarki lewisi*. Pages 1–10 in D. A. Duff, technical editor. Conservation assessment for inland Cutthroat Trout distribution, status and habitat: management implications. U.S. Forest Service, Intermountain Region, Ogden, Utah.

West, J. L., S. E. Moore, and M. R. Turner. 1990. Evaluation of electrofishing as a management technique for restoring Brook Trout in Great Smoky Mountains National Park. U.S. Department of Interior, Research/Resources Management Report SER-09/01, Gatlinburg, Tennessee.

White, G. C., D. R. Anderson, K. P. Burnham, and D. L. Otis. 1982. Capture–recapture and removal methods for sampling closed populations. U.S. Department of Energy, Los Alamos National Laboratory, Report LA-8787-NERP, Los Alamos, New Mexico.

Wydoski, R. S., and E. L. Cooper. 1966. Maturation and fecundity of Brook Trout (*Salvelinus fontinalis*) from infertile streams. Journal of the Fisheries Research Board of Canada 23:623–649.