Demographic Responses of Brook Trout to Removal of Brown Trout from a Driftless Area Stream in Minnesota[1].

Final Report

STUDY 677

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Abstract: Although laboratory studies have provided evidence for competition between brook trout and brown trout, it is unknown how this competition affects larger scale demographics in a natural setting. We tested the effects of brown trout on brook trout demographics by removing brown trout from a sympatric population using a before-after control-impact (BACI) study design. Abundance of brook trout increased after brown trout removal primarily as a result of increased recruitment and immigration. Size structure also shifted towards larger individuals resulting from increased growth rates and a decrease in emigration of larger trout. Size at maturity and condition factor did not change after brown trout removal. Adult brook trout survival increased during the post-treatment period in both the treatment and control reach. A decrease in flood intensity during the post-treatment time period may have led to increased survival. Adult survival may not be the best metric to use when assessing interactions between competing trout species, especially when the subordinate species has suitable areas to emigrate.

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Although competition among salmonids has received considerable attention in both laboratory and field studies (see review by Hearn 1987), it is still unclear where and when these interactions take place. Much attention in terms of replacement of native trout species is focused in the western US where native cutthroat trout (*Oncorhynchus clarkii*) have been replaced by both brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*). While it is understood that brook trout negatively affect cutthroat trout in their native range, it's been only recently that we've gained a better understanding of when and where these interactions take place (Dunham et al. 2002). For example, it appears that brown and brook trout have a competitive advantage over cutthroat trout at lower elevations in many mountainous streams (Budy et al. 2008). Competition usually does not occur throughout the year, but rather during a critical time period, for example, when prey or spawning habitat is limiting. In addition to seasonal and reach effects, age groups can also be affected differently. For example, brook trout have the largest competitive advantage over cutthroat trout as juveniles, whereas competition at the adult stage can be minimal (Peterson et al. 2004).

Although detrimental effects of invasive species on native fauna have been well documented elsewhere, little attention has been given to the effect of introduced brown trout on native brook trout populations in the Driftless Area of the Midwest. In the Midwestern United States, native brook trout are typically found in lower abundance than introduced brown trout. Much of this has to do with the successful management of brown trout by fisheries management agencies. Because of degraded stream conditions brown trout were favored over brook trout by fisheries agencies given their higher probability for success. Recent improvements in watershed and riparian areas in many parts of the Midwest have made brook trout management a viable option once again, however, increasing numbers of brown trout have made this management strategy challenging.

Similar to other invaded salmonid systems, brook trout in the Midwest are characterized by small populations confined to headwater reaches of streams with brown trout occupying middle and lower portions (Weigel and Sorensen 2001). Whether this is caused by competition or inherent longitudinal habitat differences is poorly understood (Magoulick and Wilzbach 1998). It is unclear whether brook trout would inhabit the lower portions of streams in the absence of brown trout, or whether habitat limitations would still preclude them from these areas. If brown trout are filling an available niche, then they should not have any effect on the distribution and abundance of brook trout; therefore management focus should be on habitat rehabilitation as opposed to competition with a nonnative trout species. However, if brown trout are limiting brook trout survival and movement, then any attempts at restoring brook trout populations should include the reduction of brown trout.

Removal of brown trout should allow brook trout to use more favorable feeding sites (Fausch and White 1981); however, it is unknown what sort of population effects this would have. Growth of brown trout is often faster than brook trout when they occur in sympatry, but whether this is a result of competition or inherent growth rates is unclear (Carlson et al. 2007). We would expect increased growth rates and size structure following removal of brown trout in Driftless Area streams.

The objective of this study was to test the effects of non-native brown trout on a native brook trout population using a before-after control-impact (BACI) study design. Specifically, we monitored age specific survival, growth, emigration, recruitment, and abundance of brook trout before and after a brown trout removal program in a large contiguous stream network.

Methods

Study Area

We chose a treatment and control reach on two southeastern Minnesota streams that had sympatric brook trout and brown trout populations to examine the effects of brown trout removal on growth, survival, and movement of brook trout (Figure 1). Hemmingway Creek is 3.2km in length and flows into Pine Creek, a larger 4th order stream that is 28km in length. Coolridge Creek is a small stream 1.6km in length that also flows into Pine Creek, 0.4km downstream from the mouth of Hemmingway Creek. Watersheds are primarily a mix of hardwood forests, pasture, and row crop agriculture.

Brown trout were more abundant in downstream reaches of both Hemmingway and Coolridge creeks. Therefore, we expected effects of brown trout removal to be greatest in the lower 1085-m of Coolridge Creek. Upstream from that point, brown trout were not abundant and effects should be lessened. We used a brown trout dominated portion of Hemmingway Creek as our control reach (935m) to compare with lower Coolridge. Upper portions of both streams were sampled to monitor movement in and out of our treatment and control reaches. We sampled 730 m in upper Hemmingway and 515 m in upper Coolridge. Water temperatures were similar between lower Coolridge and Upper Hemingway, whereas in summer, lower Hemmingway was the warmest reach and upper Coolridge was the coldest reach. A complete description of stream habitat for Coolridge and Hemmingway can be found in Hoxmeier and Dieterman (2013). Discharge data was gathered from a USGS gaging station in the Root River, 34 km downstream of the study site. Three major flooding events took place during the pre-treatment time period, whereas, flooding was not as intense during the post-treatment period (Figure 2).

Fish sampling and brown trout removal

Trout were sampled on 19 occasions from September 2006 thru October 2012. Trout were collected by electrofishing the entirety of each of the four stream reaches, with electrofishing gear appropriate for the stream size. In Coolridge and upper Hemmingway, we used a backpack electrofisher with one anode and dipnet. For lower Hemmingway, we used a tow barge with three anodes. Captured trout greater than 90mm total length were measured and tagged with a passive integrated transponder (PIT) and given an adipose fin clip to monitor any tag loss in future sampling occasions. After tagging, trout were released back into the pool from which they were captured. Brook trout were marked on eight occasions: September 2006, March 2007, August 2007, May 2009, October 2009, March 2011, September 2011, and March 2012. Trout were resampled about every three months before brown trout removal and at 6-month intervals thereafter to calculate growth, survival, and movement.

A barrier was constructed on the lower end of Coolridge Creek in June 2009. Brown trout were removed by electrofishing above the barrier starting in October 2009. We chose to remove brown trout in the fall when the young of year were large enough to be efficiently captured, but before spawning occurred. Brown trout were removed from the entire stream length, with the highest densities occurring in the lower reach. All brown trout captured by electrofishing were removed and stocked into Pine Creek, 2.5km downstream from the confluence of Coolridge Creek. A subsample of brown trout (N=303) were given adipose fin clips and stocked directly below the barrier in Coolridge Creek to monitor for barrier passage. Brown trout were removed during brook trout sampling every spring (March) and fall (September) after the initial removal.

To estimate brook trout abundance and recruitment, we divided the total number of fish caught during a single pass by the length of stream sampled. We defined recruitment as abundance of age-0 fish collected in our fall sample. We used a paired BACI design to test for differences in abundance of adult and age 0 brook trout before and after brown trout removal. The magnitude of brook trout response should be greater in lower Coolridge compared to upper Coolridge because of the initial brown trout densities found in these reaches.

A subsample of brook trout was sacrificed for internal examination of gonads to assess maturity before and after brown trout removal during fall of 2008 and 2012. Maturation was determined by visual examination of gonads and scored as zero for immature and one for mature. We then used logistic regression with length as our dependent variable to calculate size-at-maturation for males and females.

Growth and size structure

Growth in length was calculated from fish captured on consecutive sampling occasions and expressed as growth rate (mm/day). We used size groups of <150, 150-200, and >200mm for comparison across reaches given that growth is size dependent. Because we did not have recapture data for age-0 trout, we divided the number of days between April 1 and fall capture date by the total length at capture to get a growth rate in mm/day.

Relative condition factors (K_n) were calculated for both brook trout and brown trout before and after brown trout removal. We combined across time periods and used lengths and weights of individual fish as our replicate for our before and after comparison. Differences in condition factor were tested using the interaction term in a two-way ANOVA of reach and time.

Length frequency histograms were compared before and after brown trout removal by combining fish lengths from fall sampling across years. Differences in length distributions were tested for using a Kolmogorov-Smirnov two sample test. We calculated relative stock density by dividing the number of trout over 200-mm (RSD200) and 250-mm (RSD250) by the number of trout over 130-mm, and tested for a significant interaction of reach and time in a two-way ANOVA.

Survival and movement

We estimated survival and movement while testing for effects of brown trout removal using a multistrata Cormack-Jolly-Seber model in Program MARK (White and Burnham 1999). Multistrata models were analyzed for age-0 and adult brook trout to estimate apparent survival (S), capture probability (p), and movement (Ψ). Goodness of fit for the global model ($S_{(r*t)}p_{(r*t)}\Psi_{(r*t)}$) was tested using a JollyMove (JMV) model structure in U-CARE (Choquet et al. 2009), with r denoting reach, t denoting time, and r*t their interaction. We relied on information from our previous work on brook trout demographics in this system to develop biologically meaningful models. Based on earlier work, capture probability is time dependent for adults and reach dependent for age-0 brook trout. We tested against the best model developed from Hoxmeier and Dieterman (2013) referred to as the pre-model (before brown trout removal). Our final candidate set of models included four models: time dependent, reach dependent, best pre model, and a test of the time by reach interaction (testing for brown trout removal effects). Models were ranked using AIC_c and were determined to be supported if they had a delta AIC (Δ_i) value less than two (Burnham and Anderson 2002). We also calculated Akaike weights (w_i) to examine the relative likelihood of each model. Because time between sampling was not the same for all occasions, we scaled all estimates in Program MARK to annual estimates.

In addition to estimating movement among reaches, we also examined within reach movement of recaptured individual brook trout by recording the distance between the initial capture pool and recaptured pool. We only used brook trout that were recaptured in consecutive sampling events.

Results

Brown trout abundance in Coolridge Creek reached the highest level immediately prior to removal efforts. We removed 6052 (99.3kg) brown trout from Coolridge Creek above the barrier in fall 2009. Follow up sampling in the spring of 2010 removed another 520 brown trout from the stream. Total number of brown trout removed during subsequent sampling was less, but never approached zero (Figure 3). Abundance of age-0 brown trout decreased from 1217/mile before the removal to 200/mile after brown trout were removed. Adult brown trout decreased from an average of 285/mile to 95/mile during the brown trout suppression period. We only captured one brown trout above the barrier with an adipose clip indicating barrier passage. We were unable to remove all brown trout during the initial removal period which resulted in continued reproduction of brown trout in Coolridge Creek. After six removal attempts, brown trout still maintained successful reproduction in Coolridge Creek, although at lower levels.

Brook trout abundance increased in lower Coolridge after brown trout suppression (2-way ANOVA interaction term, log-transformed; Age-0, $P = 0.04$; Adult, $P = 0.01$). The magnitude of response was greater in the lower reach compared to the upper reach of Coolridge Creek where few brown trout were present before removal efforts. Adult brook trout increased from a pre-treatment mean of 51/mile to 164/mile in lower Coolridge. Recruitment of age-0 brook trout was higher in lower Coolridge after brown trout removal, increasing from a mean of 67/mile to 326/mile. Abundance of both adult and age-0 brook trout steadily increased after the initial brown trout removal, and reached their highest levels at the end of the study (Figure 4).

Survival

There was a reach by time interaction for survival and movement for both age-0 and adult brook trout that indicated an effect of brown trout removal (Table 1). Not all survival and movement parameters were estimatable in the interaction models. Therefore, to generate pre and post means and standard errors, we used estimates from models with time constrained to pre and post time periods for both adults and age-0 brook trout. Poor recruitment in Hemmingway Creek made estimating survival and emigration of age-0 brook trout difficult in the post treatment time period. In addition to low recruitment in Hemmingway Creek, suspected predation on brook trout by river otter *Lontra canadensis* resulted in high mortality during winter 2010-2011. Survival of age-0 brook trout increased in both reaches on Coolridge Creek after brown trout removal, whereas survival decreased in both control reaches (Table 2). Survival also increased for adult brook trout in Coolridge Creek after brown trout removal, but it also increased in our lower control reach, suggesting no benefit of brown trout removal on adult brook trout survival.

Movement

A lower percentage of adult brook trout emigrated out of Coolridge Creek after the brown trout removal (Table 2). Immigration of brook trout from the upper portion of Coolridge Creek into the lower portion where brown trout were removed increased after the removal (Figure 5). For age-0 brook trout emigration out of lower Coolridge was similar before and after brown trout removal. Although emigration rates changed after brown trout removal, actual distance moved within reaches remained the same (Figure 6).

Growth and size structure

Growth of age-0 brook trout increased in Coolridge Creek after brown trout removal compared to those in the control stream (Figure 7). There was not a treatment effect on growth rates of age-1 brook trout (time*reach; P = 0.31), but there was for age-2 (time*reach; P = 0.001). Growth rates of age-2 brook trout increased in lower Coolridge after brown trout removal while decreasing in the control reach.

Brook trout size structure shifted towards larger individuals in Coolridge Creek after brown trout removal, but the same trend was apparent in the control stream as well (Kolmogorov-Smirnov test; P < 0.001 for both streams; Figure 8). Lower Coolridge had a significantly greater increase in large brook trout compared to lower Hemmingway (paired t-test for RSD250; P = 0.003; Table 3). The number of 200 and 250-mm brook trout per mile increased in lower Coolridge relative to lower Hemmingway after the brown trout removal (Figure 9).

There was no effect on condition of brook trout in the lower reaches of the treatment and control stream after brown trout removal (time*reach; P = 0.32; Table 3). There also was no treatment effect on brown trout condition (time*reach; P = 0.10).

Maturation

Size at maturity was small for both males and females in Coolridge Creek regardless of brown trout abundance. There was not a difference in length at maturity before and after brown trout removal in Coolridge Creek. Male brook trout matured at 118mm before brown trout were removed and at 112mm in the third fall after initial removal (Figure 10). We did not collect any immature individuals in Hemmingway Creek during the pre-treatment time period, so we were unable to calculate size at maturity during that time. Post-treatment male brook trout were slightly larger at first maturity in Hemmingway Creek than in Coolridge Creek.

Discussion

Our study is important for understanding the underlying mechanisms responsible for increases in a native trout species following the release from a competitor. By monitoring individual fish across a large stream network we were able to measure the effects of brown trout removal on both movement and survival. Immigration into the treatment area along with increased age-0 recruitment resulted in an increase in brook trout abundance. Size structure also increased as a result of increased growth and decreased emigration of large fish. Adult brook trout survival was not effected by brown trout and may not be a good metric for measuring effects of a non-native trout species.

Our results are consistent with previous studies documenting an increase in native trout abundance following suppression of a non-native trout species (Moore et al. 1983; Peterson et al. 2004). However, cutthroat trout abundance did not appreciably increase after brook trout removal in Wyoming creeks, most likely due to habitat limitations (Novinger and Rahel 2003). Contributors to increased abundance in our study included an increase in recruitment and a decrease in emigration out of the treatment area. We did not measure recruitment until the first fall, but there is little dispersal of brook trout from spawning locations (Hudy et al. 2010; Kanno et al. 2011), and therefore we conclude that spawning success and age-0 trout survival was high in the treatment reach. Adult survival however, was not affected by removal of brown trout. This result is consistent with those of cutthroat trout, in where age-0 survival increased while adult survival remained the same after removal of brook trout (Peterson et al. 2004). Similarly, brown trout had no effect on cutthroat trout survival in Utah (McHugh and Budy 2006). Adult survival in our study may have been driven more by flooding events rather than by competitive interactions (Hoxmeier and Dieterman 2013).

The use of survival to measure the effects of an invasive species on a native trout population could be misleading in suggesting that there are no negative effects. For example, McHugh and Budy (2006) did not find any evidence of decreased adult survival of cutthroat trout in the presence of brown trout, but they did find that movement was affected. The nearly doubling of survival in our study cannot be attributed to brown trout removal given that the same magnitude of effect was observed in our control reach. Lack of a control in this study would have led to an incorrect conclusion about the effects of brown trout on brook trout survival. Similarly, if movement had not been accounted for, emigration out of the study reach prior to removal would have been interpreted as decreased survival attributable to brown trout competition. Also, not allowing a fish to emigrate may lead to decreased survival if that fish does not have access to resources that it needs. Most likely, a fish will move until it finds the resources that it needs, or die in the process if none are found. Because adult survival nearly doubled in our control reach, an increase in abundance could have been expected. However, brook trout abundance remained the same in the control reach despite the increase in survival due to low recruitment and a lack of immigration. While adult brook trout survival in this system may be primarily dependent on abiotic factors, age-0 survival appears to be driven by brown trout interactions.

Previous studies have documented few if any interactions between age-0 brook trout and brown trout. Brown and brook trout had similar first year growth rates in Egypt Creek, Michigan, suggesting minimal competition (Fausch 1981). However, juvenile brook trout (68 –

72.5 mm fork length) were the dominant competitor over equal sized brown trout in a laboratory study in which brook trout were located in upstream positions and chased brown trout downstream (Fausch 1981). Recruitment of brook trout may have increased because of decreased predation pressure from adult brown trout. Large brown trout have been shown to reduce brook trout populations by preying on juvenile brook trout (Alexander 1977).

Brook trout abundance steadily increased throughout the three year time period after brown trout removal. Density of brook trout during the last sampling occasion, was similar to that of pre-treatment brown trout densities and may have reached carrying capacity. Often, invasive competitor populations reach levels above that of the native species it replaces (Benjamin and Baxter 2010). Likewise, when invasive species are removed, native species do not reach levels of the previous invasive fish. For example, brown trout production in Valley Creek, Minnesota was nearly double that of pre-invasion brook trout production (Waters 1999). We would expect that brook trout biomass in Coolridge Creek would likely be maintained at a level slightly below previous brown trout biomass.

In addition to an overall increase in abundance, the number of larger brook trout also increased relative to the size of the population. Larger brook trout in the treatment area resulted from larger brook trout moving into the area and also faster growth of residents. Growth of the native trout species is often lower in sympatry than in allopatric populations (McHugh and Budy 2006; Seiler and Keeley 2009). Increased growth of brook trout in our study likely resulted from a competitive release from brown trout given that brown trout often outcompete brook trout for both feeding and resting areas (Fausch and White 1981; Blanchet et al. 2007). Also, the treatment reach had better growth potential for brook trout given the increased water temperatures and feeding areas compared to the upper reach where brook trout were previously isolated. Total length of age-0 brown trout in the fall increased in Coolridge Creek during the post-treatment period, similar to that of age-0 brook trout suggesting the influence of density-dependent growth mechanisms. While density-dependent growth plays a role, it is the removal of brown trout that ultimately increases availability of prey for brook trout through increased feeding opportunities.

The lack of an effect on brook trout condition after brown trout removal is similar to previous studies. Cutthroat trout did not show an increase in condition after removal of brook trout in Wyoming (Novinger and Rahel 2003). Similarly, there was no difference in condition of greenback cutthroat trout in allopatry versus in sympatry with brook trout (McGrath and Lewis 2007). Condition of cutthroat trout did decrease in the presence of brown trout when they were held in enclosures, but not at a population level in unconfined stream reaches

(McHugh and Budy 2005; McHugh and Budy 2006). Body condition may only be affected if the native species is not allowed to emigrate into more favorable areas with less interspecific competition.

Movement of the subordinate trout species can be limited in sympatric populations (McHugh and Budy 2006). Despite the increase in immigration into our treatment reach following brown trout removal, brook trout did not increase distance traveled once they immigrated into the reach. In other words, once brook trout located suitable pools in the treatment reach where brown trout were previously abundant, they tended to stay in that same pool over time. Forced immigration of a subordinate species is not well documented in salmonids. The current study confirms previous work that suggests emigration is a major factor influencing longitudinal trout distribution (Hoxmeier and Dieterman 2013).

Maturing at a small size is often indicative of a stressed population. In this case, brook trout could be maturing at a small size because of competition pressures from brown trout. However, even after removal of brown trout, brook trout continued to mature at a small size. Size at maturation may not respond as quickly to brown trout removal as recruitment and growth. However, bluegill (*Lepomis macrochirus)* can show a maturation response within three months after a change in their environment (presence of large males; Aday et al. 2003). It may take brook trout longer to delay maturation in this system, especially if other stressors are still acting on the population (e.g., flooding).

Nonnative trout removals are a common management technique in the Western and Southeastern United States; however, success of nonnative trout removals has varied either in terms of removing the nonnative species or the resultant effect on the native species after removal (Moore et al. 1983; Kulp and Moore 2000; Meyer et al. 2006). Our study adds to the growing literature that demonstrates the difficulty of completely eradicating non-native trout from streams (Meronek et al. 1996). We were unable to remove all adult brown trout from Coolridge Creek due to areas that were difficult to electrofish because of large woody debris and deep pools. As a result, enough brown trout remained in Coolridge Creek to have successful spawning each year. However, our program was able to successfully suppress brown trout abundance during the three years after the initial removal.

Management recommendations

Brook trout abundance and size structure in the lower portion of Coolridge Creek increased when brown trout were suppressed, suggesting that habitat was not limiting brook trout distribution in this system. Trout removals are likely to be most successful when the stream is small and lacking complex habitat (Thompson and Rahel 1996). Due to the large amount of work involved in eradicating nonnative salmonids, removals may only be justified and achievable in small streams with brook trout populations of greatest concern (i.e., native and in peril).

Future efforts at suppressing brown trout in southeastern Minnesota should focus on building a more effective barrier, and also consider the use of piscicides to obtain complete eradication of brown trout. However, isolating small brook trout populations through use of fish barriers can have negative consequences on genetic diversity and population structure if the isolated reach is small (Novinger and Rahel 2003; Peterson et al. 2008). The largest contributors to increased brook trout abundance after brown trout removal included increased recruitment and immigration into the treatment reach. Comparing survival at the population level or condition at the individual level may not reveal negative consequences on native species from an invader. While measuring emigration would provide evidence of competitive interactions, this can be time consuming and costly. Rather, changes in estimates of abundance and size structure, or differences between sympatric and allopatric populations, may give fisheries managers enough information to determine whether brown trout are having a negative effect on brook trout for a particular stream, even without revealing the processes involved. Successful brook trout management in the Driftless Area needs to address both biotic and abiotic factors. Any attempts to increase brook trout populations through watershed (decrease flooding magnitude) or instream (habitat improvement) management practices will only be effective if brown trout are also controlled.

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Table 1. Ranking of multistrata Cormack-Jolly-Seber models estimating survival (S), capture probability (p), and movement (Ψ) for two age groups of brook trout. Subscripts denote time (t), reach (r), and their interaction (r*t). Corrected Akaike's Information Criterion (AIC_c), difference in AIC_c between the *i*th and the top-ranked model (Δ_i), Akaike weights (w_i), number of parameters (*K*), and model deviance are given. The most supported models ($\Delta_i < 2$) are highlighted in bold.

Model	AIC_c	Δ AIC_c	w_i	*K*	Deviance
		Age -0			
S(r*t)p(r)Ψ(r*t)	**1156.12**	**0.00**	**1.00**	**39**	**382.43**
S(r)p(r)Ψ(r)	1182.81	26.69	0.00	12	435.46
S(.)p(r)Ψ(r)**	1192.14	36.02	0.00	9	484.29
S(t)p(r)Ψ(t)	1201.27	45.15	0.00	19	472.31
		Adult			
S(r*t)p(t)Ψ(r*t)	**5084.38**	**0.00**	**1.00**	**116**	**1372.01**
S(t)p(t)Ψ(r)**	5187.50	103.12	0.00	39	1640.49
S(t)p(t)Ψ(t)	5219.26	134.89	0.00	50	1649.34
S(r)p(t)Ψ(r)	5291.02	206.64	0.00	26	1770.79

** best models from Hoxmeier and Dieterman (2013) before brown trout removal.

Table 2. Survival and emigration estimates (SE) for before (pre) and after (post) brown trout removal in Coolridge Creek. Parameter estimates were generated in Program MARK by constraining the data based on pre and post time periods. Reaches were defined by initial brown trout density. Lower Coolridge (LC) and lower Hemmingway (LH) had high brown trout density whereas upper Hemmingway (UH) and upper Coolridge (UC) had low brown trout densities.

	Survival(%)		Emigration(%)	
Reach	pre	post	pre	post
Age 0				
UC	12.0(8.0)	77.0(13.9)	13.5(7.7)	5.1(2.7)
LC	20.7(14.1)	31.8(10.0)	13.5(9.2)	16.0(7.6)
UH	30.9(9.0)	0.5(0.9)	3.7(2.1)	0.0(0.0)
LH	17.7(6.8)	7.0(11.8)	0.9(0.9)	0.0(0.0)
Adult				
UC	21.3(3.0)	40.0(3.7)	5.6(1.5)	12.9(2.3)
LC	23.1(3.8)	48.7(3.9)	12.9(2.7)	3.8(1.2)
UH	41.1(3.5)	26.1(3.6)	0.9(0.5)	3.1(1.5)
LH	24.4(3.5)	44.4(4.8)	1.8(0.9)	1.9(1.3)

Table 3. Size and condition indices of brook trout before and after brown trout removal in lower Coolridge (treatment) and lower Hemmingway (control) creeks. Relative stock density (RSD250) is the proportion of 130mm brook trout greater than 250mm. Relative condition factor (K_n) was combined across time periods for before and after comparison.

	RSD250		Condition	
	pre	post	pre	post
Treatment	2.5	13.7	1.15 (0.011)	1.16(0.010)
Control	7.4	3.8	1.07 (0.011)	1.04(0.006)

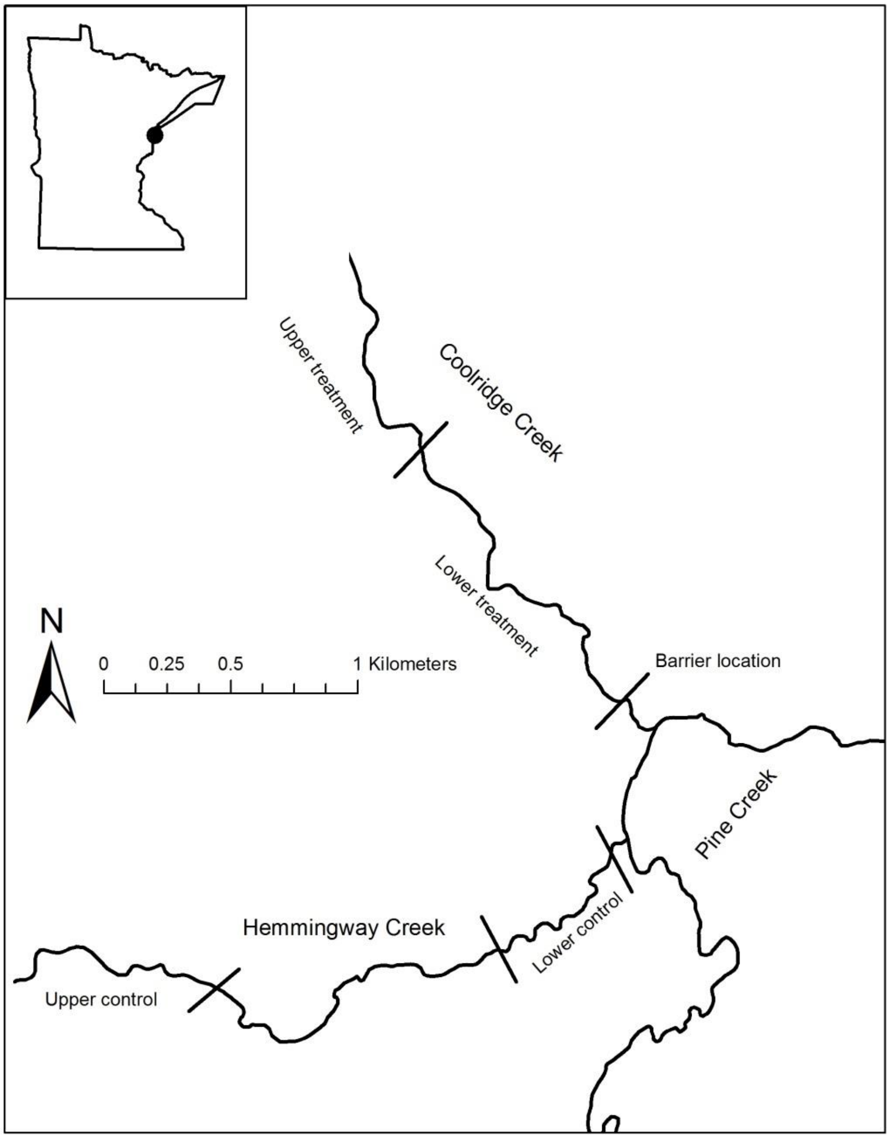


Figure 1. Map of Coolridge, Pine and Hemmingway creeks showing location of brown trout exclusion barrier installed in 2009.

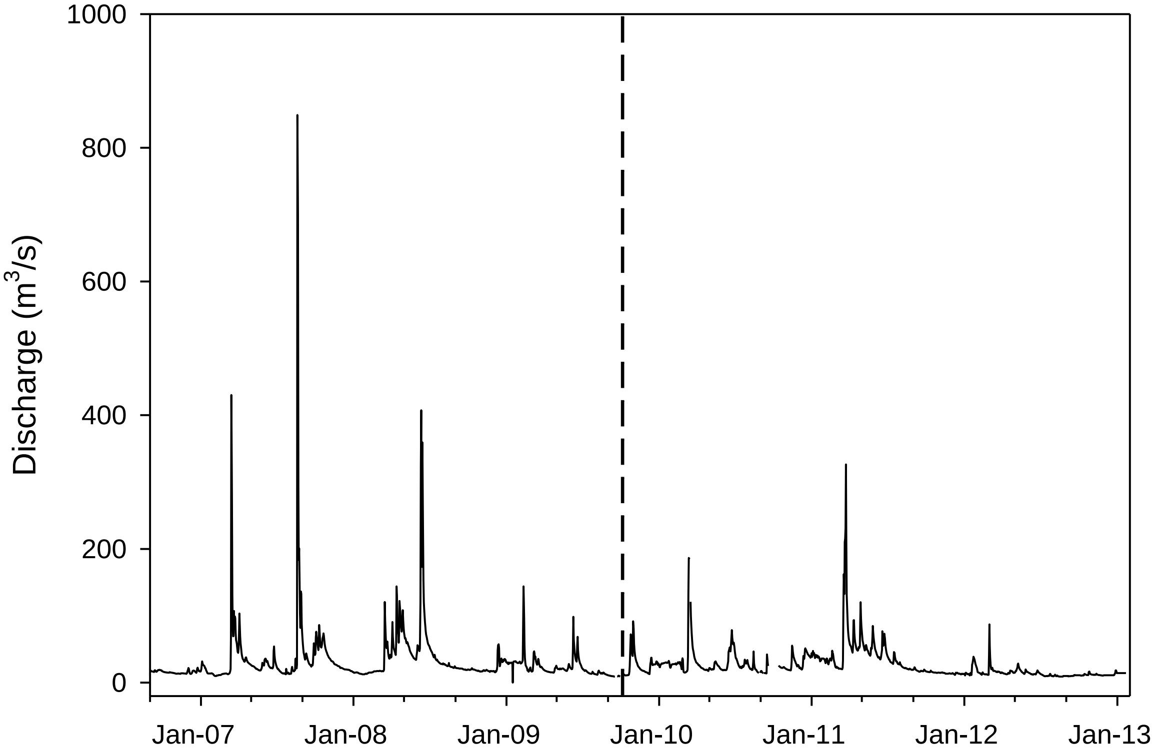


Figure 2. Discharge data from the Root River located 34 km downstream from the study area. Dashed line represents the beginning of brown trout removal in Coolridge Creek.

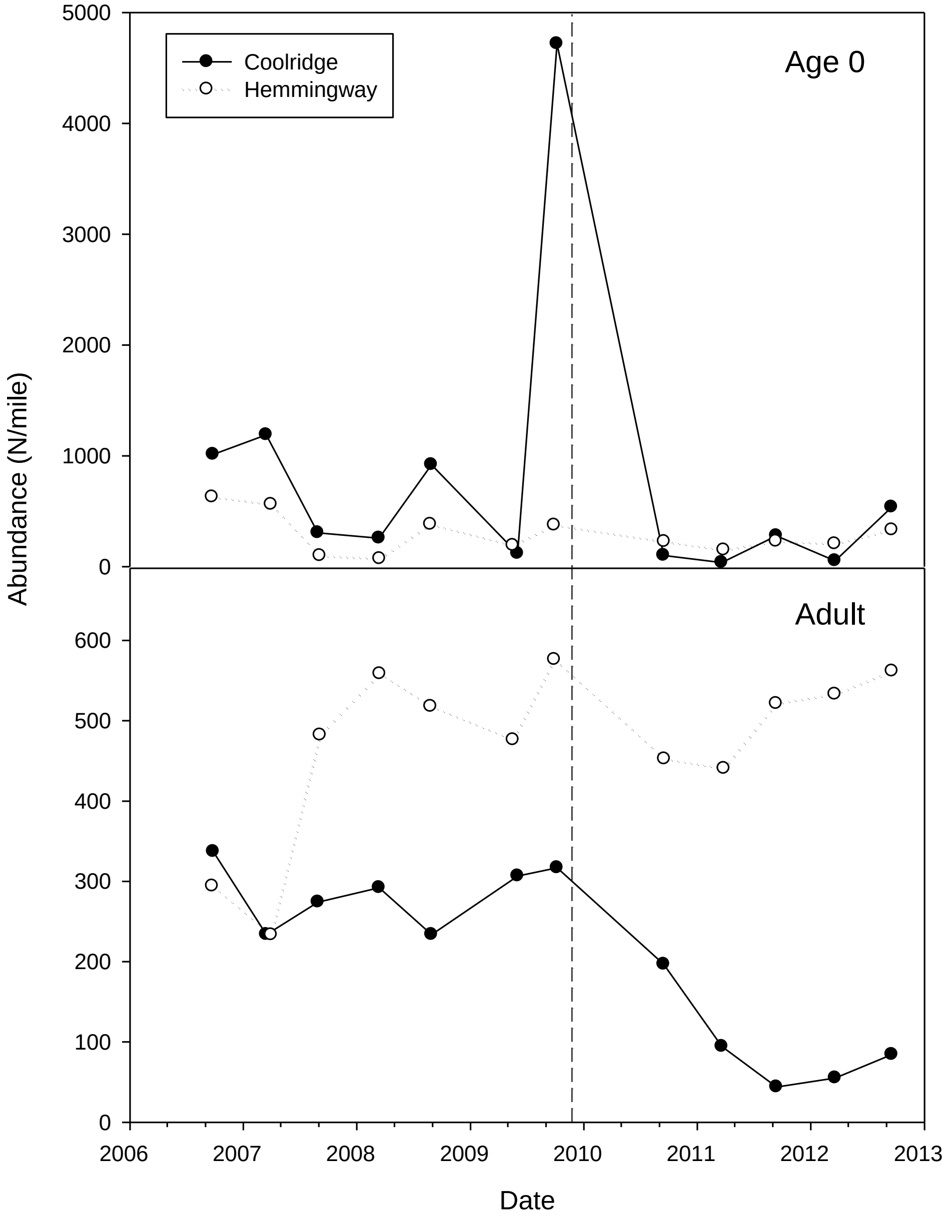


Figure 3. Brown trout abundance in Coolridge and Hemmingway Creeks from 2006 through 2012. Dashed line represents the beginning of brown trout removal in Coolridge Creek.

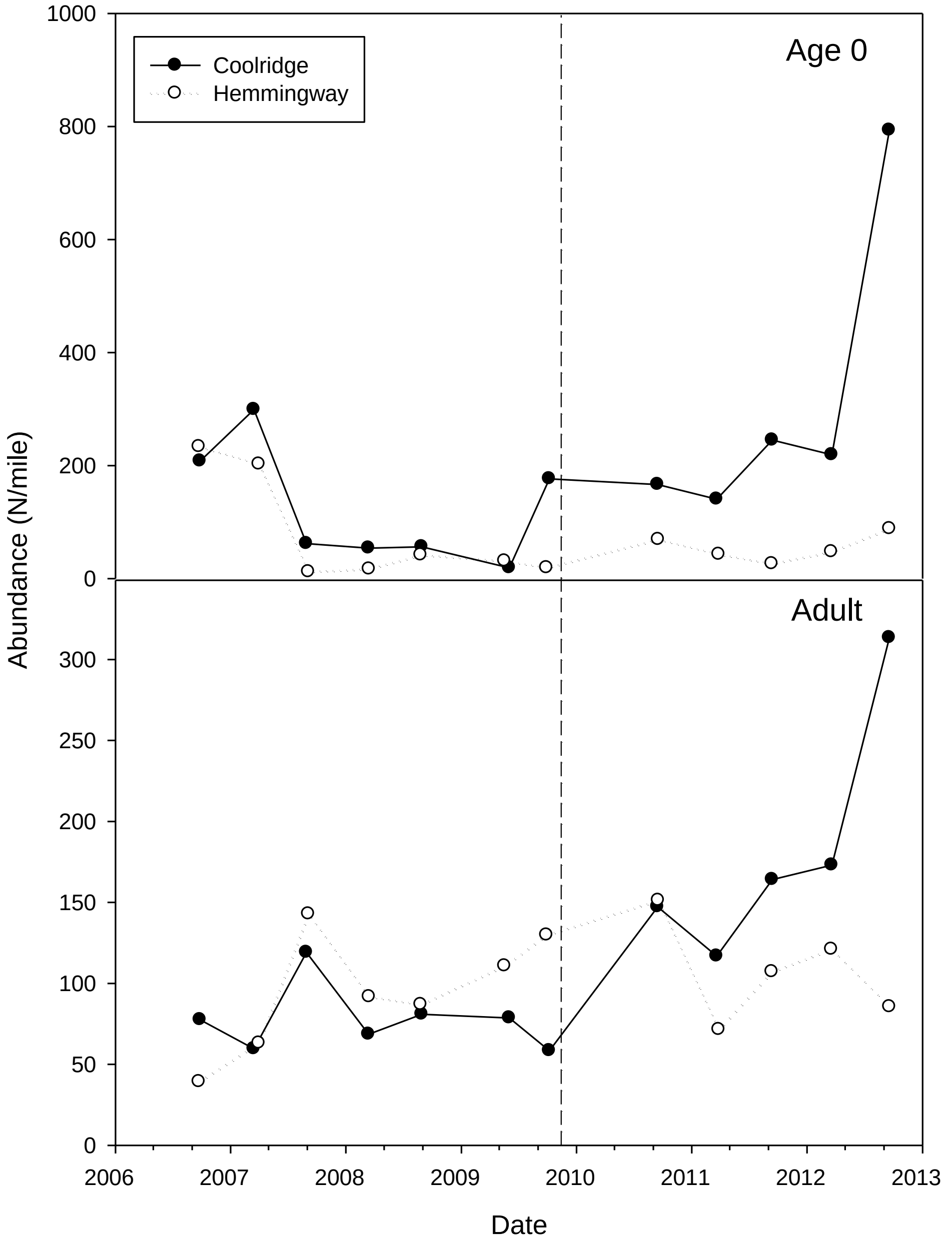
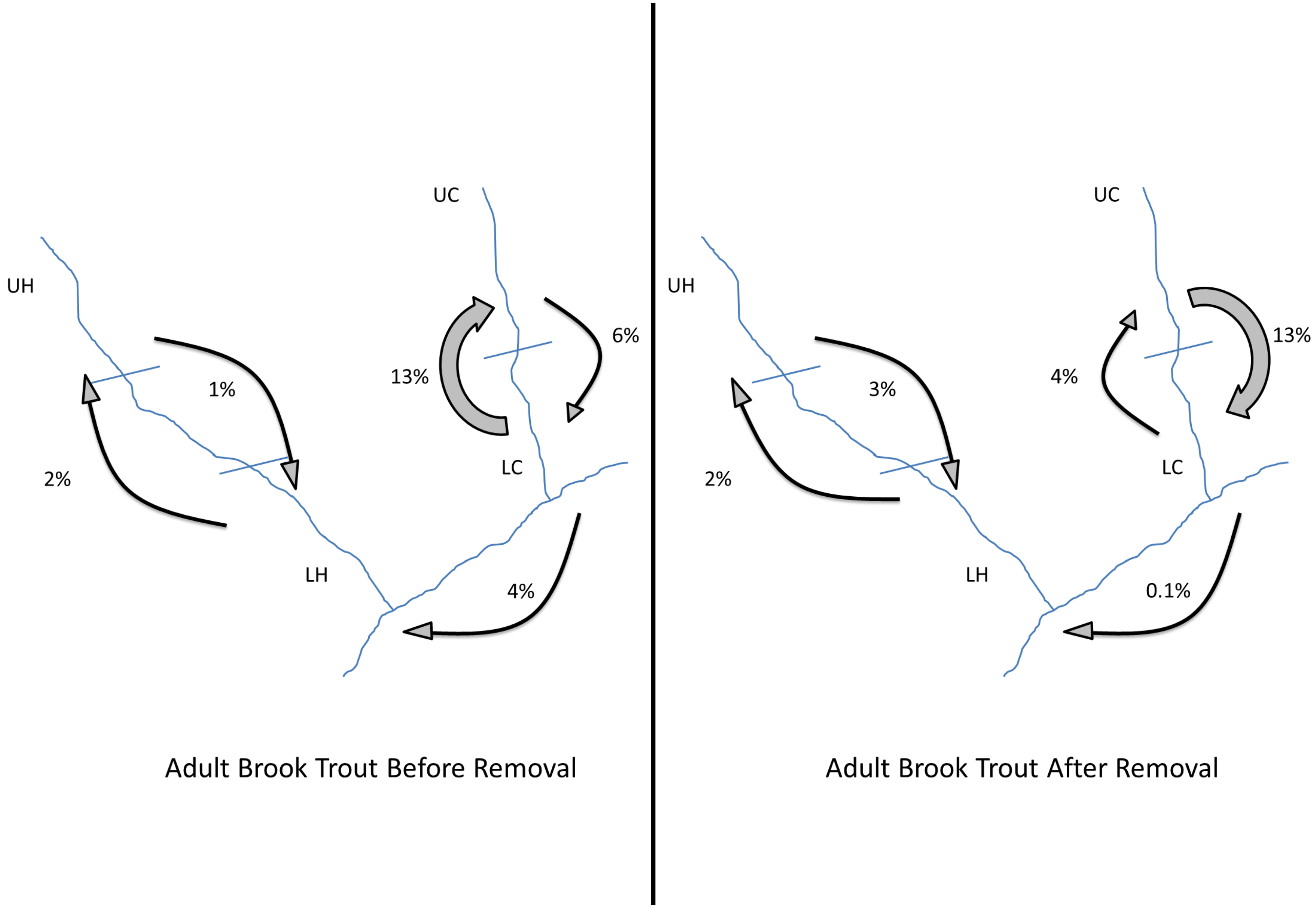


Figure 4. Brook trout abundance in Coolridge and Hemmingway Creeks from 2006 through 2012. Dashed line represents the beginning of brown trout removal in Coolridge Creek.



Adult Brook Trout Before Removal

Adult Brook Trout After Removal

Figure 5. Annual movement rates of adult brook trout before and after brown trout removal in Coolridge Creek. Upper Coolridge (UC) and upper Hemmingway (UH) are dominated by brook trout and have low brown trout density, whereas lower Hemmingway (LH) and lower Coolridge (LC; prior to removal efforts) have high brown trout density.

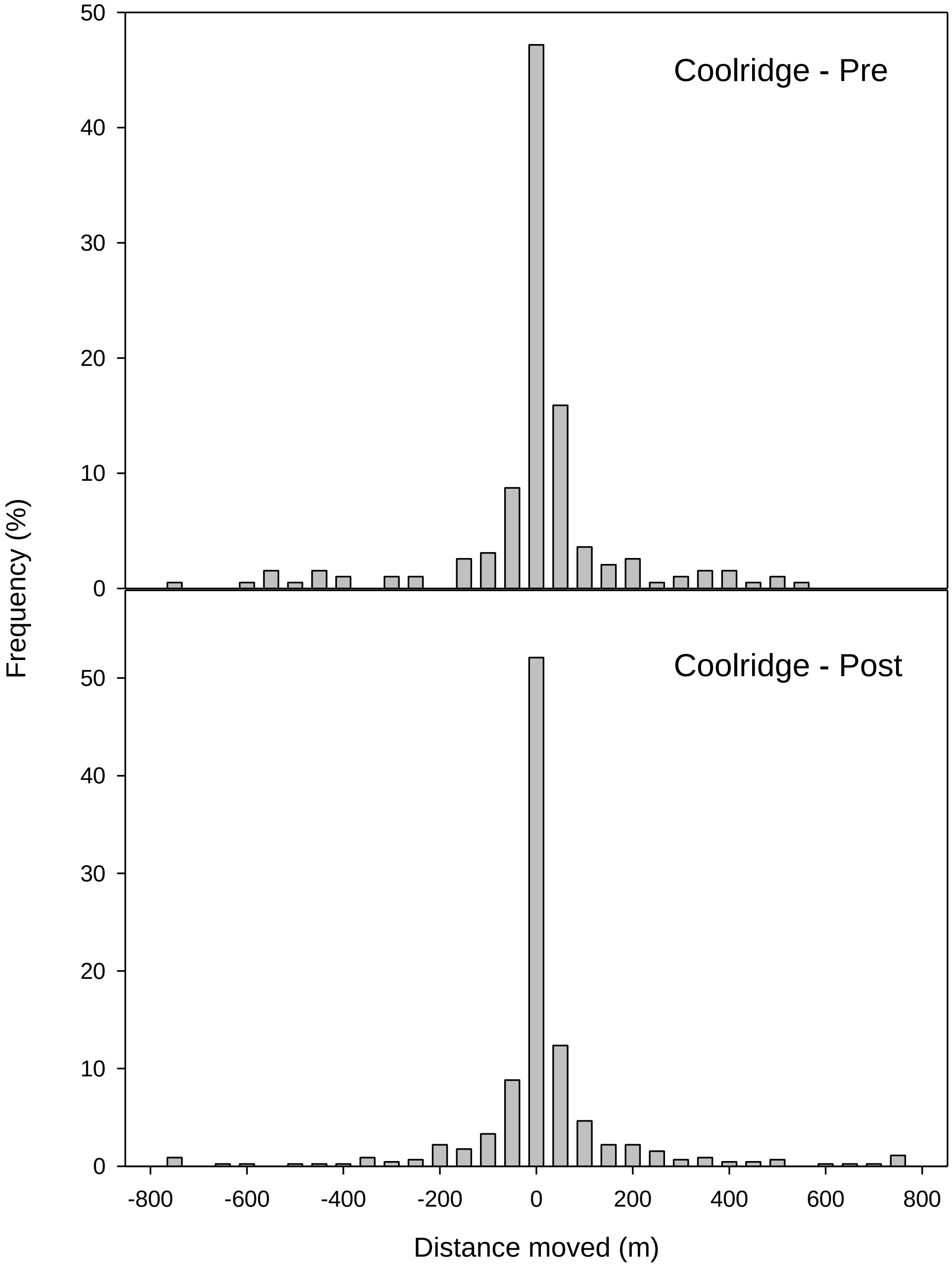


Figure 6. Distance moved by individual brook trout between consecutive sampling events in Coolridge Creek pre and post brown trout removal. Negative numbers indicate downstream movement.

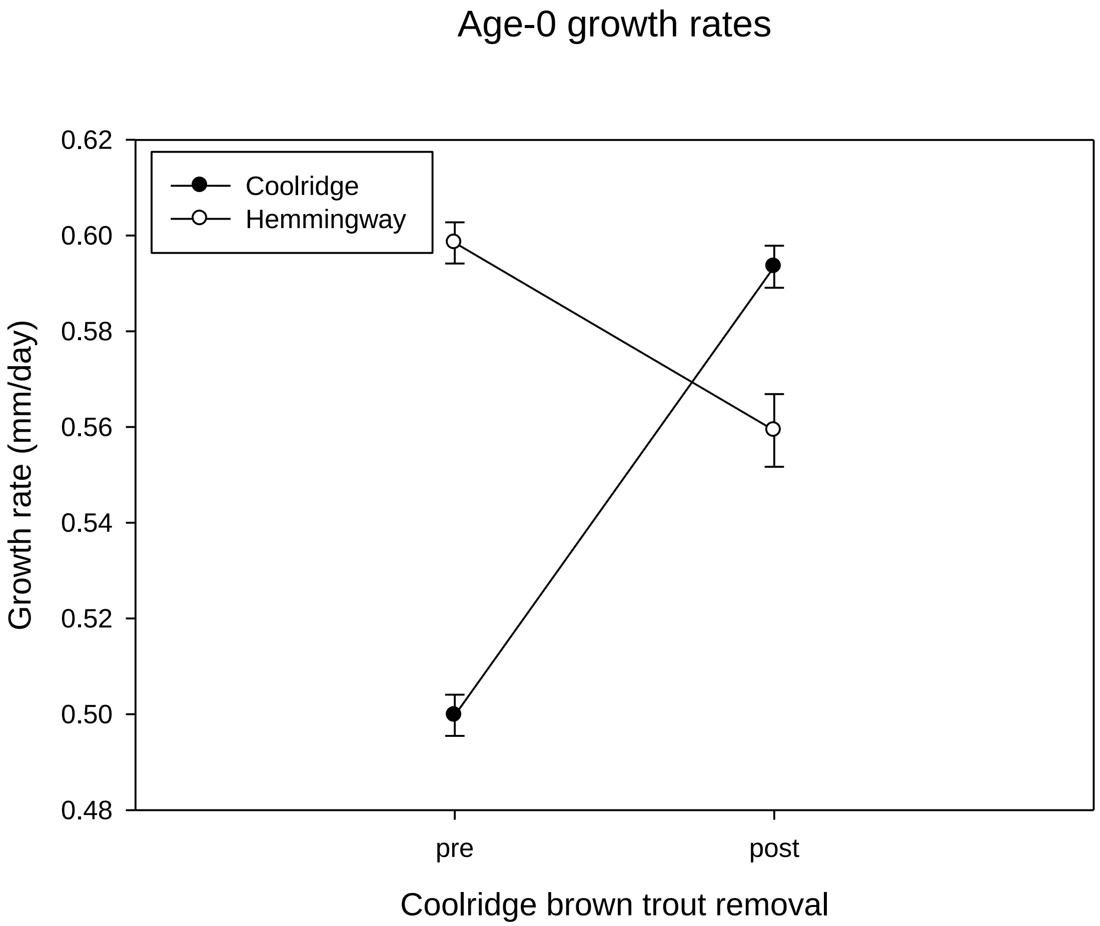


Figure 7. Growth rates of age-0 brook trout in Hemmingway (control) and Coolridge (treatment) creeks before and after brown trout removal.

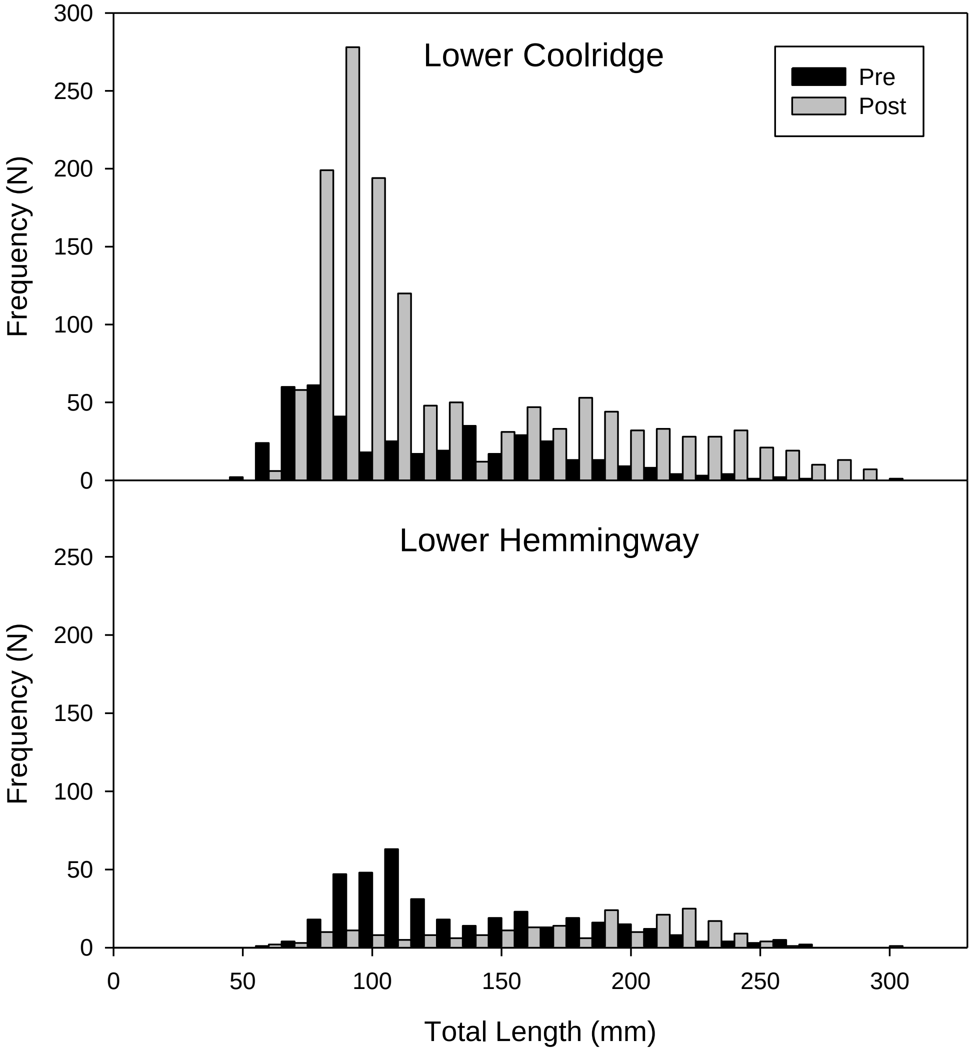


Figure 8. Length frequency histograms for brook trout found in lower Coolridge (treatment) and lower Hemmingway (control) before and after brown trout removal.

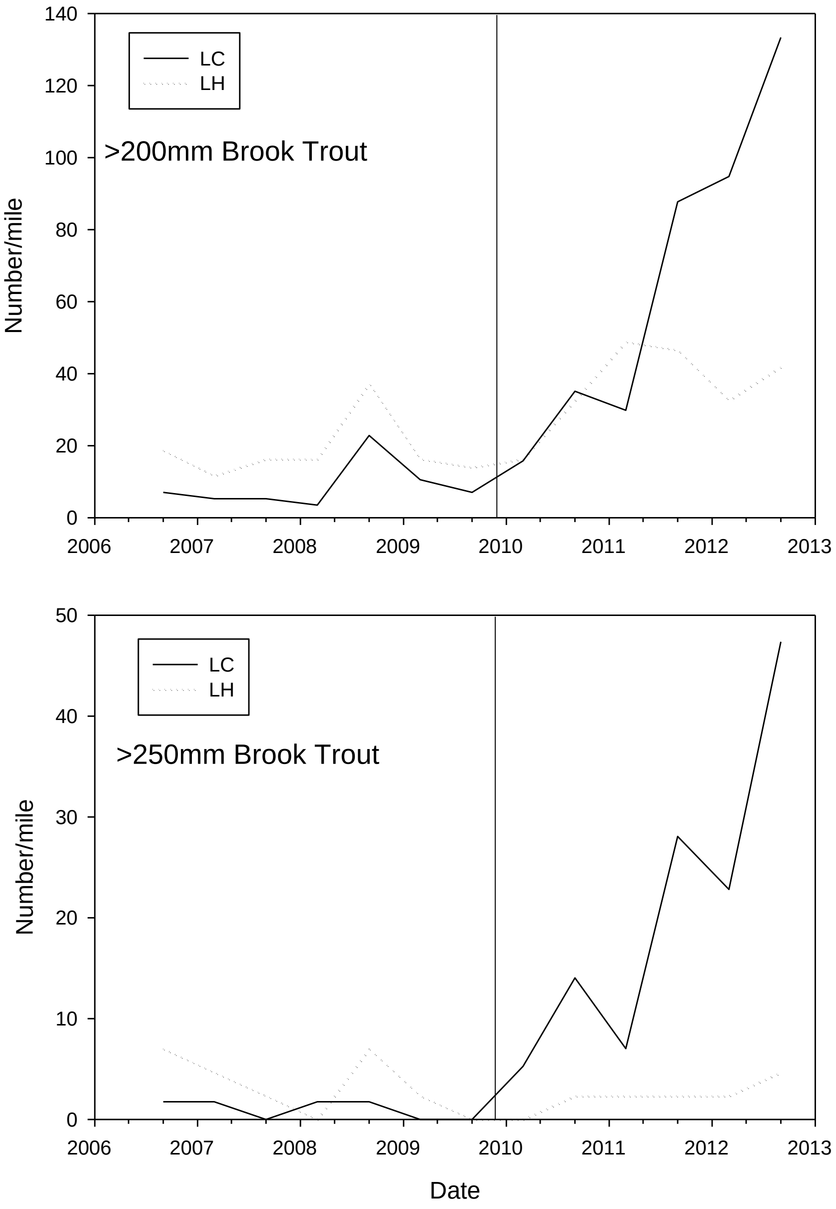


Figure 9. The number of brook trout greater than 200 and 250 mm mile before and after brown trout removal in lower Coolridge Creek (LC) compared to a control reach without brown trout removal (lower Hemmingway; LH). The solid vertical line represent timing of initial brown trout removal.

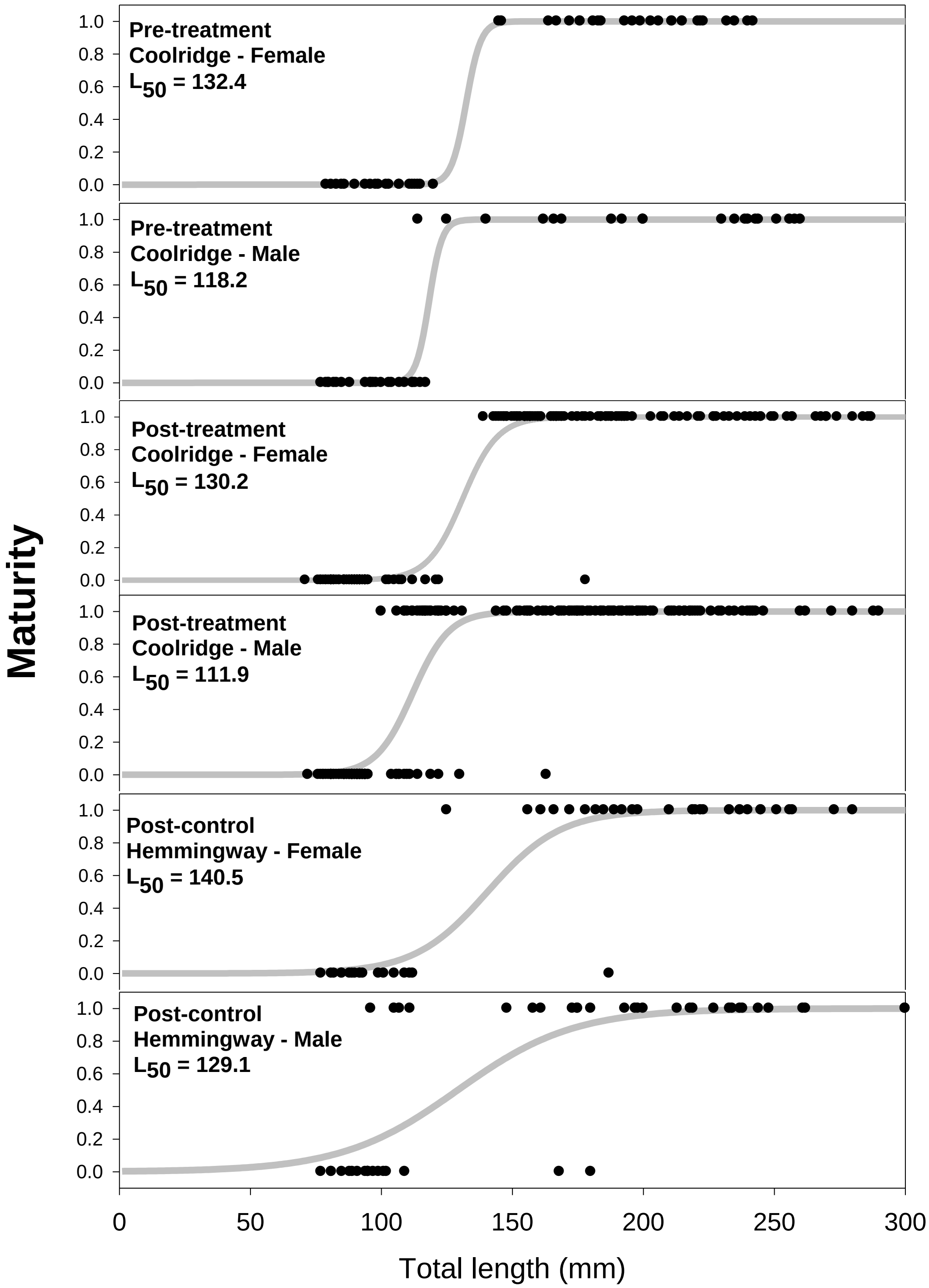


Figure 10. Size at maturity for brook trout collected in Hemmingway (control) and Coolridge (treatment) creeks after brown trout removal.

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