# Trout Population Response to Cover Habitat Enhancement in the Batten Kill Main Stem

Kenneth M. Cox
Vermont Fish and Wildlife Department
100 Mineral Street, Suite 302
Springfield, Vermont 05156-3168

March 2011

**Abstract**

Trout population response to the addition of cover structures in a section of the Batten Kill main stem was evaluated. Prior to treatment available fish cover for yearling and larger size trout in the habitat enhancement project site was estimated to be 0.7% of the wetted channel area. Placement of 85 cover structures increased available cover to a modest 3.0%. Trout abundance prior to and following habitat enhancement was estimated by annual electrofishing surveys conducted within pool and riffle habitats in the treatment section as well as at two untreated control sites. While no change in mean yearling trout numbers was observed between pre- and post-treatment periods at the control sites, average yearling fish numbers increased 4.9 fold in the treated pool and doubled in the treated riffle. In the pool habitat young-of-year trout numbers also doubled, and modest increases in the range of 1.6-1.8 times pre-treatment levels for fish in the 10-19.9 inch adult size range were observed. These results provide evidence that inadequate refuge habitats may be limiting trout abundance in the Batten Kill. Habitat restoration may be an effective management tool to compensate for factors affecting trout survival and abundance, although cost and access to private lands limit its practicality on a watershed scale. Protection and restoration of riparian habitats and its influence on instream habitats will be key to the long term health of the Batten Kill wild trout resources.

## Introduction

Cover is widely recognized as a critical component of trout habitat. It provides refuge from predators, contributes to increased survival during harsh winter seasons and extreme high and low flow events, and may reduce territorial antagonism between members of its species co-habiting the same locale by providing visual isolation (Bjornn and Reiser 1991; Dolloff et al. 1994; Hasegawa and Maekawa 2009; Sundbaum 2001). Thus, the presence of cover reduces energetic costs that may translate to increased trout survival and abundance (Sundbaum 2001). Many stream features can serve as cover including water depth and turbulence; coarse substrate materials; overhanging and undercut banks; overhanging bank vegetation; large wood (LW, such as fallen trees, limbs and brush) (Bjornn and Reiser 1991). The functionality of these features is fish-size dependent, e.g. shallow water at the stream edge having abundant coarse organic matter (leaves, twigs, etc.) may provide adequate cover for young-of-year (YOY) trout but not yearlings and larger fish.

Cover is one correlate of increased carrying capacity of streams (Boussu 1954; Whiteway et al. 2010; Sundbaum 2001; Zorn and Nuhfer 2007): streams devoid of suitable cover support fewer fish. Optimum cover required by lotic fish populations have not been well researched, although cover values expressed as area influencing total wetted area of the stream bed have been reported to be in the range of 15 to 50+ percent (Heggenes 1988; Raleigh 1982; Raleigh et al. 1986; Thorn et al. 1997). LW recruited into stream channels from adjacent and upstream riparian forest is important to the formation of cover habitat in streams and contributes to pool formation, sediment retention and macroinvertebrate production.

Other habitat variables, including flow, depth, velocity, temperature, spawning substrate and habitat connectivity, also determine habitat suitability for all trout life stages. With respect to these, the Batten Kill provides suitable habitat for brown and brook trout.

Prior to European settlement the Vermont landscape was 95% forested (Klyza and Trombulak 1999; Verry and Dolloff 2000). The mean age of "old growth forests" in Vermont at the time was in the range of 150-200 years (Albers 2000). The riparian component of these forests undoubtedly had a significant influence on stream and river structure and processes as well as in-stream habitat formation and maintenance. Riparian forests would have been a dominant source of LW recruited to the stream channel either creating fish shelters or contributing to fluvial processes that form features, such as pools that also function as cover. LW in streams increases habitat complexity, greater invertebrate production and fish abundance (Richards and Hollingsworth 2000).

Nearly 250 years of human activity since first European settlement has profoundly altered the Vermont landscape. Timber harvesting for lumber, fuel wood and potash, and conversion of forestland to farmland reduced forests on the Vermont landscape to 40% by the mid 1800s (Klyza and Trombulak 1999). Riparian forests were some of the first to be cleared given that rivers and streams were frequently "cleaned out" and used to transport logs downstream to mills for processing. This transformation of the landscape would have negatively affected streams and fish communities that evolved in a primarily forested setting. Increased erosion, sedimentation, elevated water temperatures resulting from lost forest canopy, and reduction in LW input are all likely consequences occurring on a large scale and deleterious to aquatic systems. From the late 1800s through the 1950s, farmlands went through a period of abandonment and reversion back to forests. At present approximately 80% of the state is forested (Klyza and Trombulak 1999); however, from this period of "reforestation" through the present time modern forestry management came into practice promoting relatively short harvest rotations maintaining maximum forest age of less than 100 years. Consequently, current forests are less prone to damage from natural events, such as disease, ice and wind storms, and wildfire. Even though LW continues to be recruited into Vermont streams, bole diameters and lengths of these trees are likely not as large as historic inputs observed by Richmond and Fausch (1995) in undisturbed (old growth) and disturbed forested watersheds in Colorado. Additionally, LW size has a direct bearing on its retention in lotic environments, i.e., large wood with large bole lengths (longer than average bankfull width) and large diameters are less apt to be displaced downstream over the short term and thus contribute to channel and habitat formation processes (Hildebrand et al. 1998; Murphy and Koski 1989). Lands adjacent to streams are still subject to "traditional" farm and forest management or are converted to residential and commercial uses, resulting in total loss or diminished riparian function.

Since the 1980s considerable attention has been given to evaluating the role of LW in stream systems and its benefits to salmonid populations. Also, many stream habitat improvement projects place more emphasis on “natural” habitat design taking into consideration fluvial geomorphic processes or mimicking naturally occurring LW structures over the engineered structures applied in the past, such as deflectors and low crest dams.

During the mid 1990s the abundance of yearling and older brown trout in the Batten Kill main stem experienced a 70% decline. In response to this change in the fishery the Vermont Fish and Wildlife Department (VFWD) setup an interdisciplinary team of aquatic scientists to investigate possible causes of the decline through studies principally funded through cost-share agreements with the U. S. Forest Service, Green Mountain National Forest (USFS), Vermont Department of Environmental Conservation, and the Vermont Cooperative Fish and Wildlife Research Unit based at the University of Vermont.

The panel focused on possible habitat-associated causes such as water quality, stream geomorphology, flow and temperature regimes and trout cover (Cox 2009; Cox, in preparation; Field 2001; Jaquith et al. 2004; Nislow and Magilligan 2005; VDEC 2003). Assessment of the current condition of cover in the Batten Kill main stem based on a sample of 43 habitat units[1] estimated cover to be in the range of 0-66.6% of the total wetted area within each unit for an overall mean of 7.27% (SD 11.16) (Cox 2009). This is substantially below the desired condition of 20% reported by Thorn et al. (1997). In the absence of evidence that the other investigated habitat variables offer plausible explanations for the trout population decline in the Batten Kill, the following working hypothesis (in part) was offered (Cox 2006):

> *The chronic loss of trout cover in the Batten Kill main stem resulting from past river channel alterations and encroachments, the reduction and loss of forested riparian areas by land use activities, and the removal of newly recruited in-stream large woody debris and other cover structures has degraded habitat in the river at the expense of midsize [5.0-9.9 in] brown trout. Inadequate cover exposes fish to increased predation and possible environmental stresses, such as winter mortality. Cover within the river had degraded by the 1990s to the point that the habitat was no longer able to support adequate abundance of midsize trout to be recruited into the fishery.*

## Site Description

The Batten Kill watershed (Figure 1) is located in the Hudson River basin and has a total area of 450 $mi^2$ located in two states. The upper 200 $mi^2$ drain the Taconic and Green mountains

[1] A habitat unit is defined as a channel-wide segment of stream with a distinct set of characteristics (USFS 1998). For the purposes of the Batten Kill cover inventory, units were classified as either pool or riffle. Two consecutive pools separated by a short riffle (i.e., riffle length measurement is less than the channel width) were combined into a single pool.

of Vermont with the remaining 250 $mi^2$ in New York. The main stem of the river is 57.6 mi in length originating at East Dorset, Vermont. From there it flows in a generally southward direction 19.8 mi to Arlington, Vermont, where it then heads west another 7.3 mi before crossing into New York. The Batten Kill in Vermont is a wild trout stream supporting populations of brown and brook trout and has not been stocked since the mid 1970s.

A pilot project to assess response of brown and brook trout populations to the addition of cover structures was begun in the summer of 2005. The project site is located on the Batten Kill main stem in the town of Arlington and approximately 3.5 mi upstream of the Vermont-New York state line (Figure 1). The treatment site lies between River Road on the south side of the river and private lands abutting the north bank. In total the treated river section measures 1,191 ft and consists of pool and riffle segments. Additionally, two trout population monitoring sites located upstream and downstream of the treatment section were used as evaluation controls (Figure 1). Control sites were established in 1988 and have been sampled nearly annually since then. Each control site consists of 75% pool and 25% riffle habitat. Cover was estimated to be 0.2 and 0.7 percent of total wetted channel area in the Cemetery Run and West Mountain control sites, respectively. No habitat improvements have occurred within the control sites.

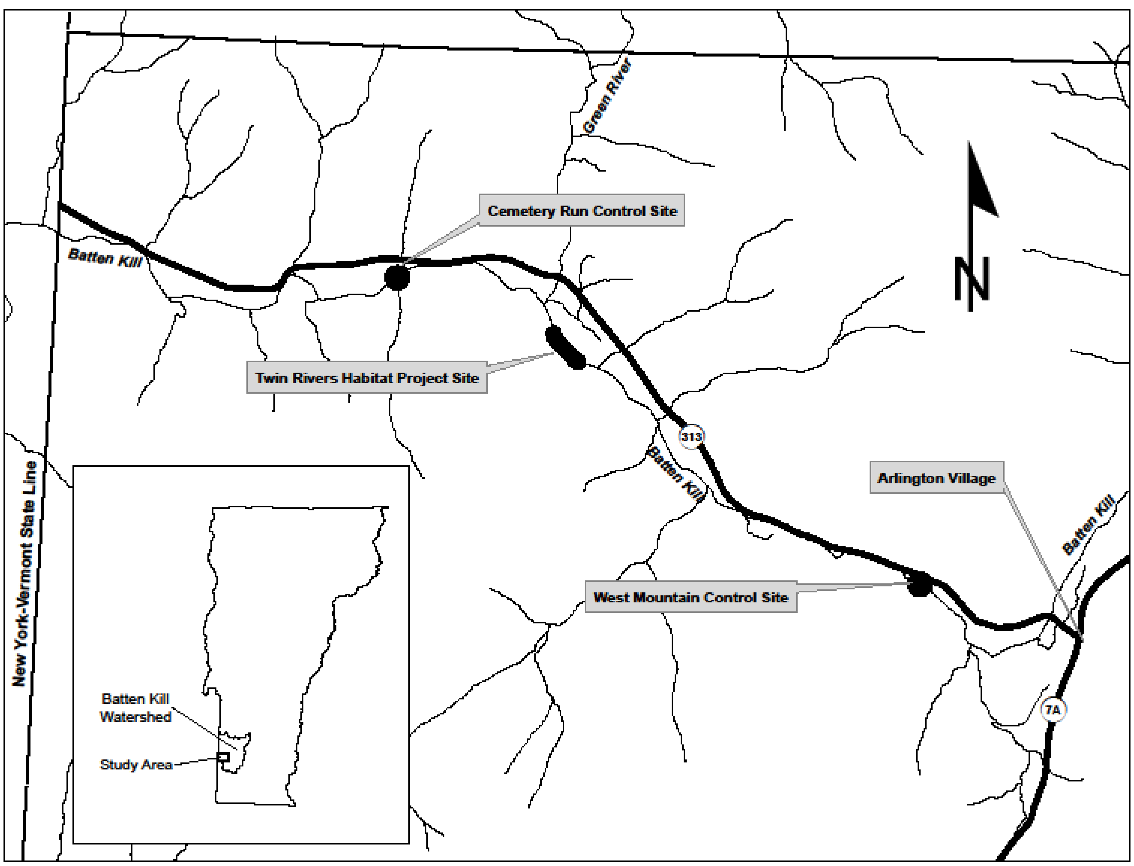



FIGURE 1. Map of Twin Rivers Habitat Project study area on lower Batten Kill main stem, Vermont.

**Methods**

Assessment of habitat improvements used a BACI (Before-After/Control-Impact)-type study design. Trout population abundance was estimated by electrofishing twice (2005 and 2006) prior to the addition of habitat structures followed by four years (2007-2010) of post-treatment evaluation. Trout population estimates at the control sites were made annually over the six year study period.

Estimations of available trout cover in treatment and control sites were made in advance of habitat improvements. This was repeated in the treated section the summer following construction. Cover measurement procedures were similar to those developed by Binns (1982); however, that guidance lacked minimum quantifiable standards on which to define various cover types to be considered effective refuge habitat for specific trout size classes of most interest to this study, i.e. yearling size and larger fish. Therefore, criteria were developed from a review of the literature leading to the methods employed for this study (Cox 2001).

Annual population estimates were made by electrofishing stations within each of the pool and riffle treatment areas as well as both control sites. The pool section measures 337 ft and the riffle section 315 ft in length. Standard VFWD shocking gear consists of a Georator© portable gas-powered DC generator rated at 250 volts, 2 amps and 500 volts, 1 amp output. The generator delivers electrical current to the river flow via two separate lengths of cables each connected to an anode wand. A canoe is used as a floating barge to transport the generator as the sampling crew wades upstream through the population monitoring station. Optimally five people fill out the fish collection crew: two operating the anode wands, two backup netters, and a person towing the canoe and managing the electrical cords and generator. Due to wetted channel width at the sites included in the study, three crews were required to provide complete coverage of the river.

Fish immobilized by the electric field were netted and placed in temporary holding vessels containing fresh water. After completion of the first pass through the sampling section all fish were transferred to a live cage placed in the river. Successive trout samples were held in separate live cages. A minimum of two passes were made for population estimation.

Captured trout were anesthetized, identified to species and measured for total length (mm) and wet weight (g). Fish were then placed into a receptacle with fresh water to recover from anesthesia and redistributed back to the sampling section. The maximum likelihood modification of the Zippin method (Carle and Strub 1978) was used to estimate trout populations by size class: ≤4.9 in, 5.0-9.9 in, 10.0-14.9 in, 15.0-19.9 in, ≥20.0 in. Length frequency distribution determined the ≤4.9 in and 5.0-9.9 in classes represent YOY and yearling age classes, respectively. Annual standing stock estimates are expressed as fish/mi and lb/acre.

Three basic types of cover structures, described below, were used in the treatment section. Layout of the cover structures (see example in Appendix, Figure 1) was determined on the basis of pre-treatment channel and habitat survey measurements.

(1) LW clusters (Figure 2) were constructed from several trees trunks with root wad or fan attached placed at angles to one another against the river bank. Each log measured at least 12 ft in length and had a minimum diameter of 12 in. Trees were secured to the bank either by driving the small end of the log deep into the bank and/or by cabling. Whole small trees or bundles of tree limbs were worked into and/or under the logs to provide cover complexity. Large stones were incorporated into some structures.

(2) Whole tree structures (Figure 3) consisted of single or multiple trees usually with smaller minimum trunk diameters than used in LW clusters. Unlike LW clusters the tree crown, side limbs and sometimes root wad were left intact. These were positioned next to or anchored into the bank.

(3) Rock shelters used singly or in groups. Typically these structures are placed in the channel thalweg to provide fish cover with the intent of not interfering with river floaters (canoers, kayakers, tubers). The most frequently constructed rock structure is one consisting of a large flat stone (one $yd^2$ or larger) placed on top of two or more support rocks creating overhead shelter for trout.

Eighty-five cover structures were placed in the 1,191 ft long treatment section during September 2006. By type these included 20 LW clusters, four whole tree structures, and 59 rock shelters. Pool habitat with the deeper water was judged to have the greatest potential of creating refuge habitats benefiting yearling and larger trout, therefore 51 rock shelters were located there in contrast to only eight in the riffle.

Student's t tests on pre-treatment and post-treatment means were used to determine whether the addition of cover structures resulted in statistically significant differences in trout abundance compared to pretreatment estimates within the five fish size classes. The null hypothesis ($H_0$): pre-treatment mean ($\mu_1$) equals the post-treatment mean ($\mu_2$), i.e. no change occurred; and the alternate hypothesis ($H_A$): $\mu_2$ is greater than $\mu_1$. Power analyses were also done. Testing for changes in fish abundance pre-treatment and post-treatment were conducted on the pool and the riffle separately and for both habitat sections combined. The latter was done to provide a situation more comparable to both control sections which consist of both pool and riffle habitats.

## Results

Treatment of the study area with 85 structures quadrupled cover habitat from 0.7% of the wetted channel area to 3.0%. Most of the structures were placed in the pool section where water depths affecting trout usage of the habitat was believed to be less influenced by seasonal flow variability and the structures would be more apt to withstand being dislodged and washed downstream during very high flow events. Two months after installation many of the LW structures were already intercepting small branches, twigs, leaves and other organic debris being carried downstream by the river current effectively increasing the zone of influence of the cover structures. By the following spring (April 2006) water depth associated with most of the LW

FIGURE 2. Typical LW cluster.

FIGURE 3. Treated pool section of Batten Kill. LW clusters are installed along right bank and whole tree structures are on inside bend of left bank. Rock structures (not visible) are placed in thalweg (center channel).

structures on the left bank of the pool (as viewed looking downstream) had increased. Schools of small fishes (likely cyprinid species) were seen in low velocity areas created by the large wood structures, and larval caddisflies (Limnephilidae) appeared much more evident on submerged wood and accumulations of coarse detritus than observed prior to treatment. Over the next four years changes in the structures and corresponding localized channel areas were generally gradual; however, decreases in cover complexity due to deterioration of tree crowns and brush bundles and sediment deposition around large wood and rock shelters were noted. Three wood structures were lost entirely to a significant high flow event within one year of construction: two in the treated pool and one in the riffle section.

One year following cover habitat enhancement trout population assessments began showing significant increases of YOY and yearlings in the treated pool (Table 1, Figure 4 and Appendix, Table 1). Over the four-year post-treatment period YOY densities in the pool averaged 799 fish/mi compared to a mean of 337 fish/mi before habitat enhancement, representing a 2.4 fold increase ($P<0.05$). Yearling trout numbers increased by a factor of 4.9 ($0.10>P>0.50$), and increases in the order of 1.8 and 1.6 times pre-treatment means for the 10.0-14.9 in and 15.0-19.9 in size classes, respectively, are indicated but are not statistically significant (NS; $P>0.10$).

As was anticipated, trout population responses to habitat enhancements in the riffle section were more modest with the greatest improvement being a doubling of yearling numbers from 152 fish/mi to 308 fish/mi (NS; $P>0.10$). Little to no improvement in the number of trout $\geq$10.0 in occurred in the riffle. Corresponding results for the two control sites indicate no significant change ($P>0.10$) among all size classes. When pool and riffle habitats in the treatment section are analyzed as a single section to be more comparable with the mixed habitats represented by the control sections, significant increases are still apparent for YOY ($P<0.05$) and yearlings ($0.10>P>0.05$).

Trout biomass estimates (Appendix, Table 2) indicate more subtle trends particularly when size classes are combined. The pool section before treatment (22.4 lb/acre) and after (34.7 lb/acre) supported the greatest biomass with the largest weight increases occurring in the yearling, 10.0-14.9 in and 15.0-19.9 in classes. The weight change in the riffle increased from 5.3 lb/acre to 8.9 lb/acre.

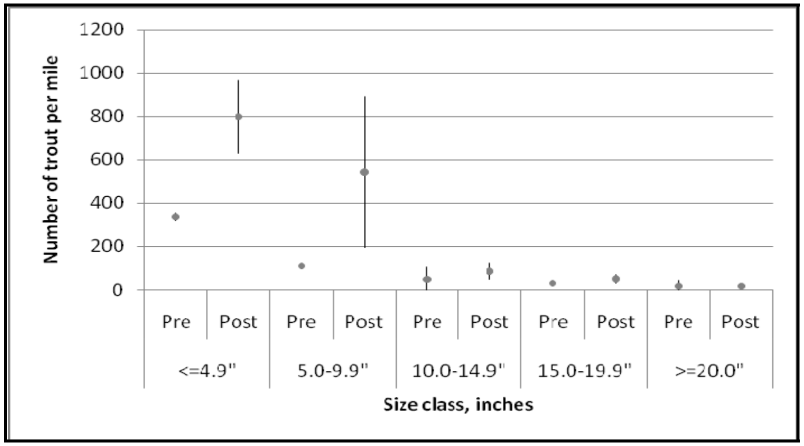
Biomass in the Cemetery Run control site was unchanged. Furthermore, even though there was a small increase in biomass at the West Mountain control site, it principally occurred within the 10.0-14.9 in size class. When estimates for pool and riffle sections before and after treatment are combined to be more comparable with the pool-riffle makeup of the West Mountain control site, total biomass of the pre-treated pool-riffle section was 14.1 lb/acre and after treatment increased to 21.9 lb/acre. Total biomass of the control site for the pre-treatment years was 14.9 lb/acre and for the post-treatment period 17.2 lb/acre.

TABLE 1. Student's *t* tests with power analyses for pre-treatment and post-treatment means (number of trout/mi by size class) for pool and riffle habitats in the Twin Rivers Habitat project section and the two untreated control sites. Significant *P*-values are in bold.

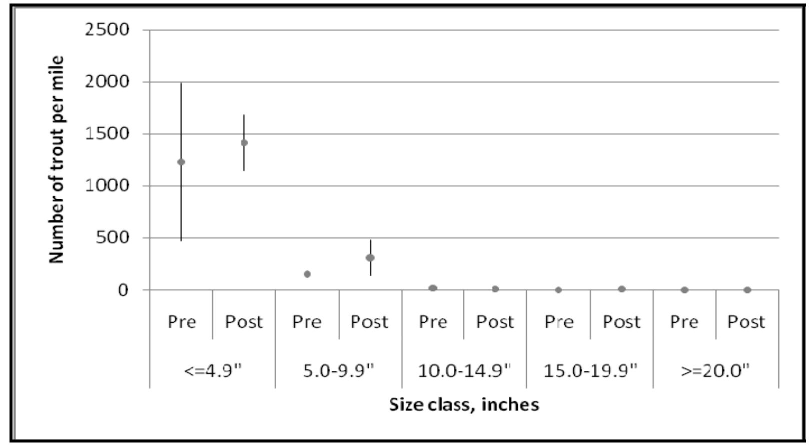
| Habitat | Size class, in | *α* level | *P* | *1-β*, % |
|---|---|---|---|---|
| **TRHP pool** | ≤4.9 | 0.05 | **0.0118** | 100.0 |
| | 5.0-9.9 | 0.10 | **0.0913** | 85.8 |
| | 10.0-14.9 | 0.10 | 0.1546 | 42.3 |
| | 15.0-19.9 | 0.10 | 0.1671 | 40.9 |
| | ≥20.0 | 0.10 | 0.4930 | 10.3 |
| **TRHP riffle** | ≤4.9 | 0.10 | 0.2962 | 20.1 |
| | 5.0-9.9 | 0.10 | 0.1538 | 67.2 |
| | 10.0-14.9 | 0.10 | 0.1563 | -- |
| | 15.0-19.9 | 0.10 | 0.1563 | -- |
| | ≥20.0 | -- | -- | -- |
| **TRHP pool and riffle combined** | ≤4.9 | 0.05 | **0.0426** | 51.9 |
| | 5.0-9.9 | 0.10 | **0.0847** | 87.6 |
| | 10.0-14.9 | 0.10 | 0.2174 | 32.7 |
| | 15.0-19.9 | 0.10 | **0.0709** | 62.4 |
| | ≥20.0 | 0.10 | 0.5000 | -- |
| **West Mountain control** | ≤4.9 | 0.10 | 0.4212 | 16.1 |
| | 5.0-9.9 | 0.10 | 0.4978 | -- |
| | 10.0-14.9 | 0.10 | 0.1148 | 78.2 |
| | 15.0-19.9 | 0.10 | 0.3726 | 14.9 |
| | ≥20.0 | 0.10 | 0.2707 | -- |
| **Cemetery Run control** | ≤4.9 | 0.10 | 0.3034 | 22.4 |
| | 5.0-9.9 | 0.10 | 0.3564 | 23.9 |
| | 10.0-14.9 | 0.10 | 0.3602 | 24.5 |
| | 15.0-19.9 | 0.10 | 0.2752 | 33.4 |
| | ≥20.0 | 0.10 | 0.3164 | 20.7 |

## Discussion

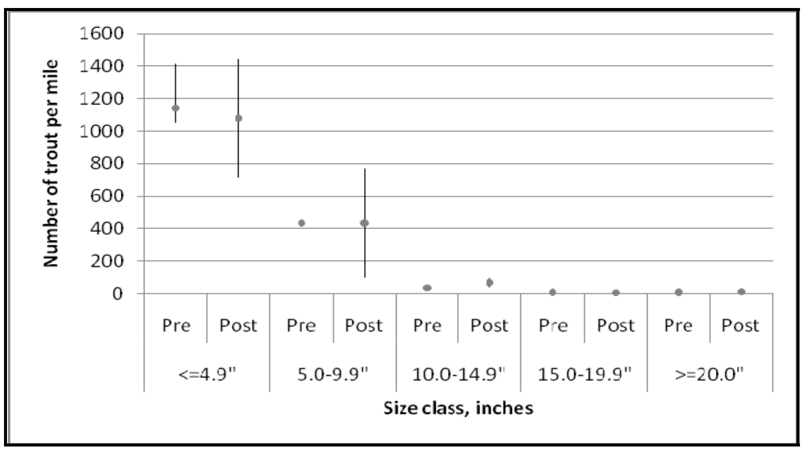
Installation of cover structures in the lower Batten Kill main stem resulted in an overall increase of trout numbers in pool and riffle sections by magnitudes of 2.8 and 1.2 times, respectively, above mean levels estimated to have been present prior to treatment, and appears to support the working hypothesis (page 3). Consistent with what was anticipated, the increase was greatest in the treated pool habitat where more cover structures were placed and water depths are less limiting to yearling and older trout. Nonetheless, results indicate substantial improvements in age-1 as well as YOY trout abundance can be achieved by enhancing cover in riffle habitats.



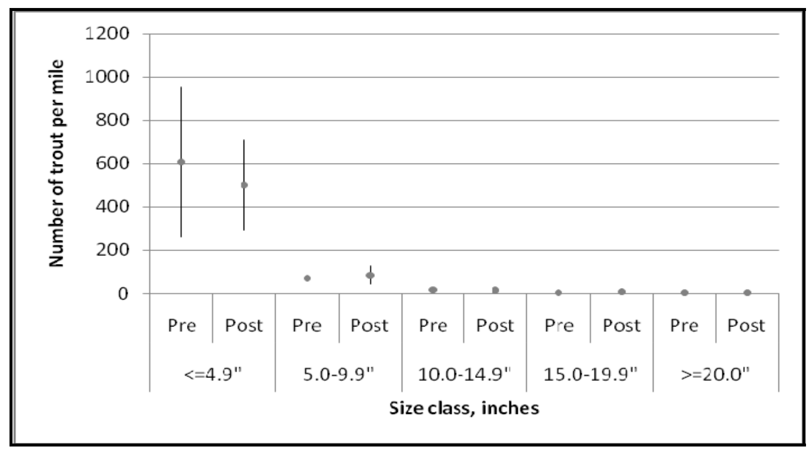

TRHP Pool




TRHP Riffle




West Mountain Control




Cemetery Run Control

FIGURE 4. Pre- and post period trout abundance (mean±95% confidence limits for brown and brook trout combined) by size class at habitat treatment and control sites on the lower Batten Kill. Pre- and post treatment years are 2005-2006 and 2007-2010, respectively.

The importance of pool habitat to brown and brook trout is well documented (Clapp et al. 1990; Heggenes 2002; Lewis 1969; Raleigh 1982; Raleigh et al. 1986). Bunnell et al. (1998) observed brown trout are significantly more likely to be found in pools (59%) than in runs (32%) and riffles (9%). This occurred independent of season of year or time of day. Even the less used habitats contributed to trout survival. Logan (2003) also showed pools are the primary habitat used by brook trout.

The interaction of water depth, current velocity and cover availability have a significant influence on juvenile and adult brown trout habitat selection (Ayllon et al. 2009). These parameters are similarly important determinants for brook trout (Raleigh 1982). However, seasonal differences in habitat use do exist. Underyearling brown and brook trout tend to be less selective in their habitat preferences than older age fish (Johnson 2008), but deep, low velocity water (i.e. pools and runs) are important to overwinter survival of juveniles of both species (Cujak and Power 1986). During open-water seasons (spring-autumn) YOY trout tend to associate with habitats providing cover with shallower, lower velocity water, such as may occur along stream channel margins in pool and riffle habitats (Cunjak and Power 1986; Kocik and Taylor 1996; Raleigh et al. 1986). In advance of winter, however, juveniles move into deeper habitats (Elliott 1994). This survival strategy may minimize energetic costs as well as redistribute fish away from stream locations vulnerable to ice exclusion or entrapment and in turn reduce overwinter mortality (Chisholm et al. 1985). Higher abundance (fish/mi) of age-1 (5.0-9.9 in) trout estimated three of the four years (2007, 2008, 2010) after cover enhancement in the Batten Kill pool appears to have benefitted overwinter survival.

The substantially lower percent change of the larger size classes (10.0-14.9 in and over; approximating age-2 and older) responding to habitat enhancement compared to changes in the two smaller size classes is not unlike results reported by others who have assessed trout population response to cover enhancement. Thorn and Anderson (2001) evaluated two methods of enhancing brown trout habitat (overhead bank cover and LW) in a Minnesota stream. They found habitat improvements increased the abundance of age-1 and older trout but had no effect on trout ≥15 in and attributed this to deficient forage and foraging sites. Hartzler (1983) observed no increase in abundance of ≥8 in brown trout after placement of half-log cover structures in an eastern Pennsylvania trout stream possibly because abundant natural cover was already available in the treated pool. In contrast, Hunt (1971) documented large increases in age-2 and older brook trout exceeding juvenile numbers when habitat was enhanced with artificial bank covers and current deflectors. Likewise, Riley and Fausch (1995) observed increased abundance of age-2 and older brook and brown trout after several Colorado streams were treated with log drop structures. Perhaps, in the case of the Batten Kill, the intensity of treatment in the pool remains suboptimal to affect age-2 and older fish. Cover in the pool was estimated at 1.3% prior to treatment and after increased to 6.0% which is still less than half the 20 to 25% suggested by Raleigh (1982) and Thorn et al. (1997), respectively, as adequate for brook and brown trout. Cover can affect intraspecific competition for suitable territories and/or foraging sites (Bachman 1984; Elliott 1994; Johnsson et al. 2004; Thorn and Anderson 2001). Or, most simply additional time is needed for trout populations in the Batten Kill treatment pool to fully respond to improved habitat conditions. Unfortunately it is not within the scope of the present study to delve into the causes beyond these suppositions.

In the case of this study, insufficient forage does not appear to be a plausible explanation as Thorn and Anderson (2001) suggested for their study stream. During trout population electrofishing surveys in the Batten Kill main stem forage fish species (blacknose dace *Rhinichthys atratulus*, longnose dace *R. cataractae*, slimy sculpin *Cottus cognatus*) are generally in high abundance. Omland and Parrish (2007) provided quantitative confirmation of these observations when they sampled the Batten Kill fish to characterize the fish forage base as part of their trout population study.

The mechanism resulting in reported increases of trout population abundance following habitat enhancement has been questioned (Hartzler 1983). Do the added cover structures actually improve the carrying capacity of the treated habitat, or more basically is the increase in fish numbers the result of non-resident fish being attracted from nearby less suitable habitats? Gowan et al. (1994) challenged the *restricted movement paradigm* (i.e. resident stream salmonids are sedentary) in lieu of increasing scientific evidence supporting the contrary. This would seem to give credence to Hartzler's supposition regarding trout being drawn into habitat enhanced stream sections from less suitable adjacent habitats. On the surface this seems to be the case. However, studies conducted in Colorado and Wyoming indicate non-resident fish are not being attracted to enhanced habitats but rather through natural dispersal encounter new unoccupied habitats and essentially fill the voids (Gowan et al. 1994).

During the first few months of life natural mortality of YOY brown trout inhabiting streams has been shown to be density-dependent with mortality being higher in streams with less habitat complexity (Elliott 1994; Mortensen 1977). This suggests that habitat complexity will have a directing bearing on carrying capacity. Omland and Parrish (2007) in their study of brown and brook trout populations in the Batten Kill of Vermont came to a similar conclusion: most mortality occurs during early summer, is density-dependent, and YOY trout recruitment has a compensatory component. Bjornn (1971) supposed age-0 salmonid abundance that exceeds the cover carrying capacity of summer habitat may induce fish to move elsewhere where habitat conditions are more conducive to over winter survival.

The results of these studies suggests that cover enhancement may increase carrying capacity of pool and riffle habitats, improving summer as well as winter survival, and result in higher trout abundance as observed in this study. However, this assumes all other necessary habitat features are in adequate supply or within the proper tolerance ranges for brown and brook trout. The trout cover inventory of 43 habitat units (pools and riffles) distributed throughout the Batten Kill main stem quantified cover as a percentage of total wetted area of each habitat unit. Estimates were in the range 0-66.6% with a mean of 7.27% (Cox 2009). Thirty-six of the 43 units (84%) had less than 15% cover, the lowest value reported by Raleigh (1982) as being adequate for brook trout, and 37 units (86%) were less than the minimum 20% cover threshold identified for brown trout (Raleigh et al. 1986). These measurements indicate cover in the Batten Kill is well below optimum levels. Furthermore, Thorn and Anderson (2001) recommend LW affect at least 5% of pool area. In the case of Batten Kill study, LW in the pool was estimated at 0.3% before treatment and about 2% after (S. Wixsom, U. S. Forest Service, personal communication). Neither estimate accounts for cover provided by the rock shelter structures.

The statistically significant increases for trout of the two smallest size classes observed during this study suggests focusing habitat enhancement in pools deficient in cover complexity may have greater benefits than enhancing riffle habitats. This may be all the more important given the enhancement costs and limits on available funds.

Since the first habitat enhancement occurred in 2006, additional sections of the Batten Kill main stem have been treated annually in much the same manner as was done in the study area. As of September 2010, nearly two miles of the lower river, or about 10% of the river currently limited to catch-and-release trout fishing, has been treated to increase fish cover. The Batten Kill Watershed Alliance in partnership with state and federal resource agencies, other non-governmental organizations, and streambank landowners continue planning treatment of additional river sections.

Construction costs for cover enhancement are itemized in Table 2. Costs actually reflect materials and labor for not only the experimental project but additional habitat work done in 2007 outside the initial treatment section. Cost of materials not used in 2006 is estimated at $8,440, therefore total cost of constructing structures in the experimental section was $41,427 ($34,783/1,000 stream-ft or $183,654/mi). The single largest expense is transportation of materials from the source to the project location. Acquiring materials locally and using people experienced in instream construction practices should lower project cost substantially. State and federal agency costs associated with project design, construction and evaluation are not included.

TABLE 2. Itemized expenditures for phase 1 (2006) and phase 2 (2007) of the Twin Rivers Project (C. Browning, Batten Kill Watershed Alliance, personal communication). Length of river treated is 2,300 feet.

| Item | Cost |
|---|---:|
| Large wood, tree purchase, harvesting and transportation | $33,843.35 |
| Transportation of donated stone | 1,445.00 |
| Structure installation (heavy equipment and labor) | 11,947.50 |
| Grass seed and hay mulcher/spreader | 460.00 |
| Administration (labor, permit fees, etc.) | 2,171.15 |
| Total | $49,867.00 |

All interest groups involved to date in restoring the Batten Kill trout fishery recognize habitat enhancements through construction of cover structures is a short term jump start to the goal of recovering wild populations. Structures have a limited life span as over time LW is lost to high water events, siltation and general decomposition and require periodic maintenance to sustain targeted fish population levels in the absence of adequate natural wood recruitment from riparian areas (Thorn and Anderson 2001). Therefore, the future of the wild trout fishery is dependent upon restoring natural habitat forming and maintenance processes in and adjacent to the river and its tributaries. If LW was historically as vital to the fluvial dynamics of this system as extensive studies done elsewhere would indicate, then increasing attention must be directed to working with riparian landowners to re-establish degraded or lost woodlands and protecting intact parcels abutting the river to the greatest extent possible. This will demand extensive public outreach to change current thinking of how riparian lands should be used and managed.

Natural resource agencies now largely acknowledge the critical role LW and riparian woodlands have in creating suitable habitat conditions required by wild trout populations and other aquatic biota. However, riparian landowners, land use planners and developers, and other state and local authorities for the most part lag behind in this understanding and continue practices that are detrimental to the stream environment, habitat and wild populations. Naiman and Latterell (2005) discuss "eight simple ecological and social principles…that could enhance the understanding of what constitutes fish "habitat" and, if implemented, could contribute to improved management and conservation strategies" affecting aquatic and riparian habitat. These are (presented here verbatim from their publication):

1. Habitat can be created by keystone species and interactions among species.
2. The productivity of aquatic and riparian habitat is interlinked by reciprocal exchanges of material.
3. The riparian zone is fish habitat.
4. Fishless headwater streams are inseparable from fish-bearing rivers downstream.
5. Habitat can be coupled in rivers, lakes, estuaries, and oceans, and in time.
6. Habitats change over hours to centuries.
7. Fish production is dynamic due to biocomplexity – in species and in habitats.
8. Management and conservation strategies must evolve rapidly in response to present conditions, but especially the anticipated future.

In these principles is perhaps the greatest challenge facing aquatic resource managers and other interest groups with a stake in having the Batten Kill and its fishery restored: how to effectively disseminate these concepts such that longstanding human perceptions and behaviors are changed.

**Acknowledgements**

This project could not have been done without the participation and support of the following: Batten Kill Watershed Alliance, Bennington County Conservation District, National Fish and Wildlife Foundation, Natural Resource Conservation Service, The Orvis Company, Trout Unlimited, and my VFWD and GMNF colleagues. I would be remiss not to give special thanks to all the private landowners who permitted access to the river via their lands and installation of habitat enhancement structures affecting their streambanks. The report benefitted greatly from comments received from Rich Kirn, Shawn Good and Steve Roy. VFWD involvement was made possible by fishing license sales and matching Dingell-Johnson/Wallopp-Breaux funds available through the Federal Sport Fish Restoration Act. Any reference to trade names does not imply endorsement by the VFWD.

**References**

Albers, J. 2000. Hands on the land: a history of the Vermont landscape. The MIT Press, Cambridge, Massachusetts.

Ayllón, D., A. Almodóvar, G. G. Nicola, and B. Elvira. 2009. Modelling brown trout spatial requirements through physical habitat simulations. River Research and Applications. Available: www.ucm.es/info/zoo/Vertebrados/elvira/Ayllonetal2010b.pdf. (December 2009).

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Transactions of the American Fisheries Society 113:1-32.

Binns, N. A. 1982. Habitat quality index procedures manual. Wyoming Game and Fish Department, Cheyenne.

Bjornn, T. C. 1971. Trout and salmon movements in two Idaho streams as related to temperature, food, streamflow, cover, and population density. Transactions of the American Fisheries Society 100:423-438.

Bjornn, T. C., and D. W. Reiser. 1991. Habitat requirements of salmonids in streams. Pages 83-138 in W. R. Meehan, editor. Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society, Special Publication 19, Bethesda. Maryland.

Boussu, M. F. 1954. Relationship between trout populations and cover in a small stream. Journal of Wildlife Management 18:232-239.

Bunnell, D. B., Jr., Isley, J. J., K. H. Burrell, and D. H. Van Lear. 1998. Diel movement of brown trout in a southern Appalachian river. Transaction of the American Fisheries Society 127:630-636.

Carle, F. L., and M. R. Strub. 1978. A new method for estimating population size from removal data. Biometrics 34:621-630.

Chisholm, I A., W. A. Hubert, and T. A. Wesche. 1985. Winter stream conditions and brook trout habitat use on the Snowy Range, Wyoming. Wyoming Research Center Final Report 15, Laramie.

Clapp, D. F., R. D. Clark, Jr., and J. S. Diana. 1990. Range, activity, and habitat of large, free-ranging brown trout in a Michigan stream. Transaction of the American Fisheries Society 119:1022-1034.

Cox, K. M. 2001. Procedures for evaluating trout cover in streams. Vermont Fish and Wildlife Department, Springfield.

Cox, K. M. 2006. Batten Kill trout management plan, 2007-2012. Vermont Fish and Wildlife Department, Waterbury.

Cox, K. M. 2009. Assessment of trout cover and its relationship to trout abundance in the Batten Kill main stem and four rivers in reference watersheds. Vermont Fish and Wildlife Department, Springfield.

Cox, K. M. In preparation. Assessment of the Batten Kill main stem in regard to brown trout *Salmo trutta* and brook trout *Salvelinus fontinalis* temperature suitability. Vermont Fish and Wildlife Department, Springfield.

Dieterman, D. J., W. C. Thorn, C. S. Anderson, and J. L. Weiss. 2006. Summer habitat associations of large brown trout in southeast Minnesota streams. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 539, St. Paul.

Dolloff, C. A., Flebbe, P. A., and M. D. Owen. 1994. Fish habitat and fish populations in a southern Appalachian watershed before and after Hurricane Hugo. Transactions of the American Fisheries Society 123:668-678.

Elliott, J. M. 1994. Qunatitative ecology and the brown trout. Oxford University Press, Oxford, England.

Field, J. 2001. A geomorphological study of channel stability and physical habitat conditions of the Batten Kill in Vermont. Report of Green Mountain College to U. S. Forest Service, Green Mountain National Forest, Rutland.

Hartzler, J. R. 1983. The effects of half-log covers on angler harvest and standing crop of brown trout in McMichaels Creek, Pennsylvania. North American Journal of Fisheries Management 3:228-238.

Hasegawa, K., and K. Maekawa. 2009. Role of visual barriers on mitigation of interspecific competition between native and nonnative salmonid species. Canadian Journal of Zoology 87:781-786.

Heggenes, J. 1988. Effect of experimentally increased intraspecific competition on sedentary adult brown trout (Salmo trutta) movement and stream habitat choice. Canadian Journal of Fisheries and Aquatic Sciences 45:1163-1172.

Hildebrand, R. H., A. D. Lemly, C. A. Dolloff, and K. L. Harpster. 1998. Design considerations for large woody debris placement in stream enhancement projects. North American Journal of Fisheries Management 18:161-167.

Hunt, R. L. 1971. Response of a brook trout population to habitat development in Lawrence Creek. Wisconsin Department of Natural Resources, Technical Bulletin 48, Madison.

Hunt, R. L. 1974. Annual production by brook trout in Lawrence Creek during eleven successive years. Wisconsin Department of Natural Resources, Technical Bulletin 82, Madison.

Jaquith, S., M. Kline, J. Field, and J. Henderson. 2004. Phase 1 geomorphic assessment of the batten Kill main-stem and major tributaries. Report of Vermont Department of Environmental Conservation, River Management Program to U. S. Forest Service, Green Mountain National Forest, Rutland.

Johnsson, J. I., A. Rydeborg, and L. F. Sundström. 2004. Predation risk and the territory value of cover: an experimental study. Behavioral Ecology and Sociobiology 56:388-392.

Klyza, C. M., and S. C. Trombulak. 1999. The story of Vermont: a natural and cultural history. University Press of New England, Hanover, New Hampshire.

Kocik, J. F., and W. W. Taylor. 1996. Effect of juvenile steelhead on juvenile brown trout habitat use in a low-gradient Great lakes tributary. Transactions of the American Fisheries Society 125:244-252.

Lewis, S. L. 1969. Physical factors influencing fish populations in ponds of a trout stream. Transactions of the American Fisheries Society 98:14-19.

Logan, M. N. 2003. Brook trout (*Salvelinus fontinalis*) movement and habitat use in a headwater stream of the central Appalachian Mountains of West Virginia. Master's thesis. West Virginia University, Morgantown.

Mortensen, E. 1977. Density-dependent mortality of trout fry (*Salmo trutta*) and its relationship to the management of small streams. Journal of Fish Biology 11:613-617.

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

Naiman, R. J., and J. J. Latterell. 2005. Principles for linking fish habitat to fisheries management and conservation. Journal of Fish Biology 67 (Supplement B):166-185. Available: www.cnr.uidaho.edu/fish510/PDF/Dudley/Naiman%20%20Latterell_2005_fish%20habitat%20management.pdf . (November 2010).

Nislow, K. H. and F. J. Magilligan. 2005. Analysis of hydrologic regimes in the Batten Kill basin. Poster presentation delivered at Batten Kill Open House, October 27, 2005, Manchester, Vermont. (Available from Vermont Fish and Wildlife Department, Springfield, Vermont).

Omland, K. S., and D. L. Parrish. 2007. Population modeling for Batten Kill trout. Report of Vermont Cooperative Fish and Wildlife Research Unit to U. S. Forest Service, Green Mountain National Forest, Rutland, Vermont.

Raleigh, R. F. 1982. Habitat suitability index models: brook trout. U. S. Fish and Wildlife Service, FWS/OBS-82/10.24, Washington, D. C.

Raleigh, R. F., L. D. Zuckerman, and P. C. Nelson. 1986 (revised). Habitat suitability index models and instream flow suitability curves: brown trout. U. S. Fish and Wildlife Service, FWS/OBS-82/10.124, Washington, D. C.

Richards, C., and B. Hollingsworth. 2000. Managing riparian areas for fish. Pages 157-168 *in* E. L. Verry, J. W. Hornbeck and C. A. Dolloff, editors. Riparian management in forests of the continental eastern United States. Lewis Publishers, Boca Raton, Florida.

Richmond, A. D., and K. D. Fuasch. 1995. Characteristics and function of large woody debris in subalpine Rocky Mountain streams in northern Colorado. Canadian Journal of Fisheries and Aquatic Sciences 52:1789-1802.

Sundbaum, K. 2001. Importance of woody debris for stream dwelling brown trout (*Salmo trutta* L.). Ph.Licentiate thesis. Vattenbruksinstitutionen, Umeå, Sweden.

Thorn, W. C., and C. S. Anderson. 2001. Comparison of two methods of habitat rehabilitation for brown trout in a southeast Minnesota stream. Minnesota Department of Natural Resources, Section of Fisheries Investigational Report 488, St. Paul.

Thorn, W. C., C. S. Anderson, W. E. Lorenzen, D. L. Hendrickson, and J. W. Wagner. 1997. A review of trout management in southeast Minnesota streams. North American Journal of Fisheries Management 17:860-872.

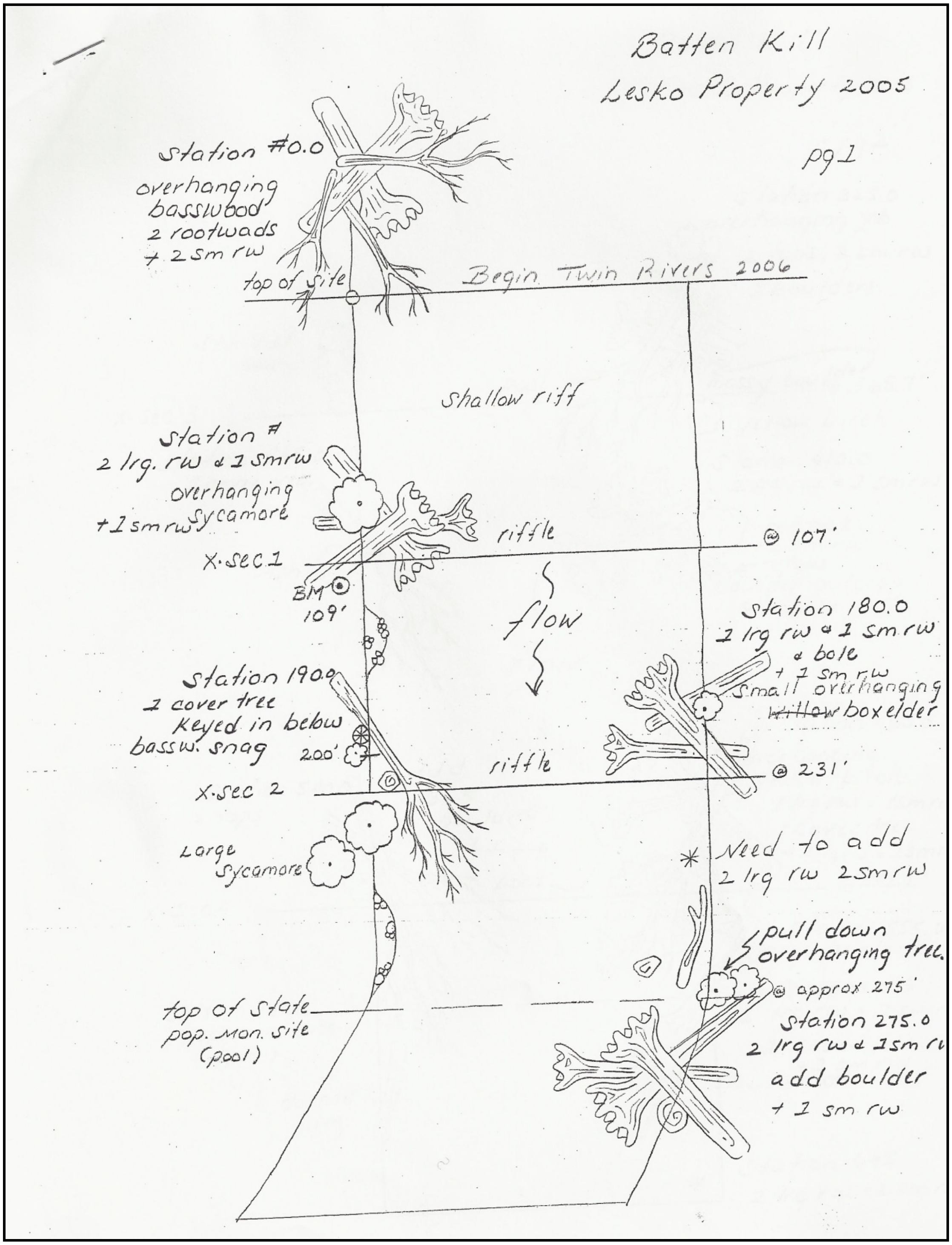
USFS (U. S. Forest Service). 1998. Stream inventory handbook: level I and level II. USFS, Pacific Nortwest Region (Region 6) Version 9.8, Portland, Oregon.

VDEC (Vermont Department of Environmental Conservation). 2003. A comparative assessment of the water quality and macroinvertebrate assemblage characteristics of the Batten Kill with several other wild trout streams in Vermont. Report of VDEC to U. S. Forest Service, Green Mountain National Forest, Rutland.

Verry, E. S., and C. A. Dolloff. 2000. The challenge of managing for healthy riparian areas. Pages 1-22 *in* E. L. Verry, J. W. Hornbeck and C. A. Dolloff, editors. Riparian management in forests of the continental eastern United States. Lewis Publishers, Boca Raton, Florida.

Whiteway, S. L., P. M. Biron, A. Zimmermann, O. Venter, and J. W. A. Grant. 2010. Do in-stream restoration structures enhance salmonid abundance? A meta-analysis. Canadian Journal of Fisheries and Aquatic Sciences 67:831-841.

Zorn, T. G., and A. J. Nuhfer. 2007. Influences of brown trout and brook trout population dynamics in a Michigan stream. Transactions of the American Fisheries Society 136:691-705.




APPENDIX, FIGURE 1. Schematic plan (not drawn to scale) illustrating a typical layout of artificial cover structures installed in a section of the Twin Rivers Habitat Project study area. Habitat design developed by Scott Wixsom, USFS.

APPENDIX, TABLE 1. Trout per mile of brown and brook trout (combined) estimated in Twin Rivers Project study area and control sites prior to and after cover habitat enhancement. Pre- and post treatment years are 2005-2006 and 2007-2010, respectively.

| | | Pre-treatment years | | | Post-treatment years | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Inch class** | **2005** | **2006** | **Mean** | **2007** | **2008** | **2009** | **2010** | **Mean** |
| **TRHP Pool** | **≤ 4.9** | 345 | 329 | 337 | 971 | 642 | 924 | 658 | 799 |
| | **5.0-9.9** | 67 | 157 | 112 | 924 | 674 | 78 | 501 | 544 |
| | **10.0-14.9** | 16 | 78 | 47 | 110 | 63 | 47 | 125 | 86 |
| | **15.0-19.9** | 47 | 16 | 32 | 47 | 78 | 47 | 31 | 51 |
| | **≥20.0** | 31 | 0 | 16 | 31 | 16 | 16 | 0 | 16 |
| | **Total** | 504 | 580 | 544 | 2,083 | 1,473 | 1,112 | 1,315 | 1,496 |
| **TRHP Riffle** | **≤ 4.9** | 843 | 1,619 | 1,231 | 1,518 | 1,687 | 1,046 | 1,400 | 1,413 |
| | **5.0-9.9** | 135 | 169 | 152 | 371 | 219 | 118 | 523 | 308 |
| | **10.0-14.9** | 17 | 17 | 17 | 0 | 17 | 0 | 17 | 9 |
| | **15.0-19.9** | 0 | 0 | 0 | 0 | 0 | 17 | 17 | 9 |
| | **≥20.0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Total** | 995 | 1,805 | 1,400 | 1,889 | 1,923 | 1,181 | 1,957 | 1,739 |
| **West Mountain** | **≤ 4.9** | 1,048 | 1,233 | 1,141 | 548 | 1,290 | 1,104 | 1,378 | 1,080 |
| | **5.0-9.9** | 435 | 435 | 435 | 500 | 137 | 210 | 887 | 434 |
| | **10.0-14.9** | 32 | 40 | 36 | 81 | 56 | 32 | 97 | 67 |
| | **15.0-19.9** | 0 | 16 | 8 | 8 | 8 | 0 | 8 | 6 |
| | **≥20.0** | 8 | 8 | 8 | 16 | 8 | 8 | 8 | 10 |
| | **Total** | 1,523 | 1,732 | 1,628 | 1,153 | 1,434 | 1,354 | 2,378 | 1,597 |
| **Cemetery Run** | **≤ 4.9** | 784 | 432 | 608 | 540 | 259 | 432 | 770 | 500 |
| | **5.0-9.9** | 79 | 65 | 72 | 137 | 43 | 101 | 58 | 85 |
| | **10.0-14.9** | 22 | 14 | 18 | 22 | 7 | 22 | 7 | 15 |
| | **15.0-19.9** | 0 | 7 | 4 | 0 | 14 | 22 | 0 | 9 |
| | **≥20.0** | 0 | 7 | 4 | 7 | 7 | 7 | 0 | 5 |
| | **Total** | 885 | 525 | 705 | 706 | 330 | 584 | 835 | 614 |

APPENDIX, TABLE 2. Pounds per acre of brown and brook trout (combined) estimated in Twin Rivers Project study area and control sites prior to and after cover habitat enhancement. Pre- and post treatment years are 2005-2006 and 2007-2010, respectively.

| | | Pre-treatment years | | | Post-treatment years | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Location** | **Inch class** | **2005** | **2006** | **Mean** | **2007** | **2008** | **2009** | **2010** | **Mean** |
| **TRHP Pool** | **≤ 4.9** | 0.4 | 0.7 | 0.6 | 0.9 | 0.8 | 0.9 | 0.8 | 0.9 |
| | **5.0-9.9** | 1.1 | 3.1 | 2.1 | 14.0 | 12.0 | 1.5 | 9.1 | 9.2 |
| | **10.0-14.9** | 1.1 | 7.3 | 4.2 | 7.7 | 5.1 | 3.8 | 11.6 | 7.1 |
| | **15.0-19.9** | 13.8 | 5.2 | 9.5 | 9.6 | 16.9 | 13.1 | 7.7 | 11.8 |
| | **≥20.0** | 12.1 | 0 | 6.1 | 11.2 | 4.9 | 7.1 | 0 | 5.8 |
| | **Total** | 28.5 | 16.3 | 22.4 | 43.4 | 39.7 | 26.4 | 29.2 | 34.7 |
| **TRHP Riffle** | **≤ 4.9** | 0.9 | 3.1 | 2.0 | 1.3 | 2.1 | 1.2 | 1.6 | 1.6 |
| | **5.0-9.9** | 1.1 | 2.9 | 2.0 | 3.9 | 3.0 | 1.7 | 8.0 | 4.2 |
| | **10.0-14.9** | 1.5 | 1.0 | 1.3 | 0 | 1.1 | 0 | 0.9 | 0.5 |
| | **15.0-19.9** | 0 | 0 | 0 | 0 | 0 | 5.5 | 5.3 | 2.7 |
| | **≥20.0** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | **Total** | 3.5 | 7.0 | 5.3 | 5.2 | 6.2 | 8.4 | 15.8 | 8.9 |
| **West Mountain** | **≤ 4.9** | 1.4 | 1.9 | 1.7 | 0.8 | 1.8 | 2.1 | 1.8 | 1.6 |
| | **5.0-9.9** | 7.5 | 7.0 | 7.3 | 9.5 | 2.5 | 3.3 | 13.7 | 7.3 |
| | **10.0-14.9** | 2.4 | 2.4 | 2.4 | 4.7 | 4.2 | 2.4 | 6.4 | 4.4 |
| | **15.0-19.9** | 0 | 2.9 | 1.5 | 1.8 | 1.2 | 0 | 1.2 | 1.1 |
| | **≥20.0** | 2.3 | 1.9 | 2.1 | 4.0 | 2.7 | 2.4 | 2.3 | 2.9 |
| | **Total** | 13.6 | 16.1 | 14.9 | 20.8 | 12.4 | 10.2 | 25.4 | 17.2 |
| **Cemetery Run** | **≤ 4.9** | 1.0 | 0.6 | 0.8 | 0.8 | 0.3 | 0.7 | 0.8 | 0.7 |
| | **5.0-9.9** | 1.3 | 1.0 | 1.2 | 2.6 | 0.6 | 1.5 | 0.7 | 1.4 |
| | **10.0-14.9** | 1.6 | 1.5 | 1.6 | 1.2 | 0.2 | 1.3 | 0.3 | 0.8 |
| | **15.0-19.9** | 0 | 1.0 | 0.5 | 0 | 2.9 | 4.1 | 0 | 1.8 |
| | **≥20.0** | 0 | 2.1 | 1.1 | 1.7 | 1.8 | 2.2 | 0 | 1.4 |
| | **Total** | 3.9 | 6.2 | 5.1 | 6.3 | 5.8 | 9.8 | 1.8 | 5.9 |