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Hemlock Woolly Adelgid Control Project Annual Report 2012

New River Gorge National River, Gauley River National Recreation Area, and Bluestone National Scenic River

Natural Resource Report NPS/NERI/NRR—2014/818

ON THE COVER
A hemlock (*Tsuga canadensis*) forest along the Endless Wall hiking trail in New River Gorge National River.
Photograph by: Layne Strickler

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Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the protocols. This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

This report is available from New River Gorge National River website http://www.nps.gov/neri/naturescience/index.htm, Gauley River National Recreation Area website http://www.nps.gov/gari/naturescience/index.htm, Bluestone National Scenic River website http://www.nps.gov/blue/naturescience/index.htm, and the Natural Resource Publications Management website (http://www.nature.nps.gov/publications/nrpm/). To receive this report in a format optimized for screen readers, please email irma@nps.gov.

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Abstract

Eastern hemlock (*Tsuga canadensis*) forests are valued for their ecological attributes, aesthetic worth, and recreational uses. Since the 1950s, these long-lived trees have been under attack in the eastern United States from an exotic invasive insect, the hemlock woolly adelgid (HWA). At New River Gorge National River (NERI), Gauley River National Recreation Area (GARI), and Bluestone National Scenic River (BLUE), HWA started infesting stands of hemlocks in 2002, 2007, and 2000 respectively. With a foresight for the inevitable infestation of HWA, 36 long term monitoring plots were set up across 3 soil moisture gradients (hydric, mesic, xeric) in 1998 before HWA was present in any of the parks. The xeric plots seem to be the most affected by HWA with the highest mortality and least healthy crown vigor. Mesic and hydric plots both show overall negative crown vigor and positive mortality trends. Other supportive evidence for the devastation of HWA on hemlock comes from treatment monitoring in three different areas. The amount of HWA found on an untreated hemlock is inversely proportionate to the crown vigor rating; as the rating increases, or becomes less vigorous, the density of HWA increases. Treated trees do not show the same trend as untreated trees and there is a statistical difference (α=0.05) at two locations. This suggests that the efficacy of the pesticide treatments is high, which increases or stabilizes the health of hemlocks in highly infested areas. Throughout the three parks, a total of 12,094 trees have been treated with pesticides. Because pesticide treatment is only a temporary solution, three species of HWA predatory beetles have also been released: *Laricobius nigrinus*, *Sasajiscymnus tsugae*, and *Sycmnus sinuanodulus*. Ecologists are hopeful that predatory beetles will suppress HWA populations to levels where the majestic hemlock forest is preserved into the future.

Introduction

The hemlock woolly adelgid (HWA) (*Adelges tsugae* Annand) is an aphid-like insect that is native to Japan but has become an invasive pest to the eastern United States (McClure et al. 2001). First observed in Richmond, Virginia in 1951, HWA has attacked eastern hemlocks (*Tsuga canadensis* (L.) Carrière) and Carolina hemlock (*Tsuga caroliniana* Engelm.) ranging from Maine to Georgia (Wood 1999, USDA Forest Service 2012). By feeding at the base of hemlock needles, HWA depletes nutrition from the xylem cells, which leads to desiccation and the inability for the hemlock to produce new apical buds (McClure et al. 2001). Mortality for *T. canadensis* can occur as soon as four years after infestation.

The identifying characteristic of HWA is the presence of cottonball-like ovisacs that are produced. The white fluffy masses are made to protect HWA from predators and keep the eggs from drying out. Ovisacs are present during the late fall to early summer and are easily seen on the underside of a hemlock twig.

HWA is spread and introduced to new areas via wind, birds, deer, and humans (McClure et al. 2001). The first observation within park boundaries occurred along the Bluestone National Scenic River (BLUE) in April 2000 and in the New River Gorge National River (NERI) in March 2002 (Perez 2006). The spread then continued throughout and up to the Gauley River National Recreation Area (GARI).

HWA is also found in the Pacific Northwest, but not in overwhelming, harmful numbers like in the eastern United States. Havill and Montgomery (2008) analyzed DNA from HWA found in the eastern US, Pacific Northwest, Japan, and China. Results suggest that the HWA in the eastern US is a match to populations in southern Japan. However, the Pacific Northwest samples did not match the eastern US or Asian samples. This suggests that HWA found in the Pacific Northwest is a separate endemic lineage that has been diverging for thousands to millions of years.

Hemlocks are vital components of important ecological niches including moist coves, stream corridors, and mixed conifer/deciduous forests (Wood 1999). Because hemlocks have long life spans and are late successional climax trees, they grow to be dominant in stands (McClure et al. 2001). Economically, hemlock timber is undesirable for the lumber industry. Because some stands of hemlocks were not logged and usually grow in rocky terrain, they serve as some of the least disturbed habitats in NERI, GARI, and BLUE (Wood 1999). Stands of hemlock provide habitat for a variety of plants, birds, mammals, amphibians, and fish. The elimination of hemlocks can negatively affect associated species including bryophytes, lilies, orchids, trout and warblers (Wood 1999). Abiotic factors associated with an increase in hemlock mortality are increases in understory light, stream temperatures, soil nitrate/nitrogen availability, deciduous leaf litter, and understory vegetation. These factors can then cause an abundance of secondary successional tree and understory species, stream algae, and exotic invasive plants (Orwig and Foster 1998).

Within the boundary of GARI, hemlock forest community types cover 5,750 acres or about 51% of the total acres (11,507 acres) of GARI (Vanderhorst et al. 2010). Along the Bluestone River, hemlock forest communities comprise 286 acres, 6.6% of the total land of 4,336 acres.

(Vanderhorst et al. 2008). NERI consists of 72,189 acres, 3,310 acres (4.6%) of which are hemlock forest communities (Vanderhorst et al. 2007). Many hemlock areas serve many different recreational activities including fishing, hiking, bird watching, and picnicking.

Different control strategies are in place in order to minimize the impact of HWA. Chemicals and biological predators are used to control HWA. Monitoring the health and progress of hemlock ecosystems is necessary to understand the impact from HWA and the efficacies of treatments and control strategies.

Hemlock Woolly Adelgid Suppression

Pesticide Treatments

Chemical suppression for HWA has occurred for seven years, 2006 through 2012 (Table 1). A total of twelve areas in NERI, BLUE, and GARI have been treated and include: Grandview, Fern Creek, Kate's Branch, Long Point, Glade Creek, Laing Woods, Kaymoor Top, Bluestone, Bridge buttress, Junkyard, Butcher's Branch, and Woods Ferry. Treatments consist of the systemic insecticide imidacloprid being applied to the soil or trunk of the tree. There are two types of soil application: liquid and tablet. The liquid solultion is made by mixing water with a powder containing 75% active ingredient imidacloprid (Mallet 75WSP®). A Kioritz hand soil injector is used to apply the insecticide into the soil near the major roots of the tree. The tablet insertion is an easy and quick application method. Two to three tablets per inch diameter continaing 20% imidacloprid (CoreTect®) are inserted into the soil evenly around the tree. Stem injection using the Arborjet Tree I.V.® system is useful around areas with water so that imidaclprid does not leach into water systems and harm aquatic invertebrates. Small holes are drilled around the base of the tree, into which the chemical is then injected.

Over the years, some trees were re-treated after three years in order to keep the tree from becoming re-infested. However, Cowles and Lagalante (2009) showed that imidacloprid concentrations were found in new growth foliage five to seven years after treatment. Imidacloprid was found to translocate to new growth for several years, allowing for continual suppression of HWA over several years. This suggests that re-treatments should occur every five, instead of three years.

Figure 1. An example of the new hemlock tagging system put into place in 2012. See table 1 for color descriptions.

March through July 2012, a total of 1,986 hemlocks were chemically treated to suppress HWA infestations in ten different areas (Table 2). A running tally of the number of hemlocks treated, DBH, and amount of imidacloprid used was kept track of each day treatments occurred (See Appendix C). 79% of the treatments were re-treatments of trees that were previously treated in 2006, 2007, or 2008. Re-treated trees are located in every area. Treatment areas covered 307 acres throughout the nine areas (See Appendix A).

A new tree marking system for treated trees was implemented in 2012. Vinyl tags with the year of treatment(s) and a number are attached to the south side of the trunk, usually above the old spray paint mark if the tree was a re-treatment. The tags come in three colors and correspond with the method of treatment: yellow is soil injection, orange is CoreTect®, and white is stem injection. See Figure 1 for an example of the tagging system. The previous method of marking treated trees was by spray painted shapes and is described in the 2009 Annual Report (DeMaio 2010).

Table 1. Summary of the number of hemlocks treated by soil injection, Coretect, or stem injection

	Soil injection	CoreTect	Stem injection	Total
2012	382	1604	0	1986
2011	90	266	0	356
2010	1304	183	40	1487
2009	3137	168	11	3316
2008	1150	154	10	1314
2007	2000		62	2062
2006	1500		33	1533
Total	9563	2375	156	12094

Table 2. Summary of HWA suppression activities from March through July 2012.

Location	Total trees	Number of retreats	Total DBH (in.)	Total Acres	Treatment method	Amount of chemical used
Grandview	366	360	3070.4	53.7	Soil injection	102.4 oz.
Fern Creek	616	615	8022	38	CoreTect	16085 tablets, 1421.7 oz.
Kate's Branch	646	404	7924	77	CoreTect	15732 tablets, 1936.8 oz.
Glade Creek	58	43	484	100	CoreTect	968 tablets, 85.5 oz.
Long Point	78	78	1107	13	CoreTect	2204 tablets, 194.8 oz.
Laing Woods	5	0	298	0.5	Soil injection	3.2 oz.
	102	1	1205	13.6	CoreTect	2220 tablets, 215.9 oz.
Kaymoor Top	64	24	764	1.9	CoreTect	1532 tablets, 135.4 oz.
Butcher's Branch	40	31	397	2.6	CoreTect	772 tablets, 68.2 oz.
Bluestone	11	11	78	6.7	Soil injection	3.2 oz.
Total	1986	1567	..	307	..	..

Biological Controls

Chemical control is only a temporary solution, but allows more time to establish and test more permanent resolutions. Several predatory beetles in the HWA native ranges of China, Japan, and the Pacific Northwest have been observed. Three species of beetles have been released in NERI and GARI: *Laricobius nigrinus*, *Sasajiscymnus tsugae*, and *Scymnus sinuanodulus*. The HWA Predator Release and Monitoring Database (Virginia Tech) tracks all the releases of non-native predators of HWA.

Laricobius nigrinus

A native to the Pacific Northwest United States and British Columbia, *L. nigrinus* (Figure 2) is a successful HWA predator (Reardon and Onken 2011). *L. nigrinus*' life cycle coincides with HWA; eggs are laid by adults in late spring, pupation occurs followed by aestival diapause for three to four months and maturation to adults proceeds in the fall (Zilahi-Balogh 2001). Adult *L. nigrinus* lay eggs in the ovisac of HWA and also feed on HWA nymphs and adults. Larvae *L. nigrinus* prey upon the HWA eggs and sometimes crawlers and nymphs (Zilahi-Balogh 2001).

L. nigrinus was first introduced in GARI in 2005 and NERI in 2006. A total of 3,340 *L. nigrinus* have been released in GARI and 24,910 released in NERI (See maps in Appendix B). In GARI, *L. nigrinus* has been released at Hedricks Creek and along the Meadow River. The distribution of *L. nigrinus* in NERI took place at or near Kate's Branch, Grandview, Wolf Creek, Kaymoor, Fayetteville cemetery, Fern Creek and Burnwood. Additional *L. nigrinus* will be released in 2013.

Figure 2. *Laricobius nigrinus* adults feeding on HWA. Photo credit: USFS

It is necessary to try to recover beetles in or near areas after they have been released in order to assess their establishment success. The most *L. nigrinus* recovered were 25 individuals at Burnwood in the spring of 2011 and 25 larvae in 2012. Other recoveries have been made at Hedricks Creek, Meadow River south of Carnifex Tunnel, upper Wolf Creek, Wolf Creek, and the Burnwood Ranger Station (See map in Appendix B).

Sasajiscymnus tsugae

The beetle *S. tsugae* (Figure 3) is a native to Japan and a natural predator of HWA in their native range. HWA and *S. tsugae* have similar life cycles, except during the HWA aestivation when adult *S. tsugae* survive on the dormant adelgids. Adult *S. tsugae* have a strong preference for feeding on all stages of HWA (Cheah and McClure) and are efficient in searching for HWA. *S. tsugae* is able to adapt to a wide range of climates and has a high fecundity, making it a well suited predator for release in the eastern United States. This species serves as a summer predator while *L. nigrinus* preys on HWA during the fall and winter.

Figure 3. *Sasajiscymnus tsugae* feeding on HWA eggs Photo credit:USFS

S. tsugae have only been released at two locations in NERI in May 2006. At lower Wolf Creek, 5,118 beetles were released and 5,000 were released at Burnwood. After several attempts, no recoveries of this species have been recorded in NERI.

Scymnus sinuanodulus

S. sinuanodulus (Figure 4) has a native range in China and has been introduced to the eastern United States in HWA infested areas. Larvae of *S. sinuanodulus* eat the HWA ovisacs (Hemlock Wooly Adelgid: Release and Evaluation of *Scymnus sinuanodulus*). HWA eggs are favored prey for *S. sinuanodulus*, but they are also known to eat other life stages of HWA too (McClure 2001).

In NERI, 500 *S. sinuanodulus* were released at upper Wolf Creek in May 2007. There has been no recovery of this species.

Figure 4. *Scymnus sinanodulus* adults. Photo credit: USFS

Hemlock Treatment Monitoring

In 2006 treatment monitoring protocols were implemented to follow the progress of hemlock trees treated for hemlock woolly adelgid and test the efficacy of the pesticide treatment. Data were collected from designated trees at Grandview, Fern Creek, and Bluestone. At each location, five treated trees and five untreated, control trees, were selected and monitored each year afterward. Trees were labeled with the first letter of the location, a 'C' indicating a control tree, and number (i.e. a control tree at Bluestone is BC1). Methods for monitoring these trees from 2007 and 2008 were described in the 2009 hemlock Woolly Adelgid Control Project (DeMaio 2010). In 2009, the methods were altered in order to obtain more usable data. Ten branches of a sample trees were haphazardly selected and the total number of shoots, new shoots, and dead shoots in the 30cm tip of the branch was recorded and summed together for a total representation of the tree. Up to ten evident woolly masses from the adelgid were counted on the section of branch. The totals of the woolly masses for each tree served as an infestation rating that range from 0-100. Other measurements of the sample trees included diameter at breast height (DBH), crown vigor (Table 3), and live crown ratio (LCR) which is the ratio of live crown length and actual tree length (Wood 1999). Refer to attached treatment monitoring data sheet in Appendix C.

Data analyses included averaging DBH, crown vigor, LCR, total shoots, new shoots, and dead shoots for control trees and treated trees in each location (Table 4). These averages were used to run two-tailed t-tests to find significant differences (α=0.05) between control and treated trees. A summary of the data from all three areas is presented in table 4.

Table **3.** Crown vigor index used for hemlock treatment monitoring and ecosystem monitoring. Percentages pertain to the amount of crown still present on the tree.

Crown Vigor Index	
1	>95% (healthy crown)
2	>75-95%
3	>50-75%
4	>25-50%
5	>0-25%
6	snag/dead

Grandview

Ten hemlock trees were monitored at Grandview from 2007-2012, five controls and five treated hemlock trees. In 2011, two of the trees were replaced with new monitoring trees. One of the control trees (GC5) was moved due to treated hemlocks being located too closely. These treated soil injected tress may have been affecting the non-treated control tree. Another tree (G1) was reassigned because it was located in a manicured setting, which differed from the forest habitats of the other monitoring trees.

There was a significant difference between the HWA infestation ratings of control and treatment trees at Grandview (Figure 5). The average infestation rating for control trees was 75.8 while for treated trees it was 4.0 (p=0.004, Table 4). The crown vigor of control trees averaged an index of 3 and treated trees 1.6, a significant difference (p=0.033, Figure 6). Live crown ratio and all shoot counts were not significantly different between the control and treatment trees.

Fern Creek

Five control and five treatment trees were monitored at Fern Creek. Similarly to Grandview, there was a significant difference of the HWA infestation rating between the control and treatment trees (Figure 5). The average infestation rate for control trees was 72.2 and the treated trees rating was 7.0 (p=0.022). Control trees had an average crown vigor of 4.4 and treatment trees average was 3.0, a highly significant difference in the health of the tree canopy (p=0.008, Figure 6). The difference in the number of new shoots of control trees was highly significantly lower than that of treated trees (p=0.00014). One response of a hemlock under stress is to stop producing apical buds (McClure et al. 2001). Total shoot counts and the number of dead shoots did not differ significantly.

Bluestone

Over the years, the sample size at Bluestone has decreased. In 2011, one of the control trees was excluded because there was a lack of branches that were within reach and no other untreated trees nearby that could serve as a replacement. Partial data was collected on two trees (one a control BC1 and the other a treated tree B1) in 2012 because branches were too high to sample. For these trees, DBH, crown vigor, and LCR were measured.

There were no significant differences in any of the variables measured for the control and treated trees (Table 4). Increasing the sample size would support a stronger data set. Having a reduced sample size of seven trees made it more difficult to determine significant differences between control and treated trees.

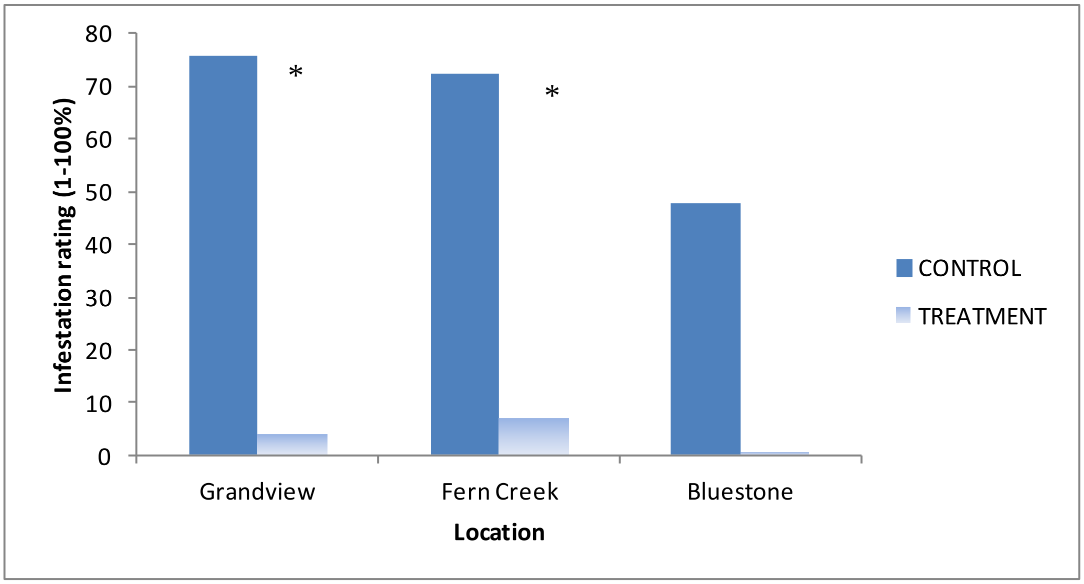

Figure 5. Average percentage of infestation per tree at Grandview, Fern Creek, and Bluestone study sites for treated and untreated hemlocks. Asterisks indicate significant differences (p<0.05) at Grandview and Fern Creek.

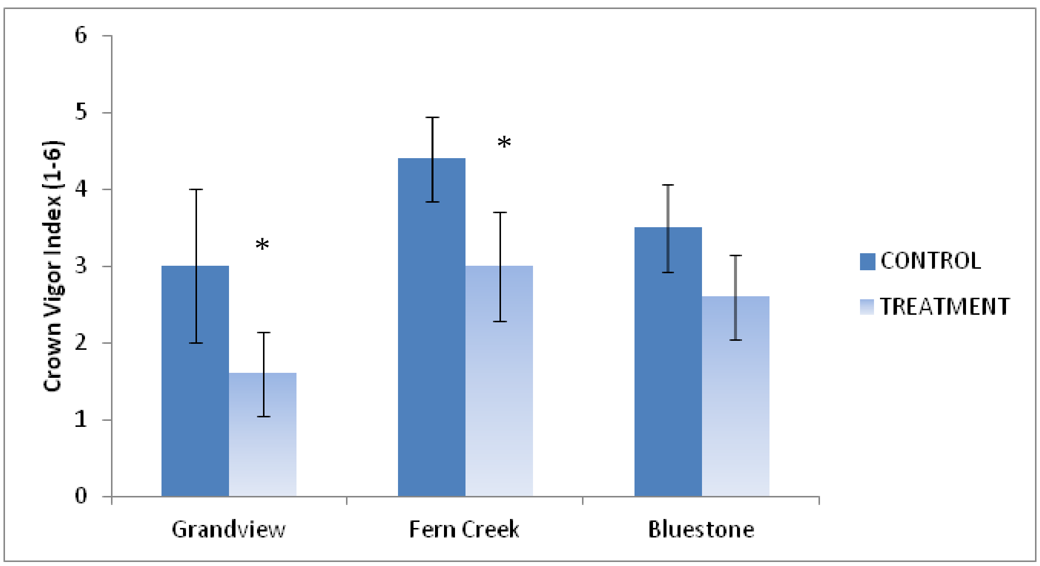

Figure 6. Average of crown vigor indices and standard deviations for Grandview, Fern Creek, and Bluestone study sites for treated and untreated trees. Asterisks indicate a significant difference (p<0.05) between treatment and control hemlocks per site. See Table 3 for explanation of crown vigor index.

Table 4. Averages of measured variables at each location for control and treated trees (HWA= infestation rating, LCR= live crown ratio, Vigor=crown vigor index).Two sample t-tests were conducted to obtain p-values ($p<0.05$). Significant differences are dictated in bold.

Location	Averages	Control	Treatment	PVALUE
Grandview	HWA	75.8	4	0.004
	LCR	89.6	89	0.89
	VIGOR	3	1.6	0.033
	TOTAL SHOOTS	303.2	272.4	0.42
	NEW SHOOTS	97.4	185.6	0.15
Fern Creek	HWA	72.2	7	0.022
	LCR	83	73	0.47
	VIGOR	4.4	3	0.008
	TOTAL SHOOTS	209.2	222	0.64
	NEW SHOOTS	39	119.4	0.00014
Bluestone	HWA	47.6	0.25	0.077
	LCR	85	81	0.72
	VIGOR	3.5	2.6	0.055
	TOTAL SHOOTS	307.7	278.5	0.49
	NEW SHOOTS	220	235.75	0.66

Hemlock Ecosystem Monitoring

New River Gorge has a unique set of data pertaining to hemlock health that extends back to 2000, before the first HWA infestation in NERI or GARI. Having pre-infestation data and post-infestation data allowed us to study the health trends of hemlocks after the introduction of HWA. Baseline data provides an understanding to the impact of HWA on hemlock mortality as well as associated plant communities (Wood 1999). Every year, except for 1999, 2005 and 2007, thirty-six permanent plots in NERI and GARI were monitored for DBH, crown vigor (Table 3), live crown ratio (0-100%), straightness, and HWA index (Table 5). Averages of crown vigor ratings of each tree were calculated for each location in all soil moisture gradients, then converted to their respective percentage to better illustrate the overall decrease in tree canopy health. For example, in 2009 the crown vigor index average for hydric plots in Carnifex Ferry was 2, representing 95% crown vigor. The same plots in 2010 had an average of 2.09, which equals 93.2%. See Appendix C for a datasheet example and Appendix D for a vigor conversion table. Over the past fourteen years, the variables that have proven to be most useful in reading the health of hemlock forests have been crown vigor and HWA index.

Table 5. Hemlock woolly adelgid index that represents the infestation abundance.

Rating	HWA Density
1	Heavily speckled and visible from 30m
2	Moderately speckled
3	Lightly speckled— only a few scattered specks
4	none

The thirty six plots were divided among different soil moisture classes in six different locations. Soil moisture classes included xeric, mesic, and hydric sites. There were six different locations in which the soil moisture classes are located: Fern Creek (FERN), Kate's Branch (KATES), Meadow River (MEADOW), Wolf Creek (WOLF), Carnifex Ferry (CARNIFEX), and Grandview (GRAND). Table 6 shows the soil moisture classes at each location.

Table 6. Location of 36 plots in NERI and GARI and the soil moisture classes at each location. (There are three plots per 'x').

	FERN	KATES	MEADOW	WOLF	CARNIFEX	GRAND
Xeric	x		x	x	x	
Mesic		x	x		x	x
Hydric	x		x	x	x	

Hemlocks greater than 8.0 cm diameter in each plot were monitored. In 2012, 532 hemlocks were measured. At every plot, HWA was present.

HWA infestation and other natural causes result in mortality and year to year fluctuations in the total number of trees measured. Monitoring protocols require that hemlocks snapped off below DBH or fallen to the ground, be removed from future tallies. This became an issue in 2012 because of two highly damaging storms. A storm with very high winds, El Derecho, came through West Virginia in June 2012 and a blizzard caused by Superstorm Sandy hit in October 2012. Both storms caused a large number of trees to be uprooted or damaged. Within the 36 plots, 22 of the 541monitored hemlocks were damaged by a portion of the canopy snapping off

(4.1%) and 32 trees out of 541 (5.9%) were uprooted, broken below DBH, or lost the entire canopy. These 32 hemlocks are also exempt from the data analysis, as not to skew the mortality from HWA results. Of the 32 trees uprooted and snapped, 24 of them will not be counted in following years according to protocol. Mortality throughout the 36 plots was broken down by soil moisture class and location (Figures 7,8).

In 1998, 36 trees were snags, but the recorded data did not separate how many snags were in each soil moisture class. An overall increase in mortality since 2000 can be seen among each soil moisture class, but more greatly in the xeric areas (Figure 8). To a lesser extent, a slight increase in mortality at each location can also be seen (Figure 9). There was an increase in the number of dead trees from 2011 to 2012 in every location except for Wolf Creek, where a tree was dropped because it uprooted. All dead trees are also omitted from vigor and HWA density data.

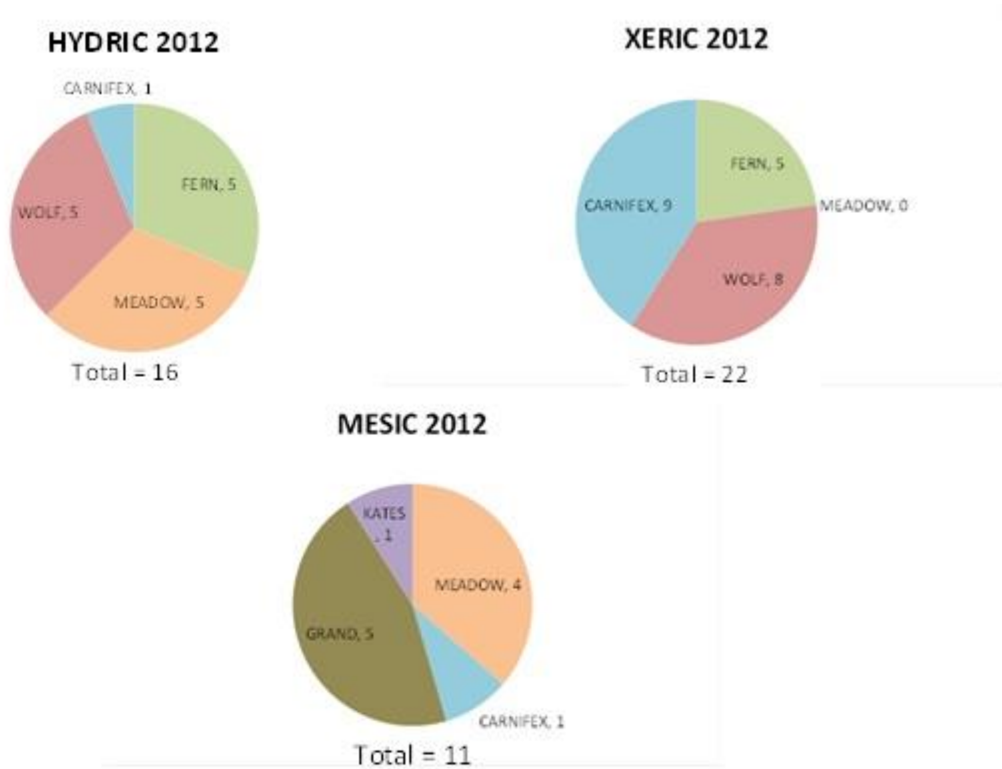

Figure 7. Hemlock mortality by soil moisture classes. The numbers of dead hemlocks are listed by location.

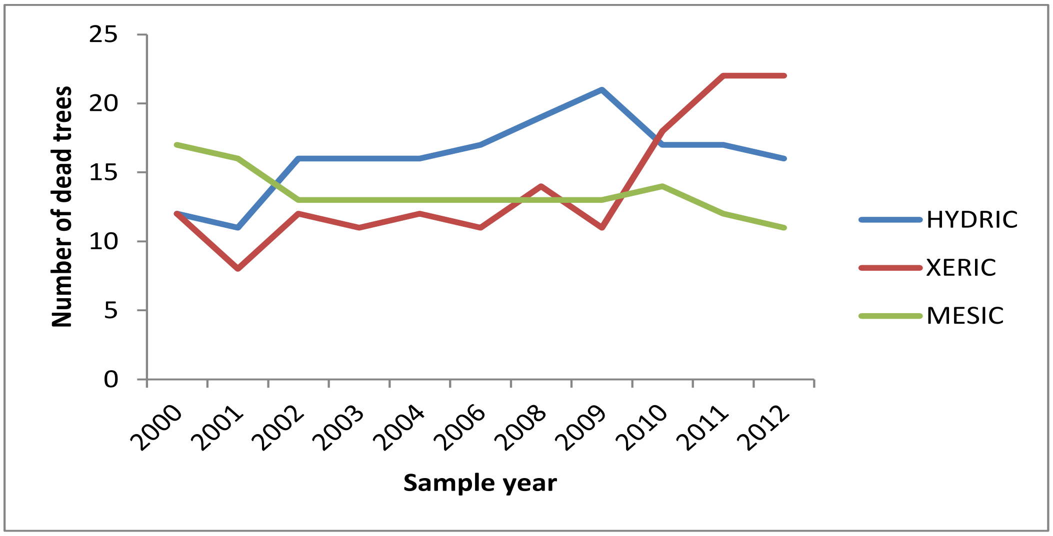

Figure 8. Mortality of *T. canadensis* from 2000 to 2012 of different soil moisture classes.

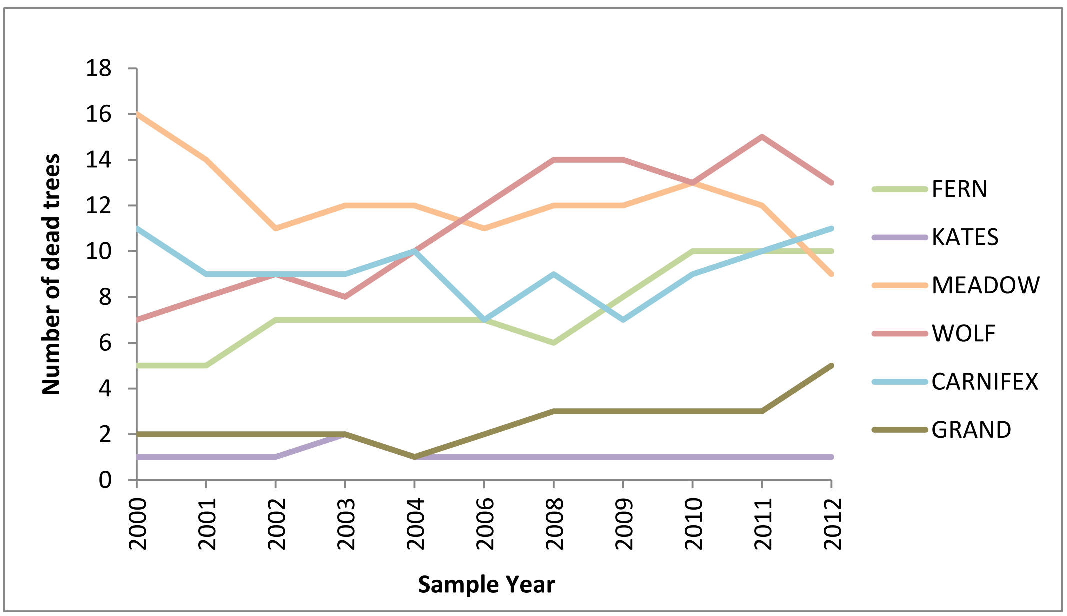

Figure 9. The number of dead *T. canadensis* in each study location from 2000-2012.

Xeric Sites

Twelve xeric plots are located at Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River (Table 6). Initial HWA observations at Wolf Creek and Fern Creek occurred in 2004, while Carnifex Ferry and Meadow River did not have HWA until 2006 (Figure 10). After the initial decrease in the HWA index, or increase in HWA density, each location continued to decline. The following were average HWA indices in 2012 for each location: Wolf Creek 2.03, Fern Creek 2.55, Carnifex Ferry 2.23, Meadow River 2.52. As of 2012, each location averages a 'moderately speckled' HWA density (Table 5).

Table 7. Averages per sample year of *T. canadensis* DBH, live crown ratio, crown vigor index, crown vigor percent and HWA index in all xeric sites.

	2000	2001	2002	2003	2004	2006	2008	2009	2010	2011	2012
DBH	23.8	23.7	24.4	24.5	24.6	25.1	25.4	25.4	25.6	26	26.2
LIVE CROWN RATIO	59.4	60.4	64.5	63.6	62.2	59.2	63.2	57.9	52	54.5	56.7
CROWN VIGOR INDEX	2.01	2.07	2.52	2.27	2.1	2.21	2.7	2.84	3	3.28	3.78
CROWN VIGOR %	94.8	93.6	84.6	89.6	93	90.8	81	78.2	75	68	55.5
HWA INDEX	4	4	4	4	3.82	3.24	2.93	3.01	2.31	2.31	2.33

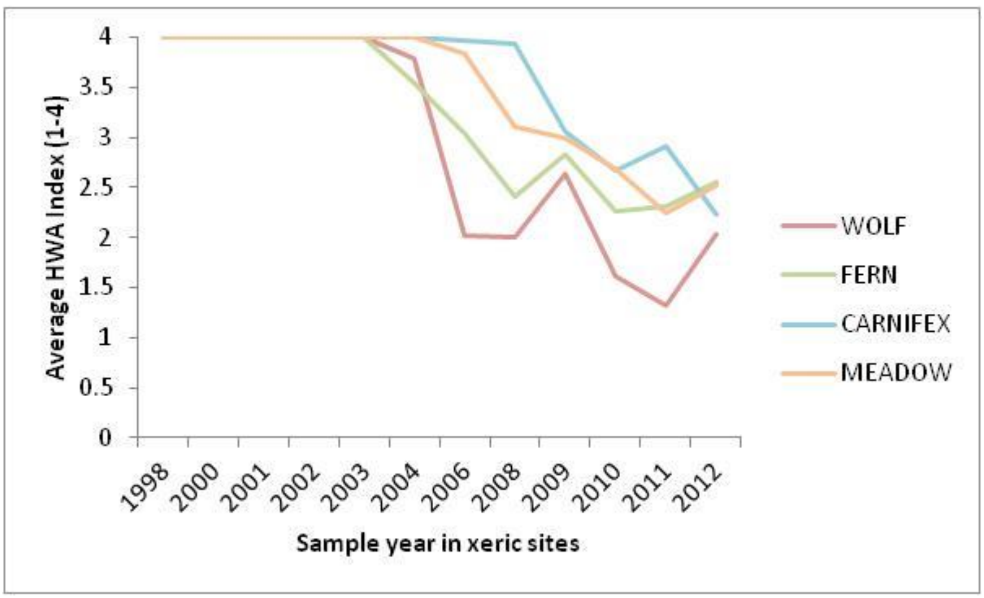

Figure 10. Average HWA indices for xeric plots located at Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River. See table 5 for the breakdown of the HWA index.

With an increase in HWA density throughout the years, percentage of live crown decreased (Table 7). Comparing the initial HWA observations and the average crown vigor per location suggests that crown vigor decreased within 1-2 years after HWA was observed (Figure 11). The average crown vigor percent for each location in 2012 follows: Wolf Creek 43.25%, Fern Creek 60.25%, Carnifex Ferry 40.75%, Meadow River 77%. The average crown vigor of all xeric sites in 2012 was 55.5 (Table 7). Carnifex Ferry has the least healthy crown vigor and the Meadow River has the healthiest crown vigor out of the xeric sites.

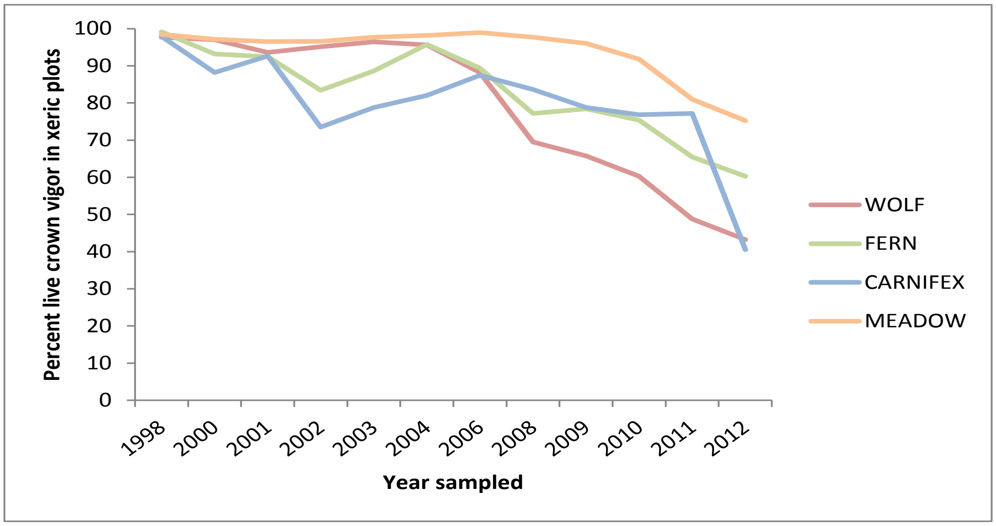

Figure 11. Average crown vigor percentages for Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River for all xeric sites.

Mesic Sites

Twelve mesic plots are located in Kate's Branch, Meadow River, Carnifex Ferry, and Grandview (Table 6). Initial observations of HWA in mesic plots occurred in 2006 at all locations except for Grandview where it was observed in 2004 (Figure 12). Subsequent years from the initial HWA observations produced lower average HWA indices, or higher HWA density (Table 8). Each location's average as of 2012 fell in the 'moderately speckled' category of the HWA index.

Table 8. Averages per sample year of *T. canadensis* DBH, live crown ratio, crown vigor index, crown vigor percent, and HWA index in all mesic sites.

	2000	2001	2002	2003	2004	2006	2008	2009	2010	2011	2012
DBH	22.5	22.9	23.3	23.3	23.5	23.8	24.8	25.5	25.4	25.8	24.8
LIVE CROWN RATIO	66.8	63.7	66.9	64.4	65.1	59.2	61.9	59.6	59.9	58.9	51.8
CROWN VIGOR INDEX	1.9	2.27	2.63	2.53	2.36	2.36	2.56	2.53	2.83	3.14	3.99
CROWN VIGOR %	95.5	89.6	82.4	84.4	87.8	87.8	83.6	84.4	78.4	71.5	50.25
HWA INDEX	4	4	4	4	3.9	3.74	3.41	3.55	2.76	2.57	2.64

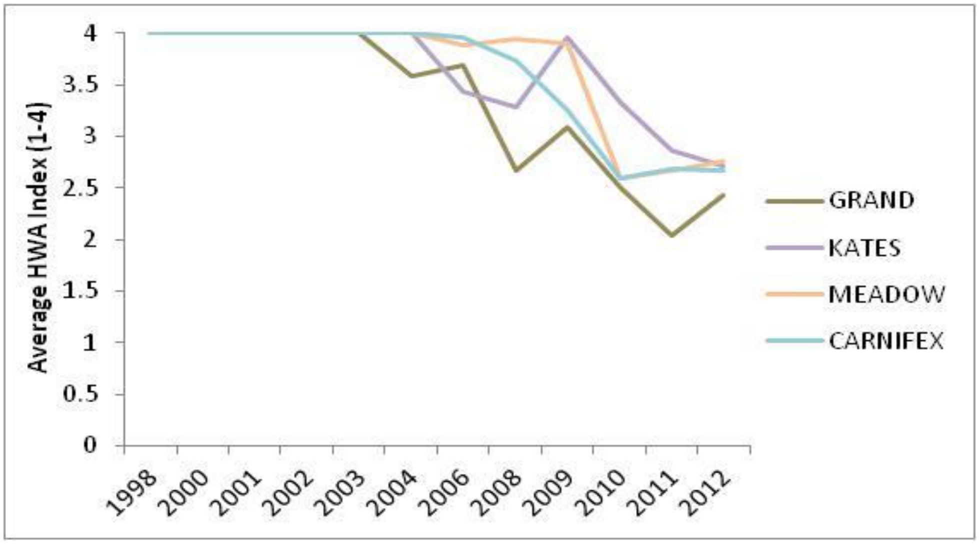

Figure 12. Average HWA indices for mesic plots at Grandview, Kate's Branch, Meadow River and Carnifex Ferry. See Table 5 for the breakdown of the HWA index.

The average crown vigor in 2012 for all mesic plots was 50.25% (Table 3). Overall for each location, the crown vigor percentage of healthy crown is decreasing (Figure 13). In 2012, crown vigor ranged from the healthiest 56.75% at Meadow River to least healthy 42.25% at Grandview (Figure 13).

Grandview plots were the first mesic sites to show HWA. The data support the concept that with longer infestation, HWA densities increase and crown vigor decreases (Figures 12,13).

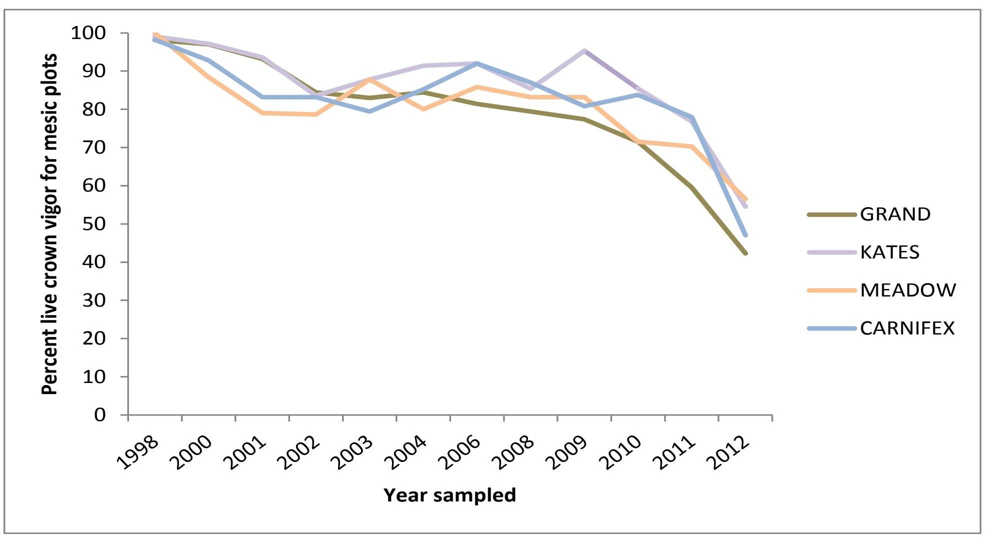

Figure 13. Average crown vigor percentages for Grandview, Kate's Branch, Carnifex Ferry, and Meadow River for all mesic sites.

Hydric Sites

The twelve hydric sites were at Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River (Table 6). The first hydric plot that HWA was observed at was Meadow River in 2004. Fern Creek and Wolf Creek had noticeable HWA in 2006, and Carnifex Ferry in 2008 (Figure 14). In 2012, the average HWA index for all hydric plots was 2.53, or moderately speckled HWA (table 5). Carnifex Ferry had the highest average HWA index in 2012, or lowest HWA density, of 2.90 and Wolf Creek had the lowest average of 2.05 (Figure 15).

Table 9. Averages per sample year of *T. canadensis* DBH, live crown ratio, crown vigor index, crown vigor percent and HWA index in all hydric sites.

	2000	2001	2002	2003	2004	2006	2008	2009	2010	2011	2012
DBH	27.1	27.9	28.1	28.1	28.1	26.2	28.4	28.9	29.7	29.1	28.6
LIVE CROWN RATIO	54.7	52.3	54.6	54.8	56.2	55.5	60.2	53.2	50.6	49.1	49.1
CROWN VIGOR INDEX	1.9	2.32	2.53	2.56	2.27	2.36	2.51	2.9	3	3.59	3.81
CROWN VIGOR %	95.5	88.6	84.4	83.8	89.6	87.8	84.8	77	75	60.25	54.75
HWA INDEX	4	4	4	4	3.96	3.8	3.12	3.33	2.39	2.7	2.53

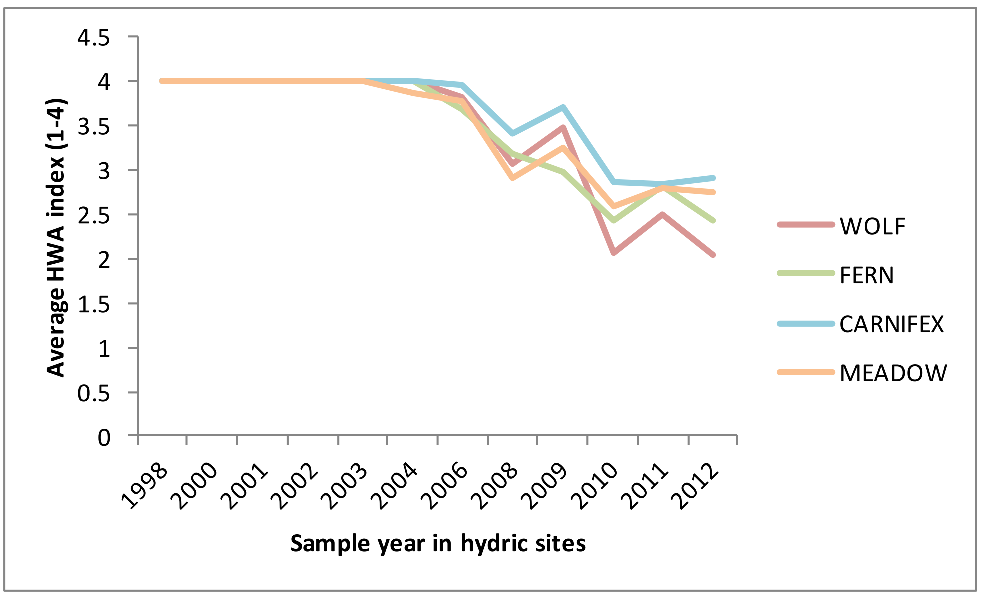

Figure 14. Average HWA indices for hydric plots located at Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River. See Table 5 for the breakdown of the HWA index.

The average crown vigor for all hydric plots in 2012 was 54.75%. Carnifex Ferry had the healthiest overall crown vigor of 70.75%, which was expected because it was the latest hydric plot to show HWA infestation and had the least HWA density (Figure 14, 15). The Meadow River had a crown vigor average of 46.25%, the least healthy, and was the first plot with observed HWA.

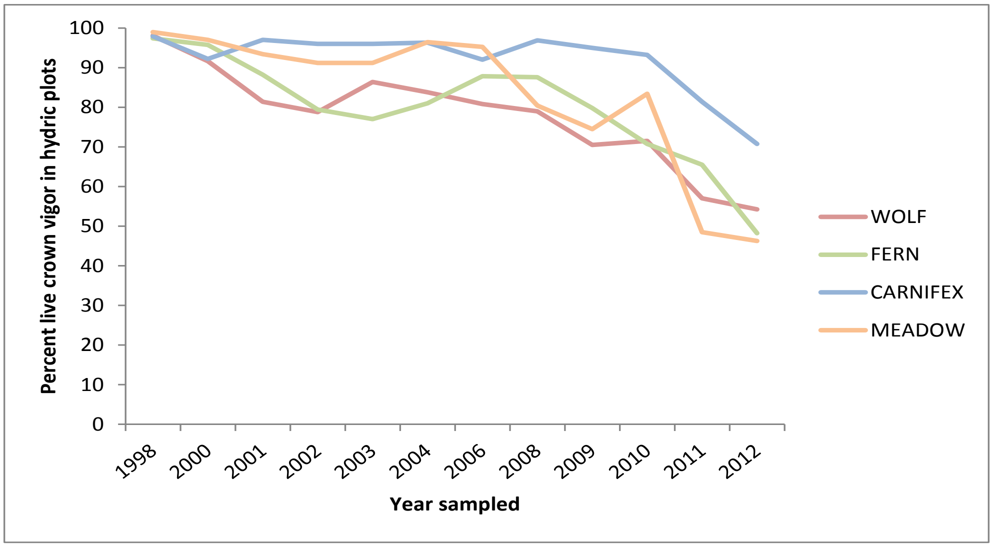

Figure 15. Average crown vigor percentages for Wolf Creek, Fern Creek, Carnifex Ferry, and Meadow River for all hydric sites.

Long Term Monitoring Sites and *L. nigrinus*

A xeric soil moisture class site in the Fern Creek locale (FX1) is next to *L. nigrinus* release sites. The plot FX1 is just west of the Burnwood release sites, where over 6,700 beetles have been released since 2006. It was observed in 2012 to have a healthier crown and less HWA density compared to other nearby xeric plots.

FX1 had healthier crown vigor and less HWA densities compared to other xeric sites (Figures 16 and 17). The average crown vigor at plot FX1 in 2012 was 73.5%. WX3 averaged the lowest crown vigor at 33.25%. Out of all the xeric plots compared, FX1 had the lowest densities of HWA, rating near the light density category. Other plots ranged in the moderate and heavy categories.

Beetle recoveries have been most successful at Burnwood. A total of 44 *L. nigrinus* have been recovered since 2011 (Appendix B). *L. nigrinus* will be monitored twice a year; once in early spring during the larval stage and again in October when adults are active.

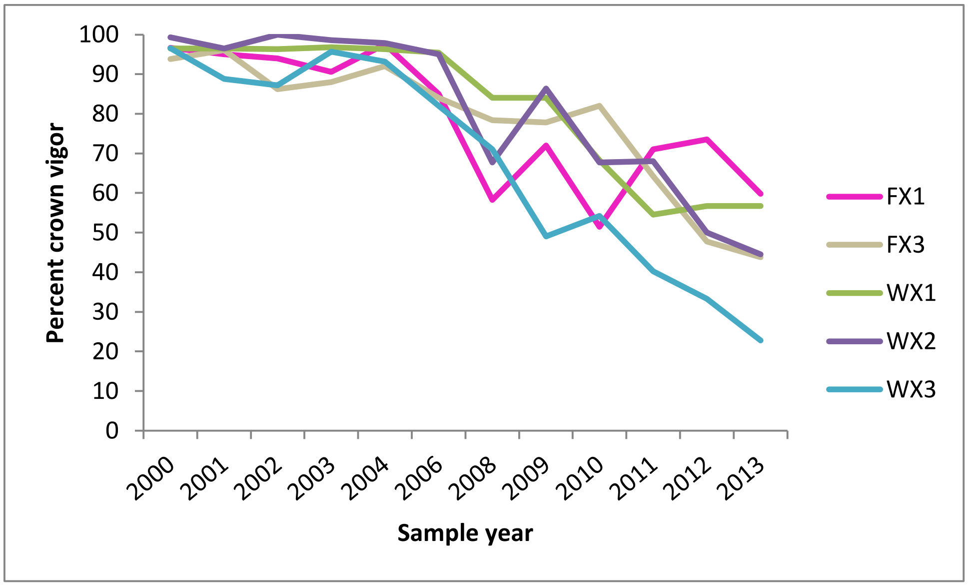

Figure 16. Average crown vigor percentages for xeric plots at Fern Creek (FX1, FX3) and Wolf Creek sites (WX1,WX2,WX3).

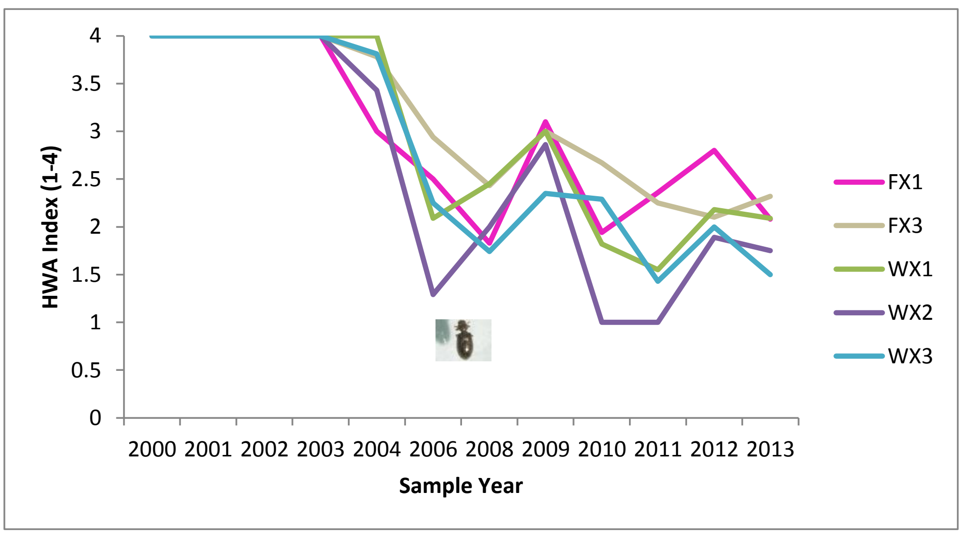

Figure 17. Average HWA index for plots at Fern Creek (FX1, FX3) and Wolf Creek sites (WX1,WX2,WX3).

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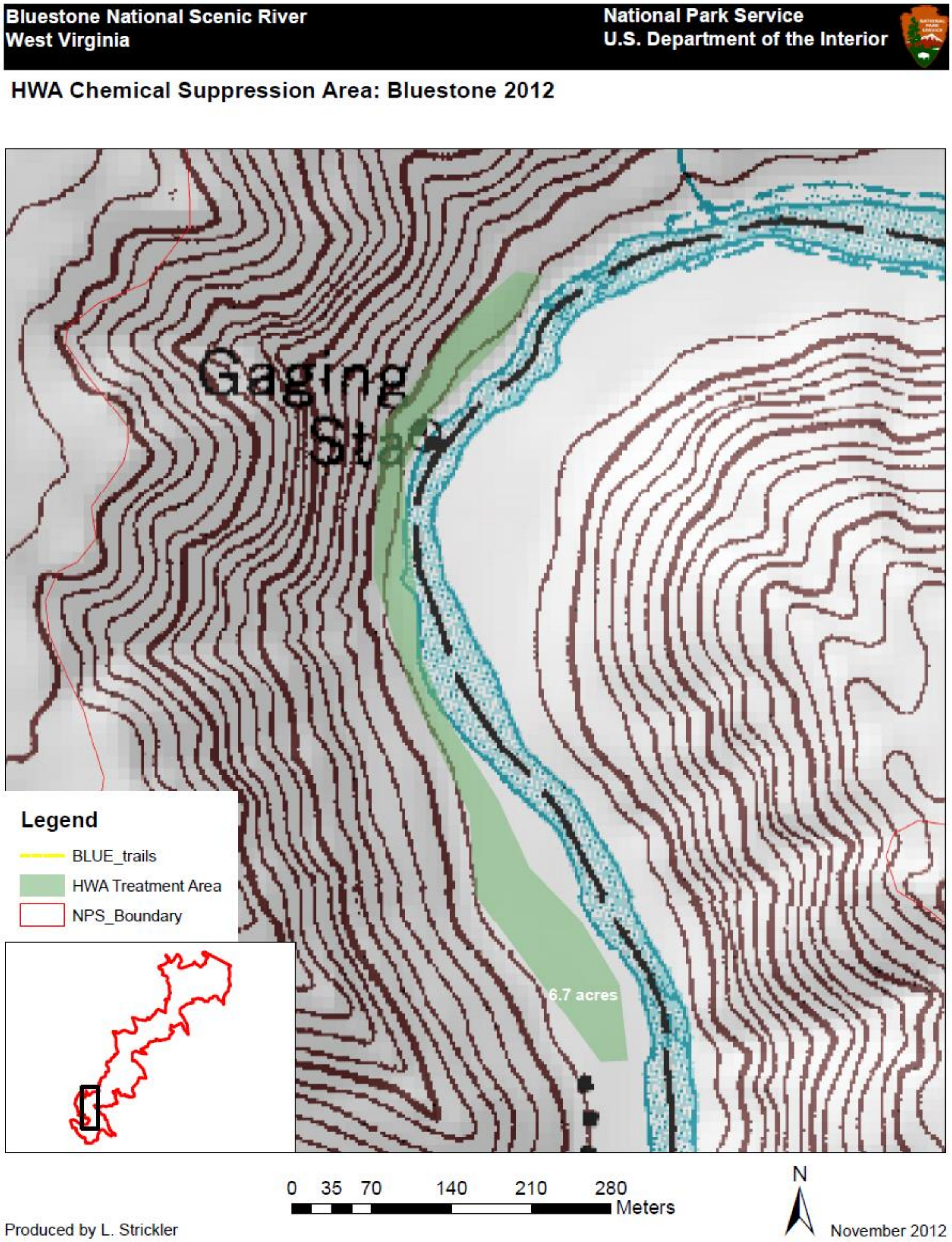
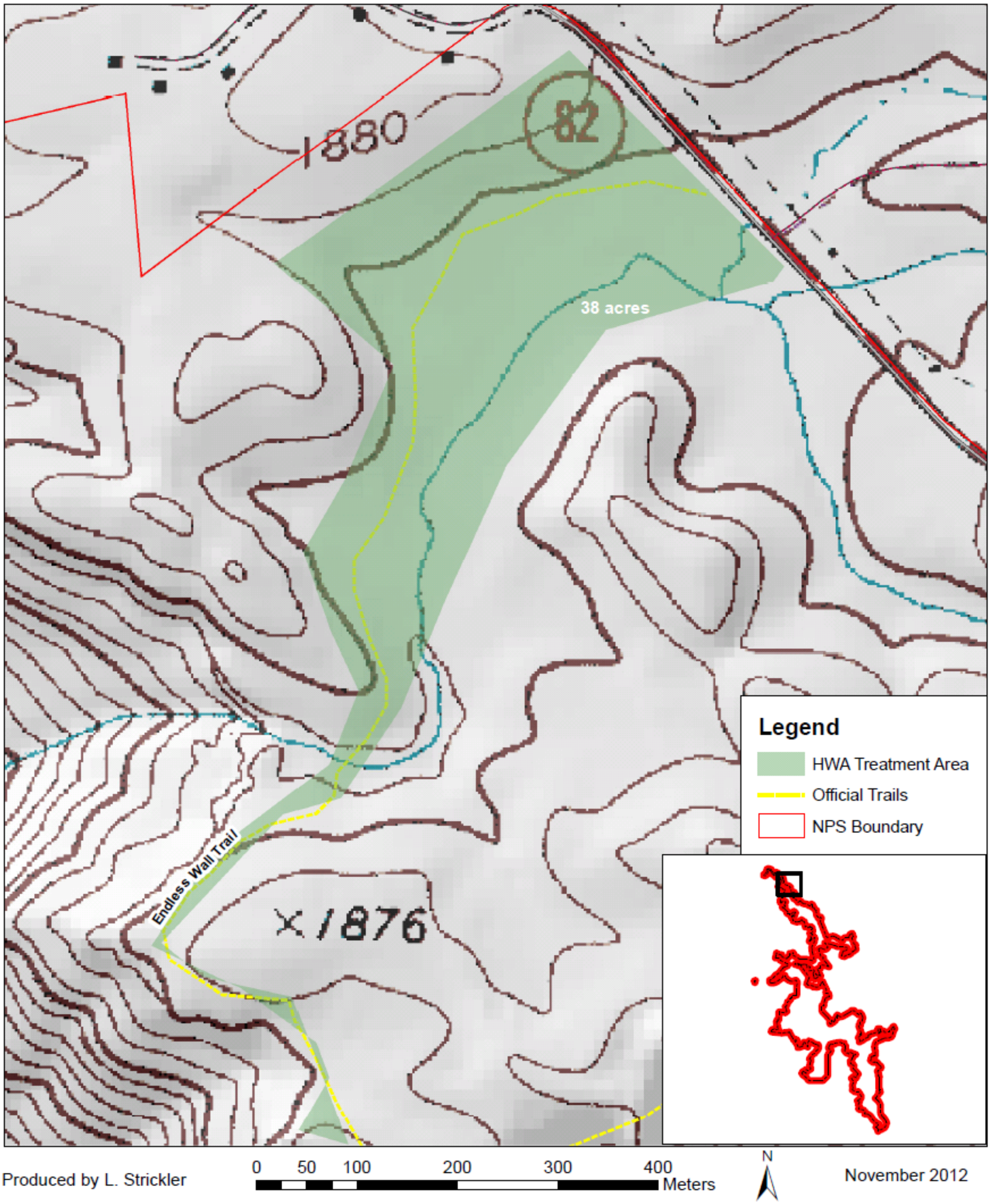
Appendix A: Chemical Suppression Areas



New River Gorge National River
West Virginia

National Park Service
U.S. Department of the Interior

HWA Chemical Suppression Area: Fern Creek 2012



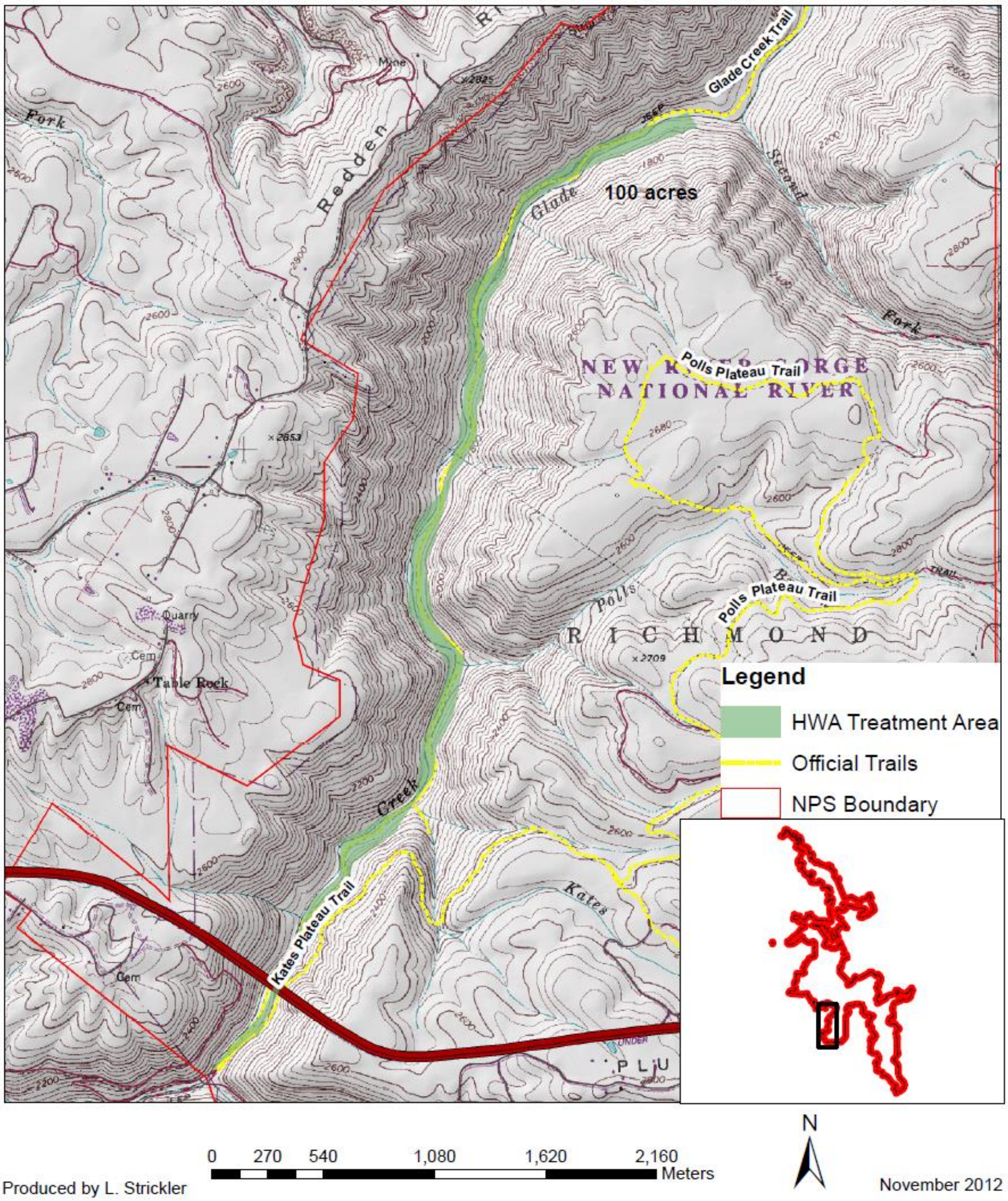
Produced by L. Strickler

November 2012

New River Gorge National River
West Virginia

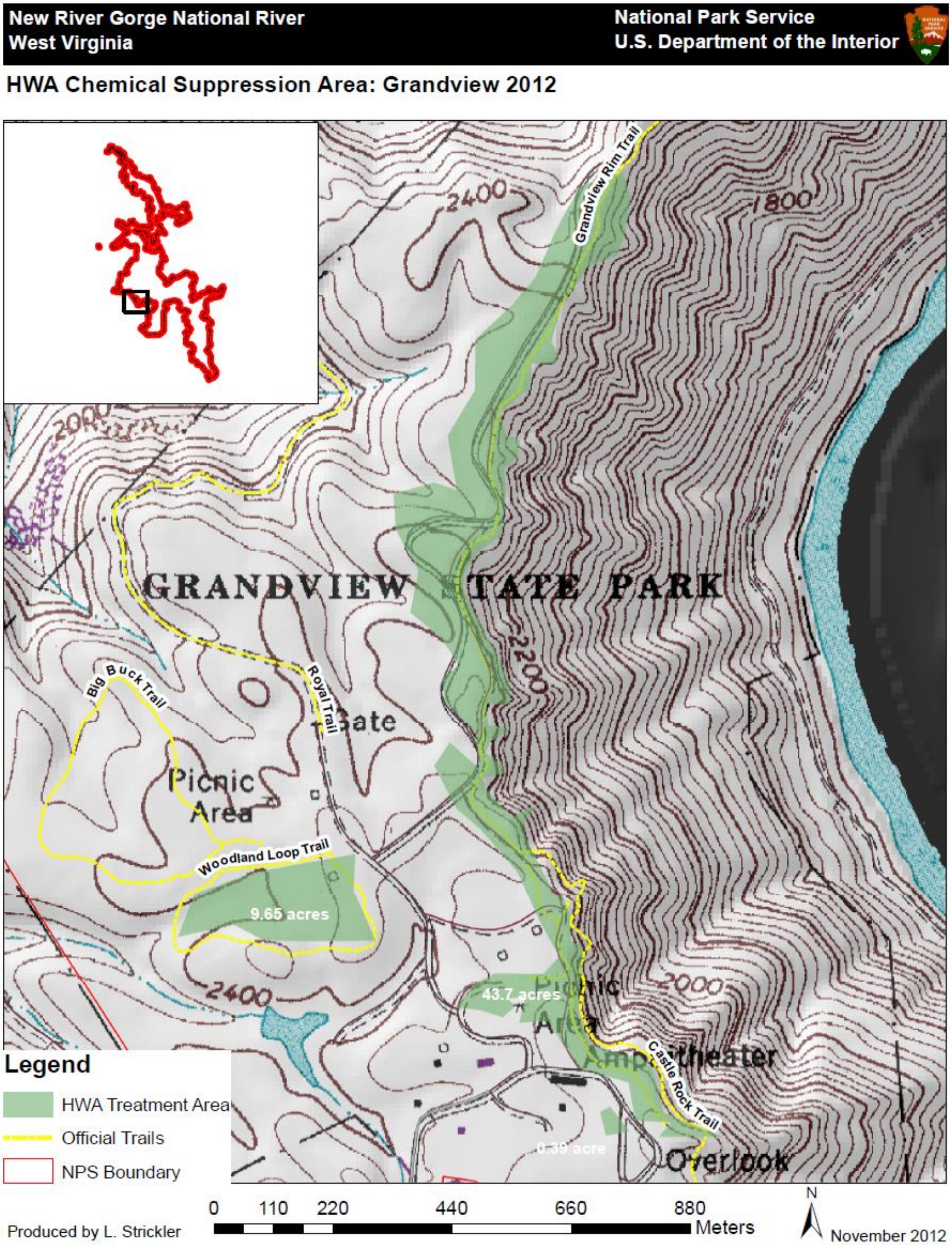
National Park Service
U.S. Department of the Interior

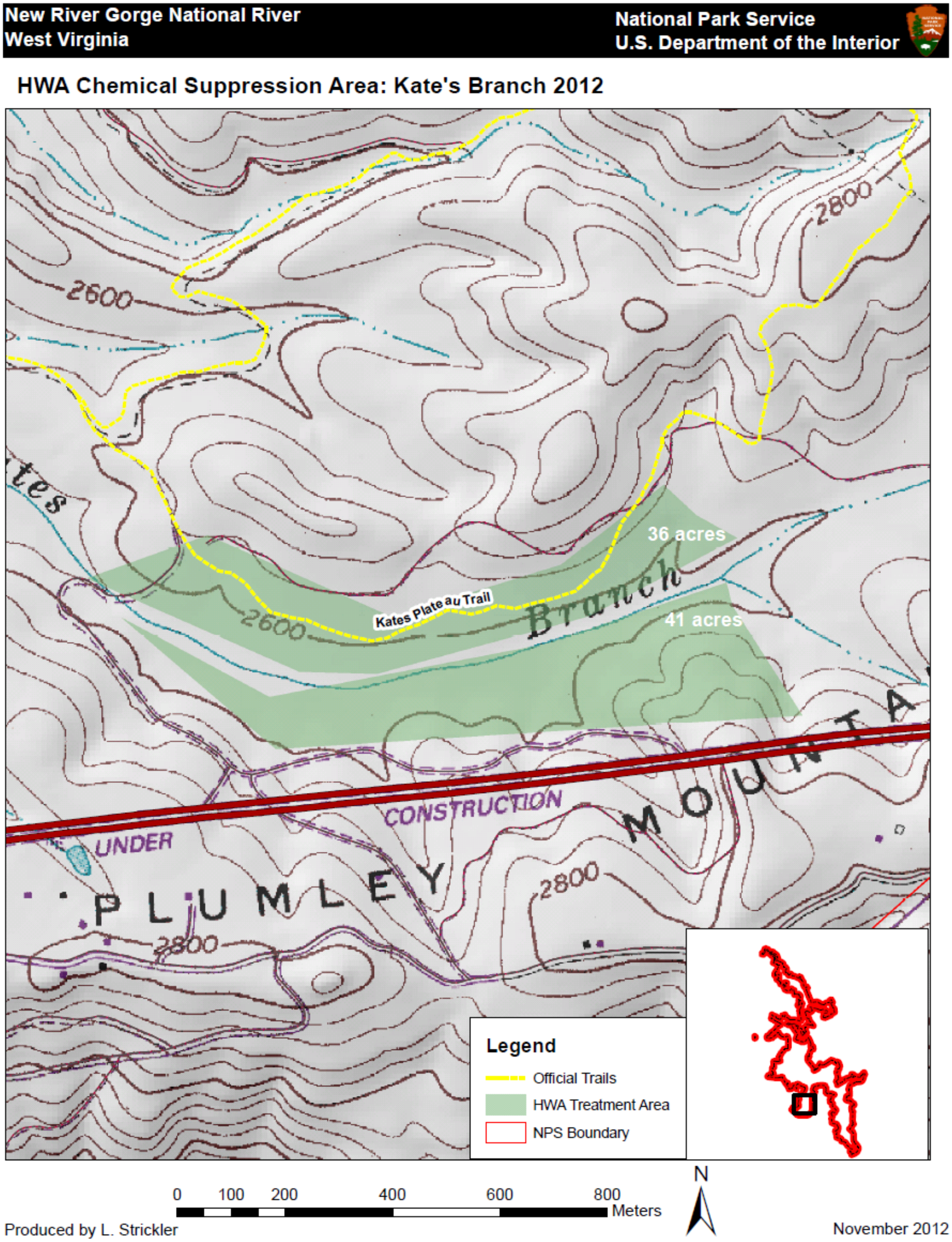
HWA Chemical Suppression Area: Glade Creek 2012



Produced by L. Strickler

November 2012

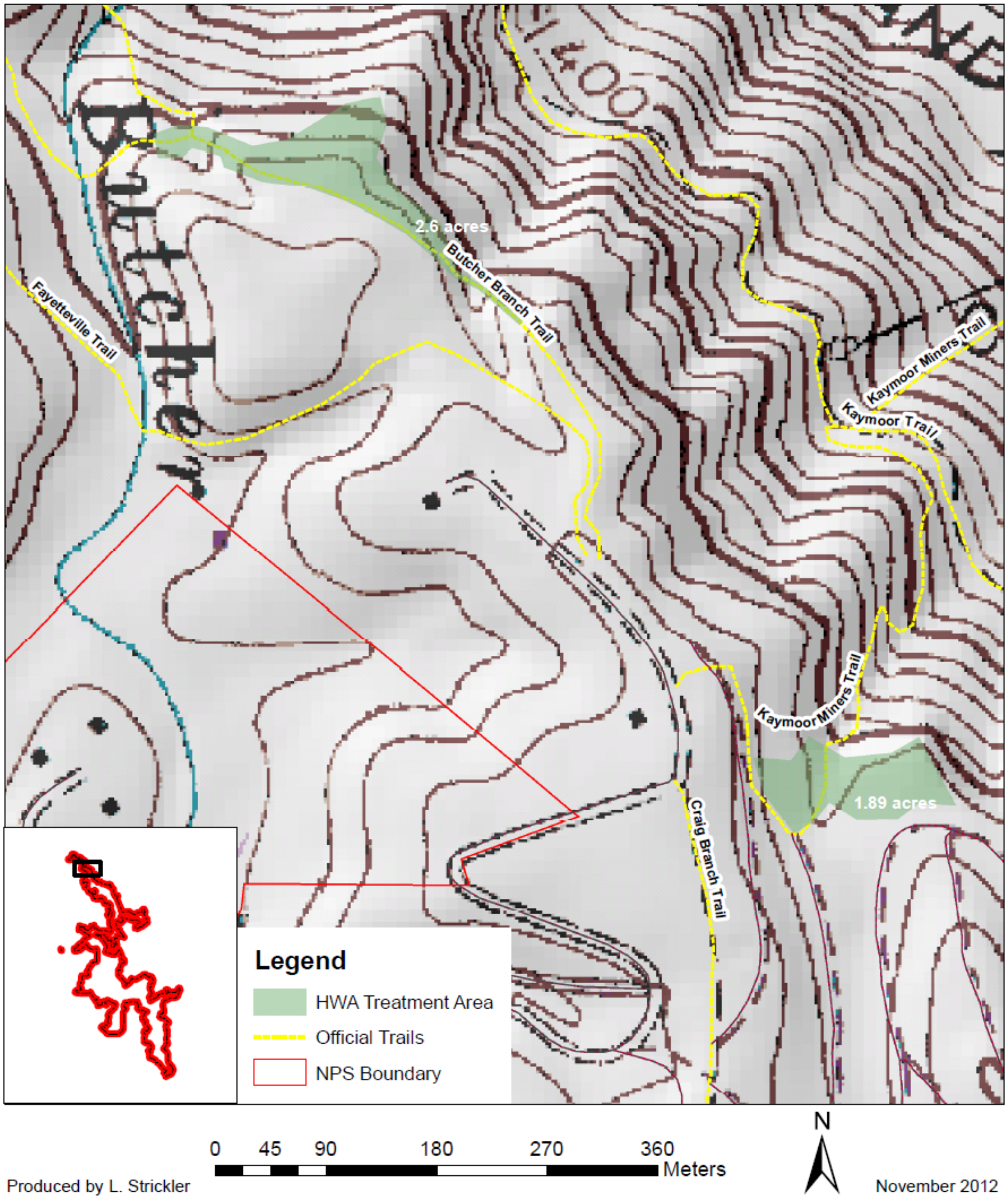

New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
HWA Chemical Suppression Area: Grandview 2012
Grandview Rim Trail
GRANDVIEW STATE PARK
Big Buck Trail
Royal Trail
Picnic Area
Woodland Loop Trail
9.65 acres
43.7 acres
0.39 acre
Castle Rock Trail
Overlook
Legend
HWA Treatment Area
Official Trails
NPS Boundary
0 110 220 440 660 880 Meters
N
Produced by L. Strickler
November 2012


New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
HWA Chemical Suppression Area: Kate's Branch 2012
2600
2800
36 acres
41 acres
Kates Plateau Trail
Branch
CONSTRUCTION
UNDER
PLUMLEY
MOUNTA
Legend
Official Trails
HWA Treatment Area
NPS Boundary
0 100 200 400 600 800
Meters
N
Produced by L. Strickler
November 2012

New River Gorge National River
West Virginia

National Park Service
U.S. Department of the Interior

HWA Chemical Suppression Area: Kaymoor Top and Butcher's Branch 2012



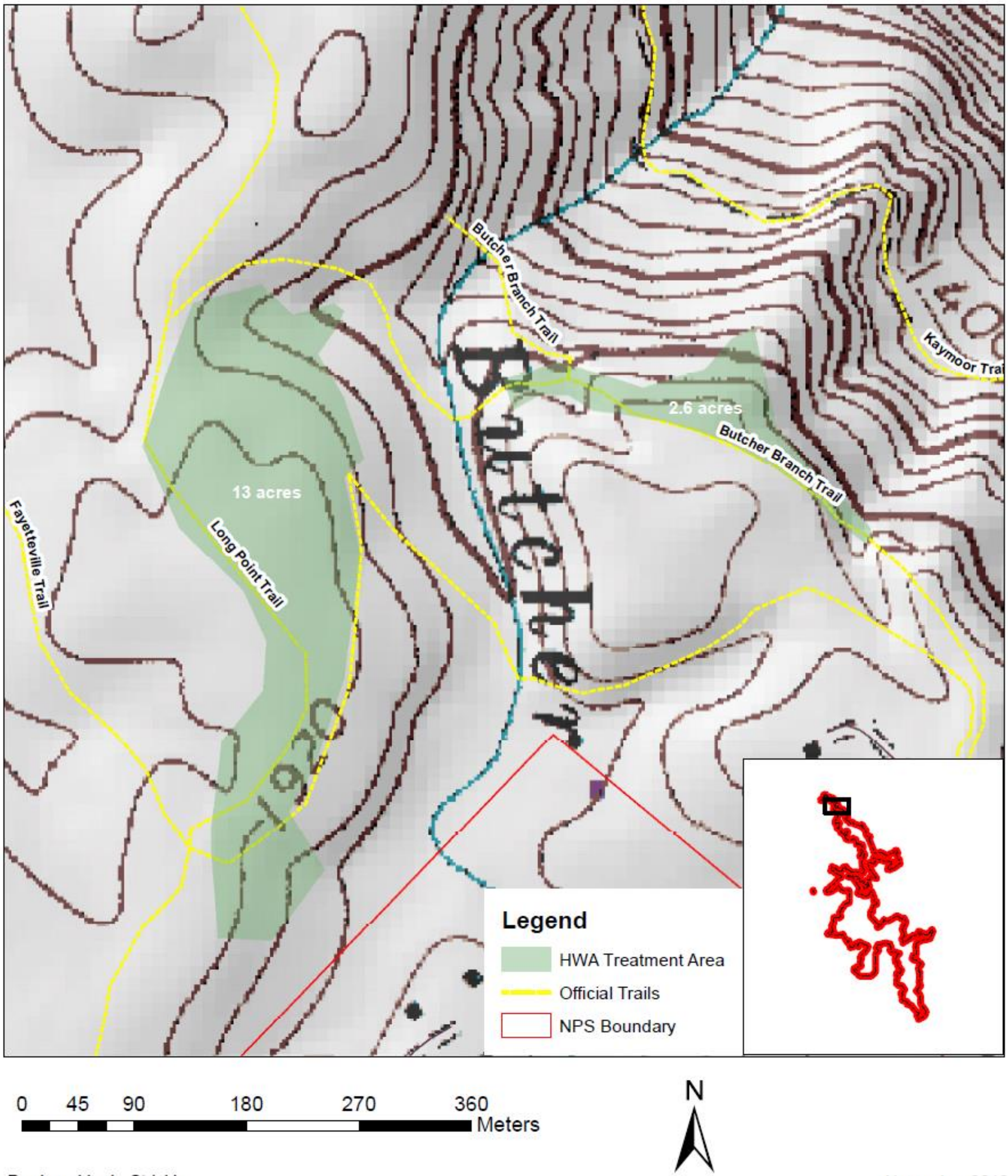
Produced by L. Strickler

November 2012

New River Gorge National River
West Virginia

National Park Service
U.S. Department of the Interior

HWA Chemical Suppression Area: Long Point and Butcher's



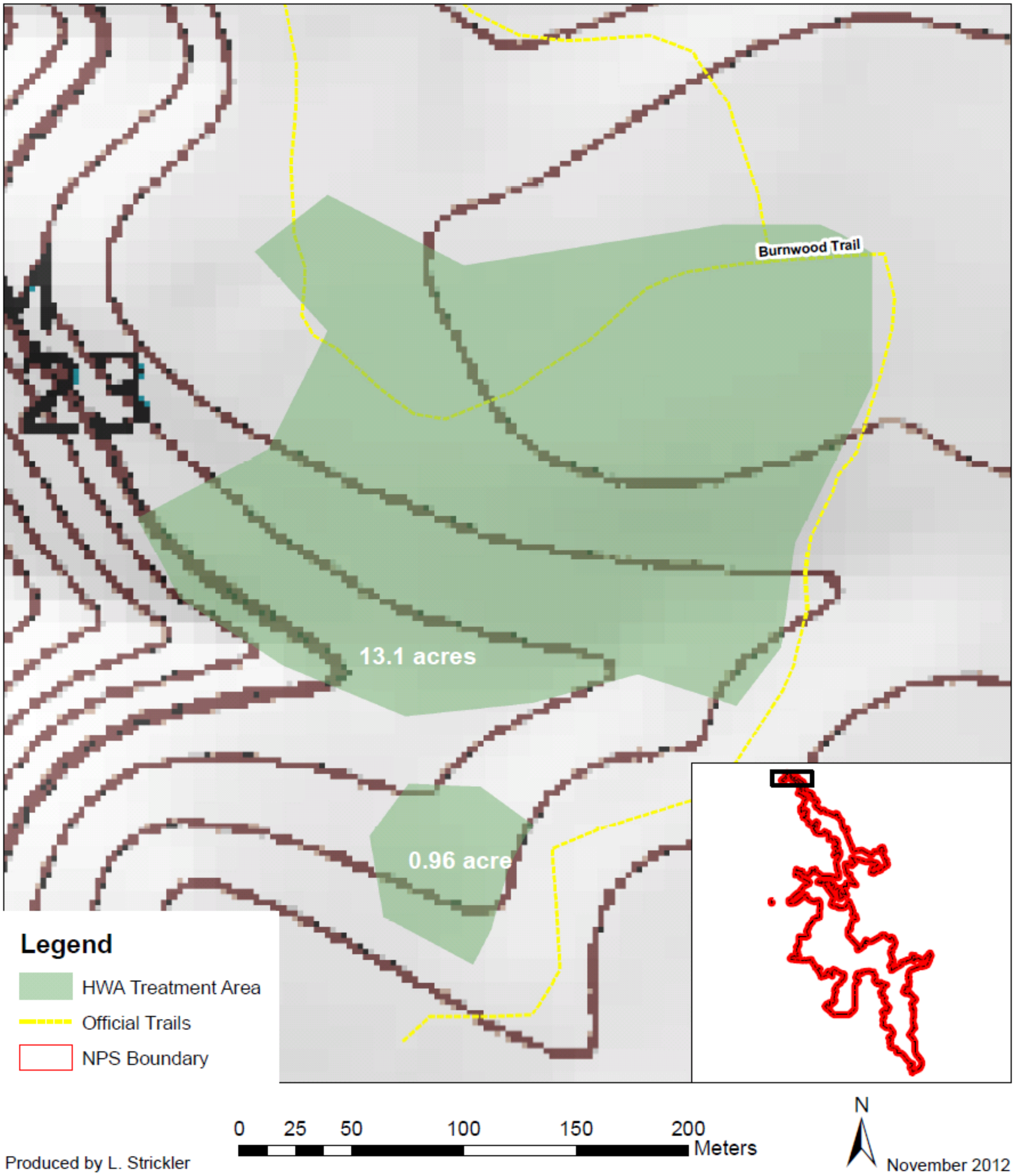
Produced by L. Strickler

November 2012

New River Gorge National River
West Virginia

National Park Service
U.S. Department of the Interior

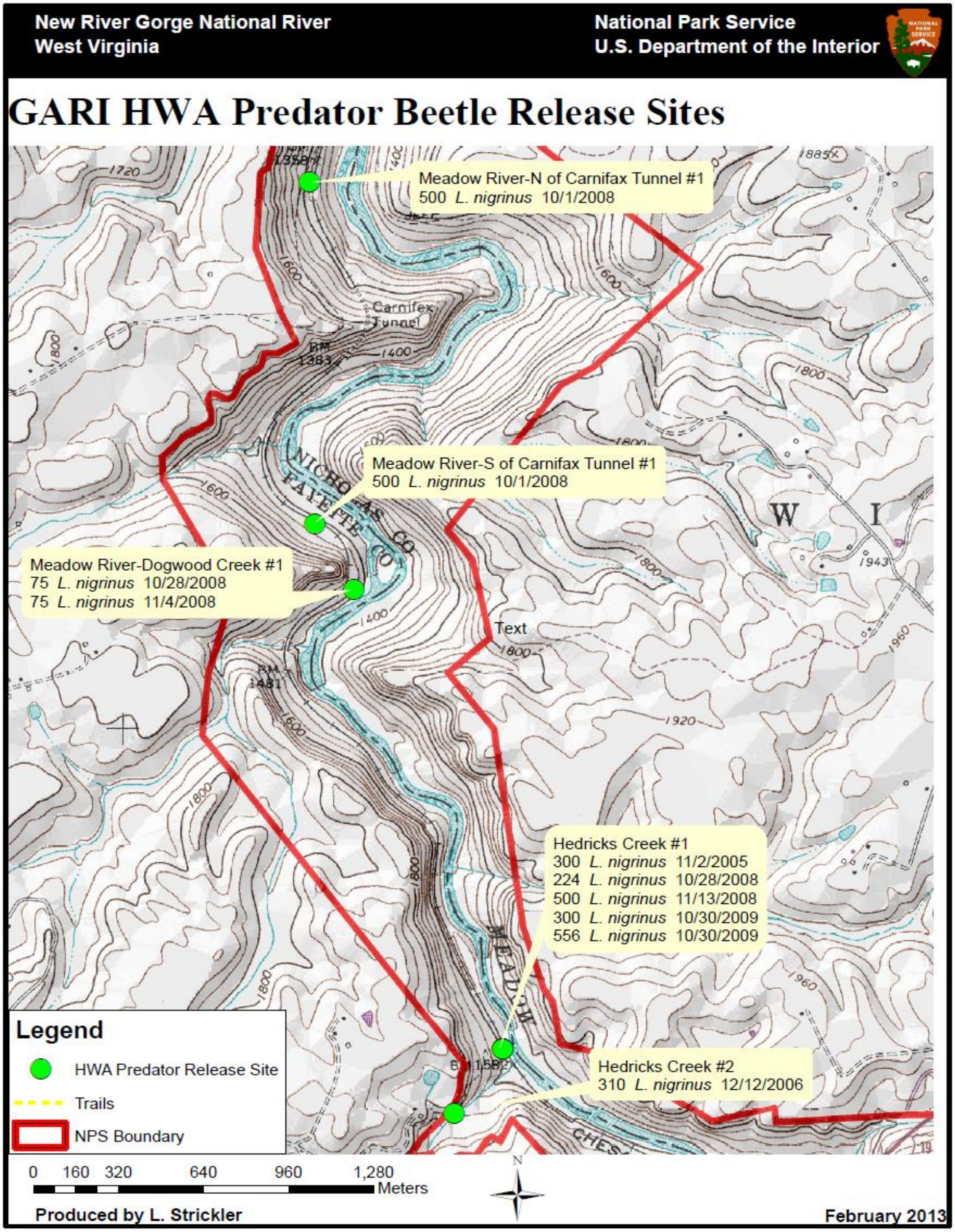
HWA Chemical Suppression Area: Laing Woods 2012

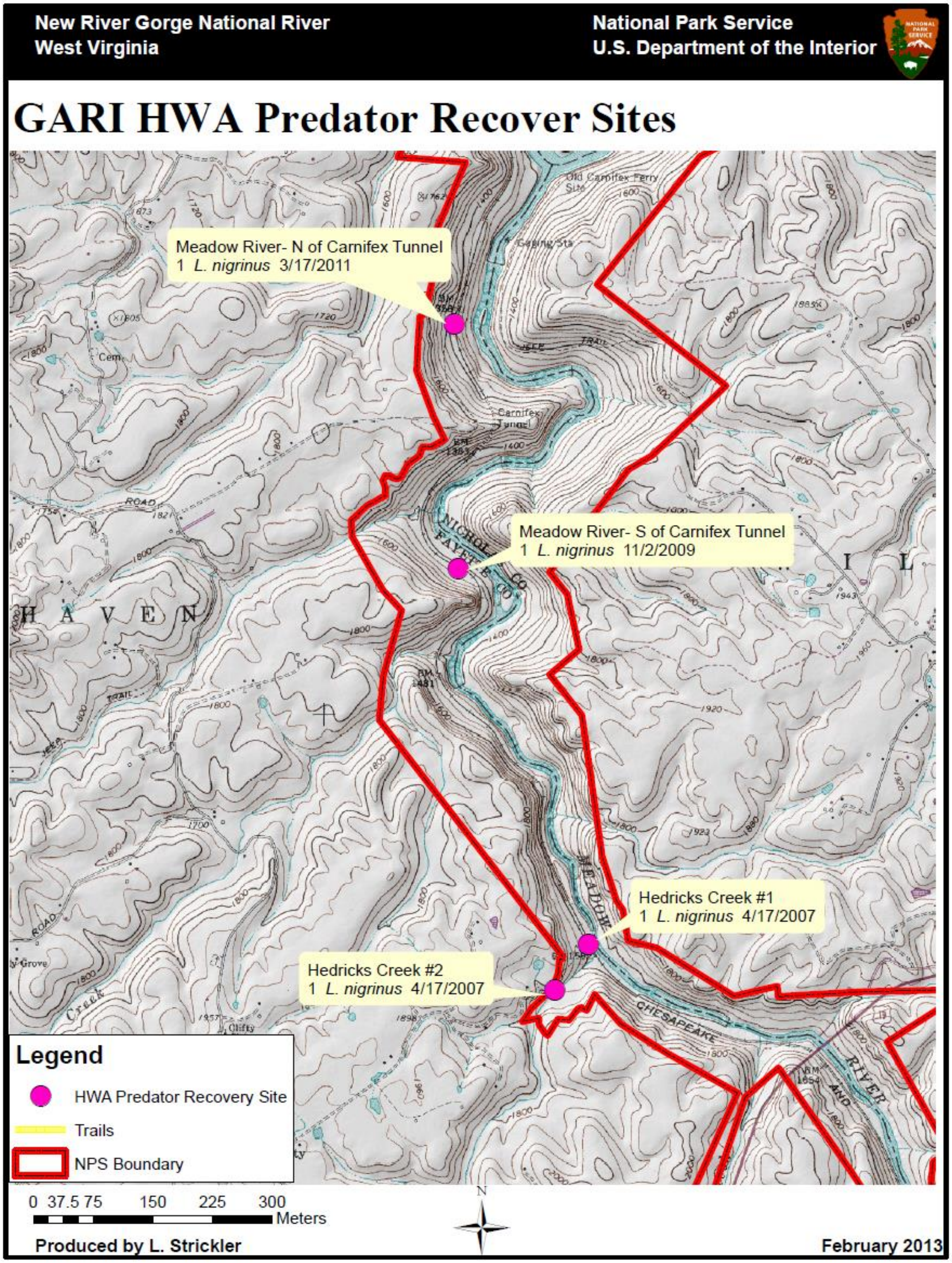


Produced by L. Strickler

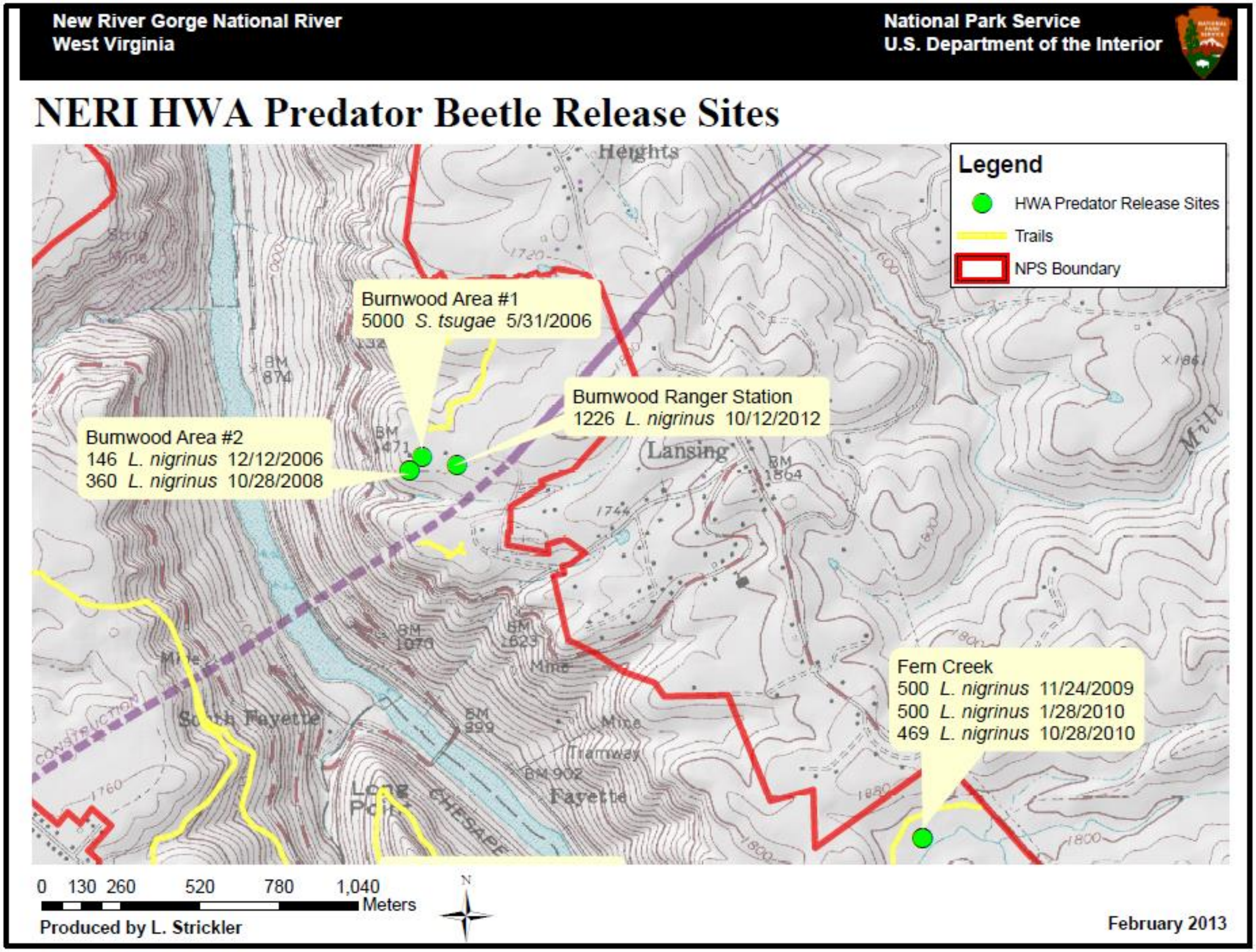
November 2012

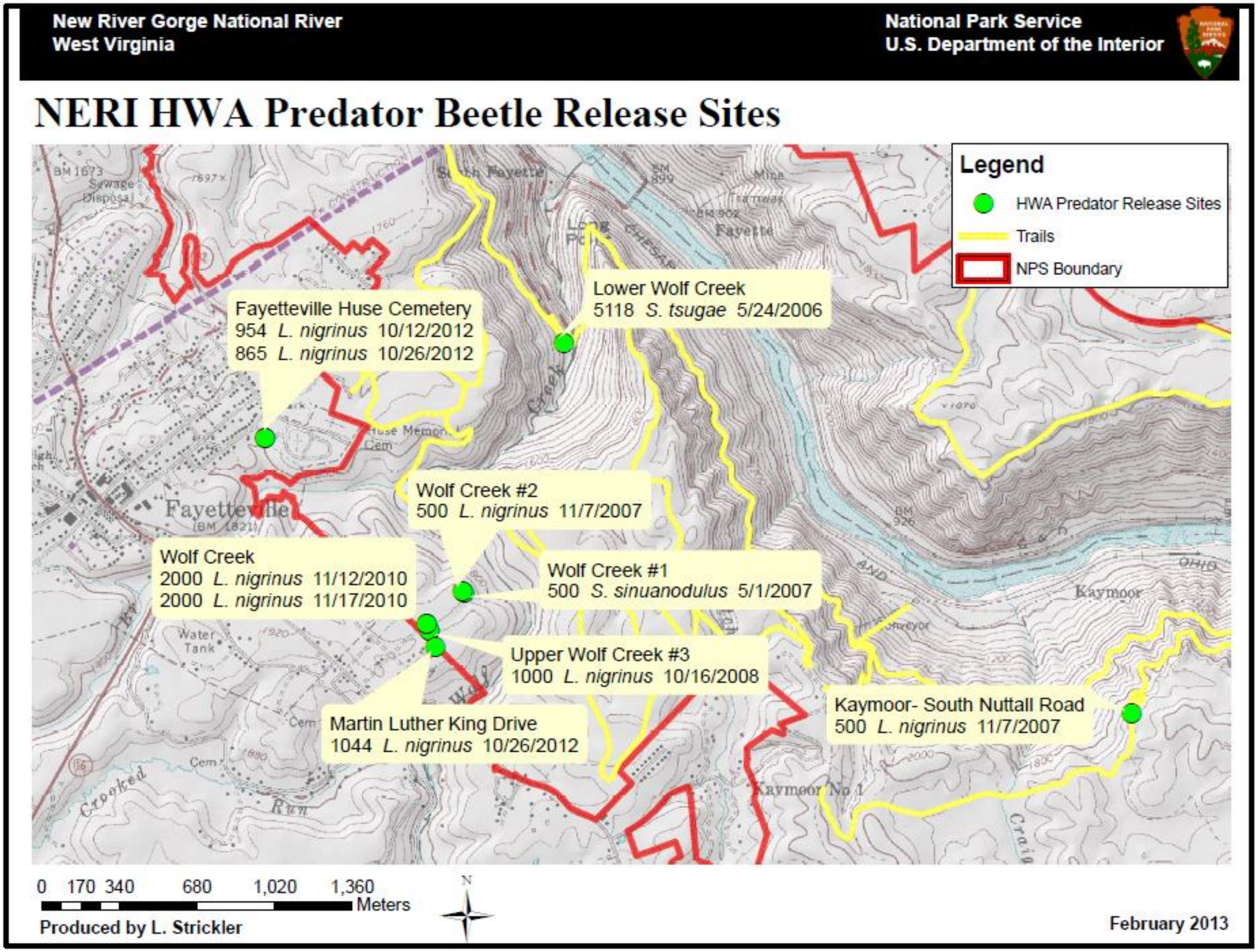
Appendix B: Beetle Release and Recovery





New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
GARI HWA Predator Recover Sites
Meadow River- N of Carnifex Tunnel
1 L. nigrinus 3/17/2011
Meadow River- S of Carnifex Tunnel
1 L. nigrinus 11/2/2009
Hedricks Creek #1
1 L. nigrinus 4/17/2007
Hedricks Creek #2
1 L. nigrinus 4/17/2007
Legend
HWA Predator Recovery Site
Trails
NPS Boundary
0 37.5 75 150 225 300
Meters
Produced by L. Strickler
February 2013

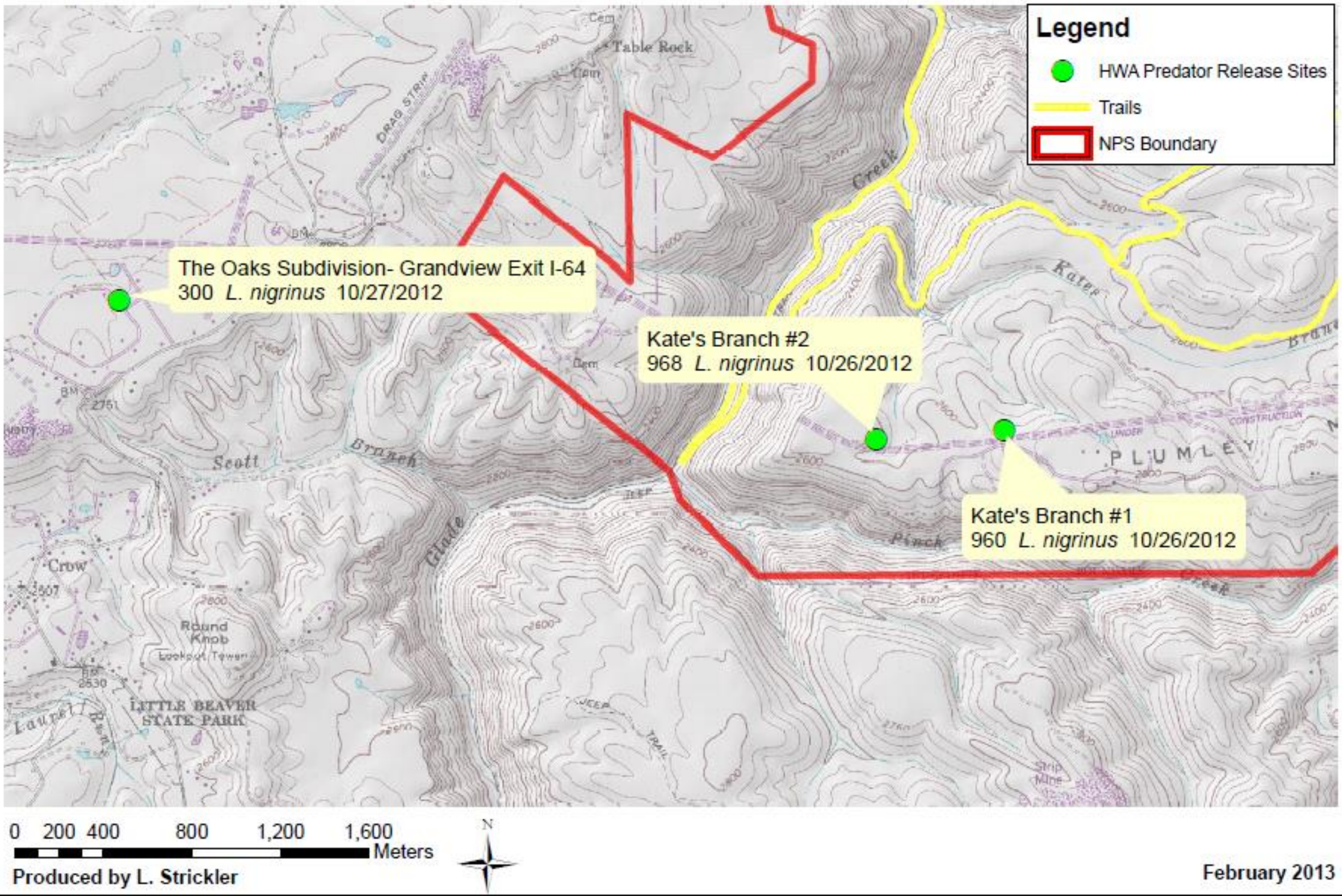

New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
NERI HWA Predator Beetle Release Sites
Legend
HWA Predator Release Sites
Trails
NPS Boundary
Burnwood Area #1
5000 S. tsugae 5/31/2006
Burnwood Ranger Station
1226 L. nigrinus 10/12/2012
Burnwood Area #2
146 L. nigrinus 12/12/2006
360 L. nigrinus 10/28/2008
Fern Creek
500 L. nigrinus 11/24/2009
500 L. nigrinus 1/28/2010
469 L. nigrinus 10/28/2010
Heights
Lansing
Mill
South Fayette
Fayette
Tramway
Mine
CONSTRUCTION
0 130 260 520 780 1,040
Meters
N
Produced by L. Strickler
February 2013


New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
NERI HWA Predator Beetle Release Sites
Legend
HWA Predator Release Sites
Trails
NPS Boundary
Fayetteville Huse Cemetery
954 L. nigrinus 10/12/2012
865 L. nigrinus 10/26/2012
Lower Wolf Creek
5118 S. tsugae 5/24/2006
Wolf Creek #2
500 L. nigrinus 11/7/2007
Wolf Creek
2000 L. nigrinus 11/12/2010
2000 L. nigrinus 11/17/2010
Wolf Creek #1
500 S. sinuanodulus 5/1/2007
Upper Wolf Creek #3
1000 L. nigrinus 10/16/2008
Martin Luther King Drive
1044 L. nigrinus 10/26/2012
Kaymoor- South Nuttall Road
500 L. nigrinus 11/7/2007
Fayetteville
Kaymoor
0 170 340 680 1,020 1,360
Meters
N
Produced by L. Strickler
February 2013

New River Gorge National River
West Virginia

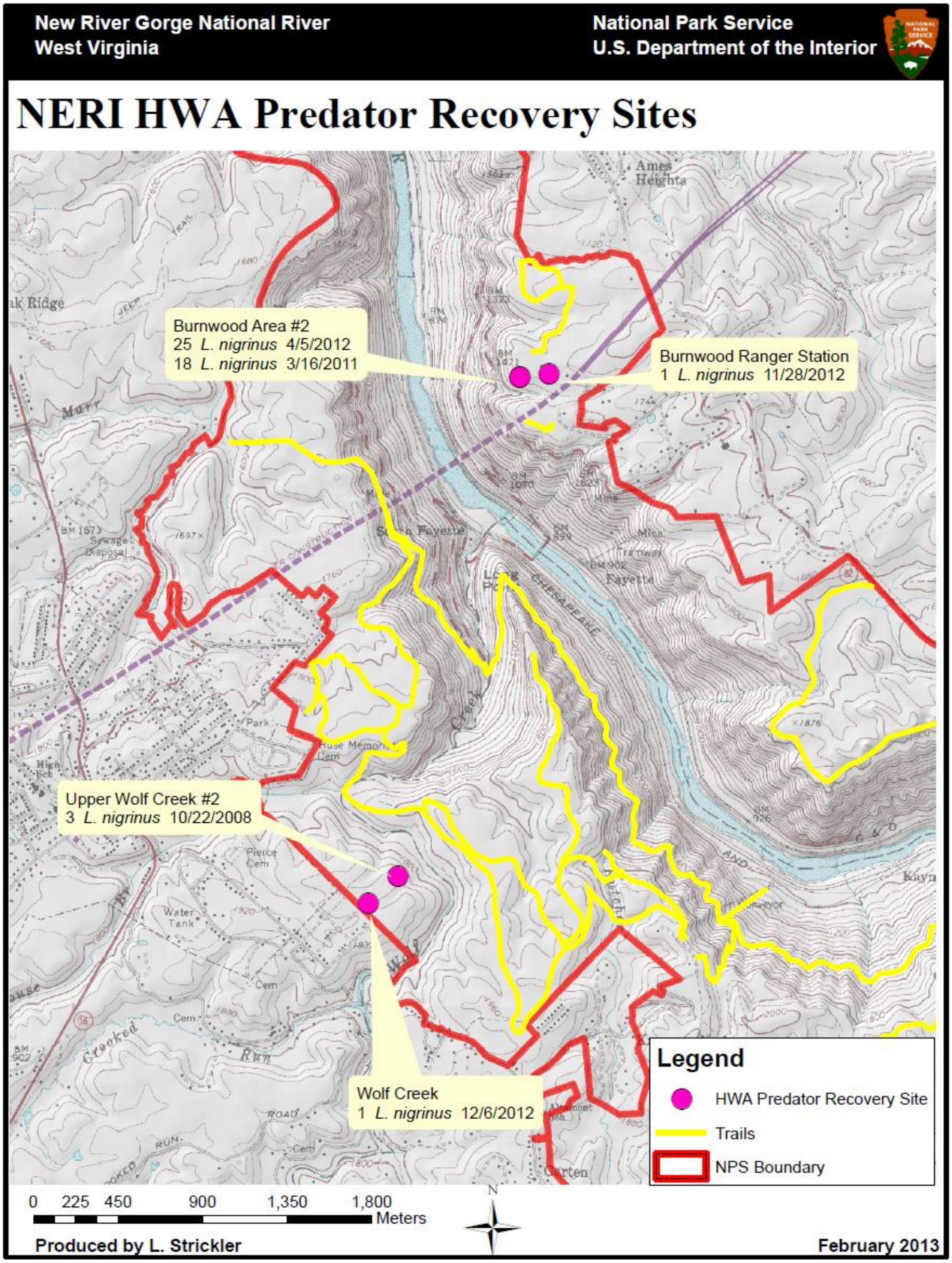
National Park Service
U.S. Department of the Interior

NERI HWA Predator Beetle Release Sites



Produced by L. Strickler

February 2013


New River Gorge National River
West Virginia
National Park Service
U.S. Department of the Interior
NERI HWA Predator Recovery Sites
Burnwood Area #2
25 L. nigrinus 4/5/2012
18 L. nigrinus 3/16/2011
Burnwood Ranger Station
1 L. nigrinus 11/28/2012
Upper Wolf Creek #2
3 L. nigrinus 10/22/2008
Wolf Creek
1 L. nigrinus 12/6/2012
Legend
HWA Predator Recovery Site
Trails
NPS Boundary
0 225 450 900 1,350 1,800
Meters
Produced by L. Strickler
February 2013

Appendix C: Datasheets

Hemlock Treatment Form

Tablet Insertion Data Form

Date: __________________ **Product Name:** ___________________

Site Name: __________________ **Application Rate:** ___________________

#Acre: __________________

Tree #	DBH	Cumulative tablets	Year treated	Tree #	DBH	Cumulative tablets	Year treated

Treatment Monitoring Form

HWA Monitoring Data Form

Date: ________________ **Site Name:** ________________

Monitoring Team: ________________

	Tree	DBH	1	2	3	4	5	6	7	8	9	10	Total	Vigor	LCR
HWA															
Total shoots															
New Shoots															
Dead shoots															
HWA															
Total shoots															
New Shoots															
Dead shoots															
HWA															
Total shoots															
New Shoots															
Dead shoots															

* Numbers 1-10 indicate branches. Cowles (2009) suggests counting no more than 10 wooly masses per branch for easier statistics.

Vigor Classes

1. 95-100%
2. 75-95%
3. 50-75%
4. 25-50%
5. 0-25%
6. dead

Hemlock Ecosystem Monitoring Datasheet

Hemlock Ecosystem Monitoring Plots — Hemlock and Pine Trees— Field Data Sheet

Plot _______ **Date** _____________ **Observer(s)** _______________

Species	dbh (≥8cm)	crown ratio (%)	crown vigor index	Straightness index	HWA index
Tsuga canadensis					
Tsuga canadensis					
Pinus strobus					

Vigor index

1 = >95% healthy crown
2 = >75-95%
3 = >50-75%
4 = >25-50%
5 = >0-25%
6 = snag/dead

Straightness index

1= 0-45 degrees (straight)
2= >45-90 degrees
(leaning/bowed to horizontal)
3= >90 degrees
(severely bowed, or
uprooted facing down slope)

HWA index

1 = heavily speckled and visible from 30m
2 = moderately speckled
3 = lightly speckled — only a few
scattered specks
4 = none

Appendix D: Crown Vigor Index to Live Crown Percentages

	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
1	100	99.95	99.9	99.85	99.8	99.75	99.7	99.65	99.6	99.55
1.1	99.5	99.45	99.4	99.35	99.3	99.25	99.2	99.15	99.1	99.05
1.2	99	98.95	98.9	98.85	98.8	98.75	98.7	98.65	98.6	98.55
1.3	98.5	98.45	98.4	98.35	98.3	98.25	98.2	98.15	98.1	98.05
1.4	98	97.95	97.9	97.85	97.8	97.75	97.7	97.65	97.6	97.55
1.5	97.5	97.45	97.4	97.35	97.3	97.25	97.2	97.15	97.1	97.05
1.6	97	96.95	96.9	96.85	96.8	96.75	96.7	96.65	96.6	96.55
1.7	96.5	96.45	96.4	96.35	96.3	96.25	96.2	96.15	96.1	96.05
1.8	96	95.95	95.9	95.85	95.8	95.75	95.7	95.65	95.6	95.55
1.9	95.5	95.45	95.4	95.35	95.3	95.25	95.2	95.15	95.1	95.05
2	95	94.8	94.6	94.4	94.2	94	93.8	93.6	93.4	93.2
2.1	93	92.8	92.6	92.4	92.2	92	91.8	91.6	91.4	91.2
2.2	91	90.8	90.6	90.4	90.2	90	89.8	89.6	89.4	89.2
2.3	89	88.8	88.6	88.4	88.2	88	87.8	87.6	87.4	87.2
2.4	87	86.8	86.6	86.4	86.2	86	85.8	85.6	85.4	85.2
2.5	85	84.8	84.6	84.4	84.2	84	83.8	83.6	83.4	83.2
2.6	83	82.8	82.6	82.4	82.2	82	81.8	81.6	81.4	81.2
2.7	81	80.8	80.6	80.4	80.2	80	79.8	79.6	79.4	79.2
2.8	79	78.8	78.6	78.4	78.2	78	77.8	77.6	77.4	77.2
2.9	77	76.8	76.6	76.4	76.2	76	75.8	75.6	75.4	75.2
3	75	74.75	74.5	74.25	74	73.75	73.5	73.25	73	72.75
3.1	72.5	72.25	72	71.75	71.5	71.25	71	70.75	70.5	70.25
3.2	70	69.75	69.5	69.25	69	68.75	68.5	68.25	68	67.75
3.3	67.5	67.25	67	66.75	66.5	66.25	66	65.75	65.5	65.25
3.4	65	64.75	64.5	64.25	64	63.75	63.5	63.25	63	62.75
3.5	62.5	62.25	62	61.75	61.5	61.25	61	60.75	60.5	60.25
3.6	60	59.75	59.5	59.25	59	58.75	58.5	58.25	58	57.75
3.7	57.5	57.25	57	56.75	56.5	56.25	56	55.75	55.5	55.25
3.8	55	54.75	54.5	54.25	54	53.75	53.5	53.25	53	52.75
3.9	52.5	52.25	52	51.75	51.5	51.25	51	50.75	50.5	50.25
4	50	49.75	49.5	49.25	49	48.75	48.5	48.25	48	47.75
4.1	47.5	47.25	47	46.75	46.5	46.25	46	45.75	45.5	45.25
4.2	45	44.75	44.5	44.25	44	43.75	43.5	43.25	43	42.75
4.3	42.5	42.25	42	41.75	41.5	41.25	41	40.75	40.5	40.25
4.4	40	39.75	39.5	39.25	39	38.75	38.5	38.25	38	37.75
4.5	37.5	37.25	37	36.75	36.5	36.25	36	35.75	35.5	35.25
4.6	35	34.75	34.5	34.25	34	33.75	33.5	33.25	33	32.75
4.7	32.5	32.25	32	31.75	31.5	31.25	31	30.75	30.5	30.25
4.8	30	29.75	29.5	29.25	29	28.75	28.5	28.25	28	27.75

	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
4.9	27.5	27.25	27	26.75	26.5	26.25	26	25.75	25.5	25.25
5	25	24.75	24.5	24.25	24	23.75	23.5	23.25	23	22.75
5.1	22.5	22.25	22	21.75	21.5	21.25	21	20.75	20.5	20.25
5.2	20	19.75	19.5	19.25	19	18.75	18.5	18.25	18	17.75
5.3	17.5	17.25	17	16.75	16.5	16.25	16	15.75	15.5	15.25
5.4	15	14.75	14.5	14.25	14	13.75	13.5	13.25	13	12.75
5.5	12.5	12.25	12	11.75	11.5	11.25	11	10.75	10.5	10.25
5.6	10	9.75	9.5	9.25	9	8.75	8.5	8.25	8	7.75
5.7	7.5	7.25	7	6.75	6.5	6.25	6	5.75	5.5	5.25
5.8	5	4.75	4.5	4.25	4	3.75	3.5	3.25	3	2.75
5.9	2.5	2.25	2	1.75	1.5	1.25	1	0.75	0.5	0.25

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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