National Park Service
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Natural Resource Stewardship and Science

Forest Health Monitoring Summary

Great Smoky Mountains National Park

Natural Resource Data Series NPS/APHN/NRDS—2012/378

ON THE COVER
Dead mature American beech (*Fagus grandifolia*), killed by beech bark disease, with dense regeneration of blackberry (*Rubus* sp.) and root sprouted beech. Note dead (gray) eastern hemlock (*Tsuga canadensis*) killed by hemlock woolly adelgid on ridge in background. Great Smoky Mountains National Park (GRSM)
Photograph by: Glenn Taylor

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Executive Summary

This document summarizes select tree health parameters for three GRSM forest health monitoring programs in GRSM- Fraser fir (*Abies fraseri*)/balsam woolly adelgid (*Adelges piceae*), butternut (*Juglans nigra*)/butternut canker [*Ophiognomonia clavigignenti-juglandacearum*, and American beech (*Fagus grandifolia*)/beech bark disease (*Cryptococcus fagisuga* (scale insect) and from two *Neonectria* species of fungi. The monitoring period covered varies by host tree species.

Balsam woolly adelgid density counts by area show a wide variation between the four monitor sites and annual variation. Butternut canker rating indices give a picture of the wave of infection and subsequent mortality or recovery over time among the small population of host trees throughout GRSM. Beech bark disease spread through high elevation 'beech gaps' is expressed by documented mortality and root sprout growth from dead parent trees within established monitor plots.

Introduction

Introduced forest insects and diseases have been present in GRSM since before park establishment. American chestnut blight was discovered in the southern Appalachians in the 1920s, and more recently balsam woolly adelgid (BWA), hemlock woolly adelgid, beech bark disease, dogwood anthracnose and other non-native forest pests have caused significant mortality of host tree species.

Long term vegetation monitoring documents forest composition change at a landscape scale on a five to ten year cycle. Introduced forest pests can infest specific forest types, and often follow a pattern of rapid infestation and high host mortality. More frequent monitoring of the health condition of affected host trees, especially those that have restricted habitat requirements, provides more detail of the state of the resource including percent mortality, potential host resistance, rate of spread, replacement species and other information.

Initially, the objective of forest health monitoring in GRSM was to determine the effectiveness of foliar spray treatments for control of the non-native balsam woolly adelgid (*Adelges piceae* [Ratzeburg]), or BWA, on Fraser fir *Abies fraseri* [Pursh Poir.], but expanded to include other pests and their hosts. Forest health monitoring captures the host impact of a pest through qualitative visual evaluation of tree crowns- percent branch dieback, percent defoliation- and quantitative measures- density of balsam woolly adelgids and butternut canker counts. Visual crown evaluation is based on protocols developed by the USDA Forest Service Forest Health program (Shoemaker, et al. 2007).

The Inventory and Monitoring (I&M) program at GRSM began in 1992 and eventually incorporated forest pest monitoring - BWA/Fraser fir, butternut canker and other emerging pests that were having a noticeable impact on forest health in GRSM. Other monitoring programs-- rhododendron decline, American holly dieback and American mountain-ash/European mountain-ash sawfly-- were terminated after several monitor cycles due to lack of definitive causal agent identification or recovery of symptomatic trees and no subsequent observable damage.

In 2009 the Division of Resource Management and Science at GRSM started a process to refocus long term monitoring needs using a critical vital signs approach. Park staff focused on 24 ecological monitoring categories and lumped those categories into four groups of critical to lesser importance. Park staff concluded that the vital signs most essential for long term monitoring were water chemistry, acid deposition, soil quality, vegetation communities, freshwater communities and climate changes. Forest health fell into the second group of categories for future monitoring consideration as budgets allow and therefore will not be a monitored stand-alone vital sign in the future.

What follows is a summary of three of the longest running forest health monitoring programs in GRSM highlighting the primary health parameter in each program and a discussion of the results.

Balsam woolly adelgid (*Adelges piceae* Ratzeburg) or BWA is an aphid-like insect native to eastern Europe that feeds on the trunks and large limbs of several species of true fir (*Abies* spp) trees. In GRSM there is only one fir species-- Fraser fir (*Abies fraseri* Pursh Poir.). Fraser fir is a forest remnant that occurs only on the highest peaks of the southern Appalachians- southwest

Virginia, east Tennessee and western North Carolina. GRSM contains 74% of all southern Appalachian red spruce/Fraser fir forest type (Dull, et al. 1988).

BWA damages firs during the feeding process which involves inserting their tube-like mouthparts into the bark and feeding on the nutrient flow of the tree. During feeding BWA produce a compound that induces cell hypertrophy in the tree's cambial bark layer and the result is a tree that can't transport nutrients and dies. BWA reproduce asexually and have 2-3 generations per year in the southern Appalachians.

First discovered in the southern Appalachians in Shenandoah National Park (SHEN) in 1956, BWA was confirmed in GRSM in 1963 on Mt. Sterling (Dull et al 1988; Ciesla, et al 1963). By the 1970s BWA was at Clingmans Dome near the southern extent of Fraser fir's range. Since then an estimated 80%-90% of mature fir in GRSM have died due to BWA.

Butternut canker [*Ophiognomonia clavigignenti-juglandacearum* (N.B. Nair, Kostichka & J.E. Kuntze) Broders & Boland 2011] is a fungal disease believed to originate outside of North America (Ostry, et al. 1996) but was discovered in GRSM in the 1980s. Trees become infected via airborne spores into flowers and twigs, as well as directly into the stem. Dark, sunken cankers form at infection sites. On branches and stems lens shaped wounds form, often with exposed wood evident. Secondary fungi can then invade the stem and cause decay and weaken the structural integrity of an infected tree.

A monitoring program was established in 1988 to document the health of these uncommon trees as they became impacted by the disease. Butternut is a shade intolerant species. As the forests of GRSM have matured butternut reproduction has been restricted to stream and road edges and areas of natural disturbance. Mechanical damage to mature trees from wind events is another common cause of butternut mortality.

Beech bark disease, a complex of non-native beech scale (*Cryptococcus fagisuga* Lind.) and two species of *Neonectria* fungi, was confirmed in GRSM on American beech (*Fagus grandifolia* Ehrh.) in the late 1980s. In 1994 a monitoring program was established to document the condition of beech in ten high elevation southern Appalachian 'beech gaps'- a G1 rank (critically imperiled) forest type dominated by beech (White, et al. 2003).

Management of forest pests is not always possible or practical but one pest that has been managed in GRSM with success is hemlock woolly adelgid (HWA). Monitoring effectiveness of HWA treatments is integral to the HWA management program but the monitoring has not been incorporated into the long term I&M program.

Methods

Balsam Woolly Adelgid

Beginning in 1986 mature fir trees along Heintooga Ridge Road (1987 at Mt LeConte and Mt Sterling, 1989 at Clingmans Dome) were selected and tagged. Trees were selected as representative of healthy trees in the area whether they were infested or not.

The monitoring protocol differs slightly at sites. Clingmans Dome methods were set up using a variable radius plot design (10 basal area factor wedge prism) while other sites were either trailside (Mt Sterling, Mt Leconte) or roadside (Heintooga Ridge Road) mature trees within or outside of treatment areas. All presented data is from untreated trees. Adelgids on the trunks of monitor trees are counted using lighted 10x magnifiers on 100 cm^2 areas of the bark of mature trees from 1.37m height down toward ground level.

Annual monitoring starts in late June at Clingmans Dome, Mt LeConte, Heintooga Ridge Road, and Mt Sterling. Data collected on each tree includes:

- adelgid density/100cm^2 of fir bark
- live crown ratio in five percent categories (Shoemaker, et al. 2007)
- visual cone count using 7x binoculars
- diameter at breast height

Butternut Canker

In 1987, 79 butternut trees at 12 locations in GRSM were tagged and evaluated for butternut canker symptoms including thinning crowns, twig dieback and visible cankers.

Trees were selected based on their occurrence and accessibility, i.e. they occur in alluvial flood plains scattered throughout the park. Data are collected every three years. Trees that die are replaced with the nearest available tree that is mature- at least mid canopy in height.

Data collected on each tree includes:

- diameter at breast height
- canker index 1=1-5 cankers, 2=6-10 cankers, 3=11-15 cankers, 4=16-20 cankers, 5=21 or more cankers
- number of nuts produced
- crown rating parameters of percent live crown ratio, crown density, crown transparency, crown twig dieback (all 5%categories)- see Shoemaker, et al 2007

Cankers are counted from ground level to crown using 7x binoculars scanning for elongate lens shaped wounds with or without obvious exposed wood. Three cankers are visible in Figure 1.

Crown ratings (percent live crown ratio, crown density, crown transparency, crown twig dieback) are based on USDA Forest Service Forest Health Crown Rating Protocols (Shoemaker, et al. 2007).

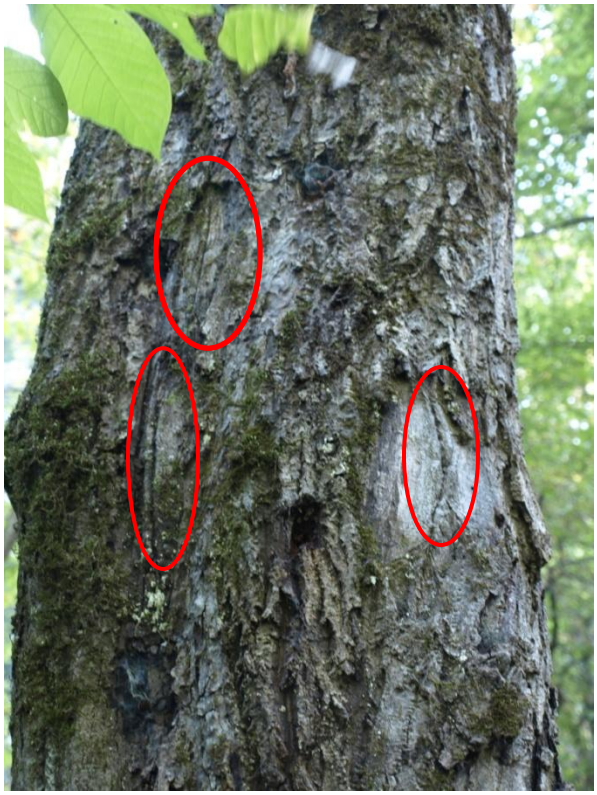

Figure 1. Three healed butternut cankers are visible as vertical seams (circled in red).

Beech Bark Disease

In 1994, ten high elevation beech plots were installed based on the previous year's survey of high elevation beech gaps that had varying degrees of beech scale and/or *Neonectria* sp. present (see Table 1 and Figure 2). The plots were 20m x 20m, had a minimum of 20 American beech trees per plot with a minimum diameter at breast height (dbh) of 3.5 cm. Live and dead beech and non-beech trees, were evaluated (Wiggins et al. 2004). Live beech trees are visually evaluated for level of scale and *Neonectria* (fruiting structure presence) infestation, category of percent branch dieback and defoliation, and scale and *Neonectria* infestation on the north and south sides in a 33cm x 33cm area of the trunk at 1.2m from ground level (Wiggins, 1997). Trees had either low, medium or high levels of beech scale infestation. Low was defined as detectable trace amount of scale, high as more than 100 white wooly ovisacs visible in the sampling area and medium as a level in between low and high.

Categories of percent branch dieback and defoliation are as follows: 0 = no dieback or defoliation, 1 = 1-10%, 2 = 11%-50-%, 3= >50%, 4 = recently dead (fine twigs intact), 5 = long dead.

Table 1. American beech monitoring plots in GRSM and the level of infestation at time of establishment.

Plot Name	Plot Number	UTME*	UTMN*	Number of Beech	Scale Density[2]	Elevation (ft)
Sweat Heifer	1	282251	3945709	28	high	5844
Jenkins Knob	3	268416	3938723	54	low	5425
Forney Ridge	4	272779	3934883	77	high	5019
Trillium Gap	6	279778	3950563	55	none	4707
Deep Creek	7	280136	3942359	31	none	4629
Indian Gap	9	279152	3943468	55	low	5331
Chimneys	10	276474	3945734	20	low	3691
Fork Ridge	14	278085	3940017	35	high	4904
Newfound Gap	16	280635	3943529	49	low	5189
Gregory Bald	17	239715	3934658	45	none	4632

[1] Number of American beech in plot >3.5cm dbh at time of plot installation
[2] Estimate at time of plot installation; none = scale not found; low = newly established populations; high = well established populations
*UTM coordinates (easting = UTME and northing = UTMN) are based upon NAD 83 datum

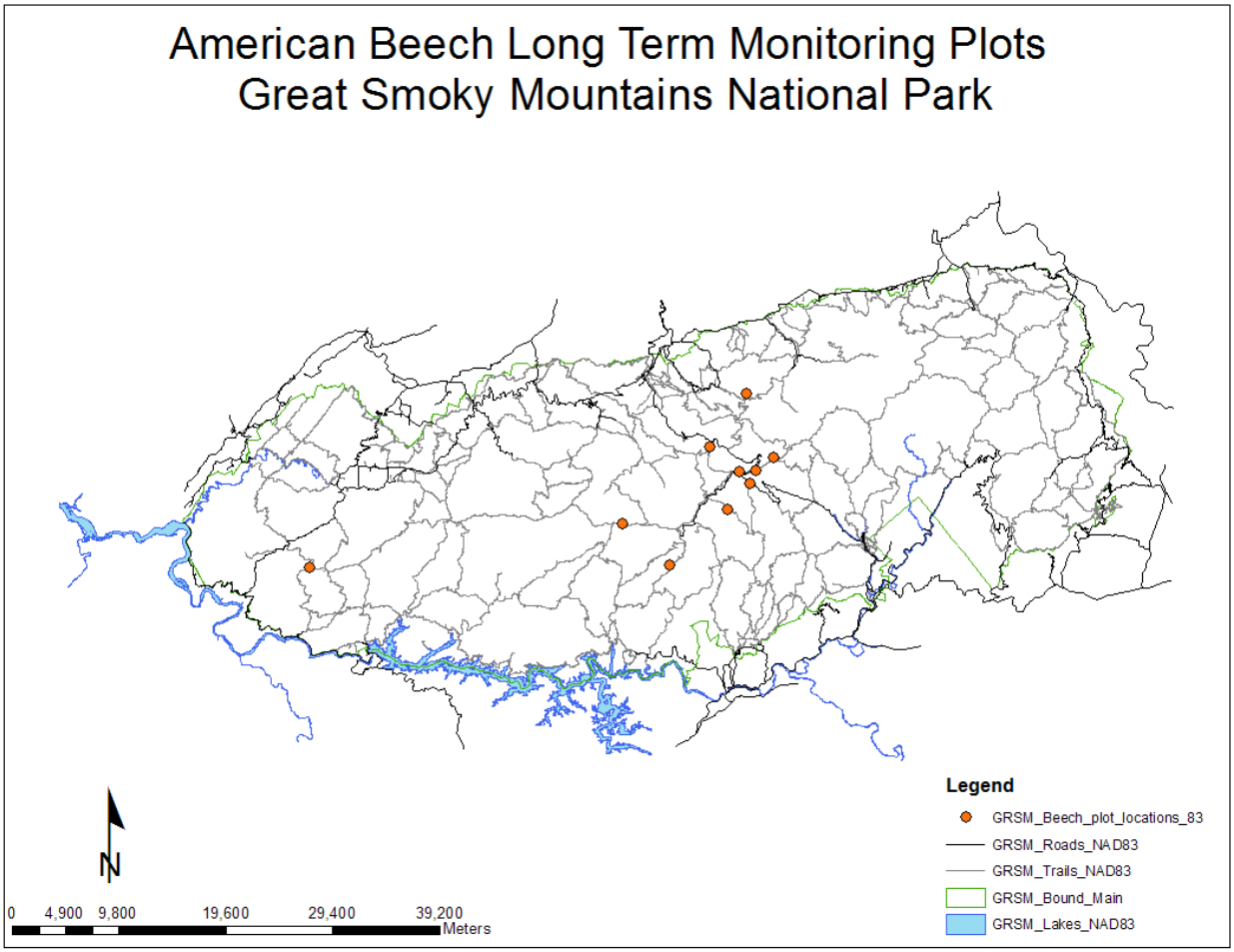

Figure 2. Locations of American beech/Beech bark disease monitoring plots.

Results and Discussion

Balsam woolly adelgid

Summaries of annual BWA densities and cone production are shown in Table 3. Densities vary widely from tree to tree, from site to site, and from year to year. Cone production is cyclical without stress from BWA feeding but on occasion cone production increases noticeably the year following high BWA densities.

Although the loss of fir on Clingmans Dome is evident to all who visit there, BWA densities have been consistently lower there than at the other three monitoring sites. The BWA densities at Heintooga Ridge Road have caused noticeable fir mortality and this lower elevation (approximately 5200'-5300') fir resource is rapidly disappearing. Fir regeneration is vigorous at points at Clingmans Dome where the over story tree canopy has died, but less so at other monitor locations. This regeneration is likely to become infested by BWA in the near future and hinder long term recovery of the fir resource.

There are remnant stands of unaffected firs at several locations in GRSM but these are approaching life expectancy. The mechanism of resistance in these trees is not fully understood but one aspect has been partially investigated. Juvabione is a juvenile insect hormone analog produced in fir bark that inhibits insect development. North Carolina State University entomologist Fred Hain has processed bark samples from some of these mature trees and discovered varying concentrations of juvabione (Newton and Hain, 2005).

Butternut Canker

Canker index was the only health measure recorded for the years 1987-1993. Canker index is a visual count of the number of cankers on an individual tree using 7x binoculars. The canker index categories are as follows: 0= no cankers, 1= 1-5 cankers, 2= 6-10 cankers, 3= 11-15 cankers, 4= 16-20 cankers, 5= 21 or more cankers.

Canker index ratings for three monitoring periods are shown in Figure 2. High canker ratings recorded in 1987 have shifted to lower ratings in successive years. This may be due to cankers healing and becoming less discernable. The crown density, transparency and dieback data show little change between 1996 and 2008. Additionally, trees have fallen out of monitoring due to mechanical damage (windthrow, wind breakage) and in some cases to removal by facilities staff.

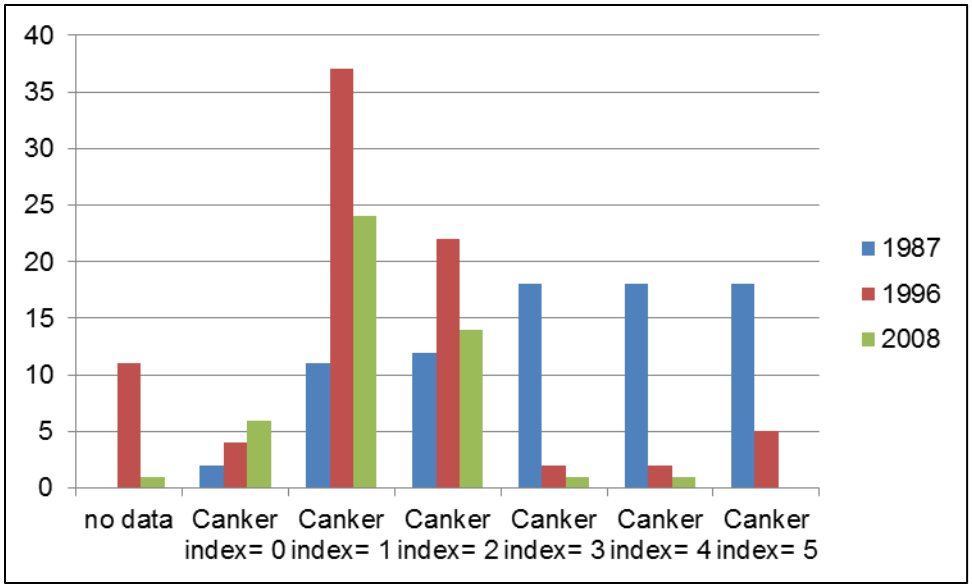

Figure 3. Number of butternut trees in each canker index category over three monitoring periods. Higher index categories are higher number of cankers.

Table 2. Mean crown rating parameters of butternut trees in GRSM for five rating periods.

Year	Number of Trees	Number of Trees No Data	Mean Percent Density	Mean Percent Transparency	Mean Percent Dieback
1996	73	11	40	38	6
1999	61	7	23	64	5
2002	29	5	35	50	16
2005	49	3	27	67	8
2008	47	5	33	53	5

Table 3. Average balsam woolly adelgid densities, number of monitor trees and average cone production, by year and site.

Year	Average BWA Heintooga Ridge road	Number of monitor trees Heintooga Ridge road	Average cones Heintooga Ridge road	Average BWA Clingmans Dome	Number of monitor trees Clingmans Dome	Average cones Clingmans Dome	Average BWA Mt LeConte	Number of monitor trees Mt LeConte	Average cones Mt LeConte	Average BWA Mt Sterling	Number of monitor trees Mt Sterling	Average cones Mt Sterling
1986	0.00	18	1.11	no data	no data	no data	no data	no data	no data	no data	no data	no data
1987	2.61	18	8.67	no data	no data	no data	3.93	28	21.82	2.05	20	4.15
1988	12.67	18	no data	no data	no data	no data	29.40	20	0.00	11.83	18	0.00
1989	5.39	18	1.11	1.09	22	no data	2.91	22	0.36	9.90	20	2.75
1990	9.94	18	0.00	2.71	21	no data	6.60	25	0.00	24.05	20	2.35
1991	3.72	18	13.56	2.14	21	70.95	1.68	25	27.40	0.79	19	15.74
1992	3.44	18	0.00	3.73	11	no data	0.68	25	no data	0.21	19	0.00
1993	40.61	28	4.14	0.00	43	no data	11.48	23	2.87	12.58	19	3.89
1994	1.18	28	44.21	5.20	69	no data	0.09	23	20.78	3.58	19	12.68
1995	1.14	28	0.00	1.19	70	0.00	0.04	23	0.00	3.15	20	0.00
1996	4.87	31	10.68	1.00	74	8.88	0.09	23	13.78	3.85	20	0.00
1997	10.71	31	4.32	0.39	64	0.00	0.14	21	0.00	5.25	20	0.90
1998	36.16	31	39.77	0.55	62	42.37	0.55	20	16.05	17.75	20	11.05
1999	55.09	33	12.58	10.65	65	0.02	15.00	28	0.29	12.10	20	4.55
2000	27.21	34	2.68	7.30	66	0.00	8.86	29	0.00	28.25	20	0.00
2001	1.31	29	23.79	0.00	59	4.54	0.57	28	2.11	1.40	20	5.95
2002	8.04	28	1.14	1.71	55	0.31	1.94	32	0.00	2.53	19	0.00
2003	1.89	28	22.25	0.43	54	10.26	1.07	29	17.07	1.15	40	6.10
2004	0.70	27	0.19	0.04	52	0.00	0.43	28	0.00	0.35	20	0.00
2005	6.00	26	4.96	0.20	48	0.21	0.00	29	3.00	0.08	24	2.67
2006	11.00	29	5.24	5.10	49	2.39	1.09	32	0.81	2.00	24	6.04
2007	27.37	27	0.00	1.30	58	0.00	0.25	32	0.00	0.80	25	0.00
2008	3.80	30	3.87	14.56	50	20.66	13.28	32	9.13	38.54	24	3.17
2009	2.40	31	2.45	0.35	51	2.18	0.00	32	0.03	3.35	26	0.00
2010	0.00	22	0.00	0.00	50	0.36	0.40	38	0.03	0.05	20	0.20
2011	0.00	30	0.20	0.80	51	0.29	0.00	33	0.82	1.20	20	0.00

American Beech

Monitoring has shown high mortality of mature beech in the plots followed in some cases by dense growth of blackberry (*Rubus* spp.) due to the newly open forest canopy. Root sprout reproduction from now dead parent beech trees is now abundant in some locations and sprouts are growing into measureable size classes. Figure 4 shows the total number of live and dead beech within plots. Most plots have few or no live over story beech trees left. Stem defects due to growth of callus tissue around dead cambial tissue are evident in some plots. This defect is characteristic of 'aftermath forest' condition.

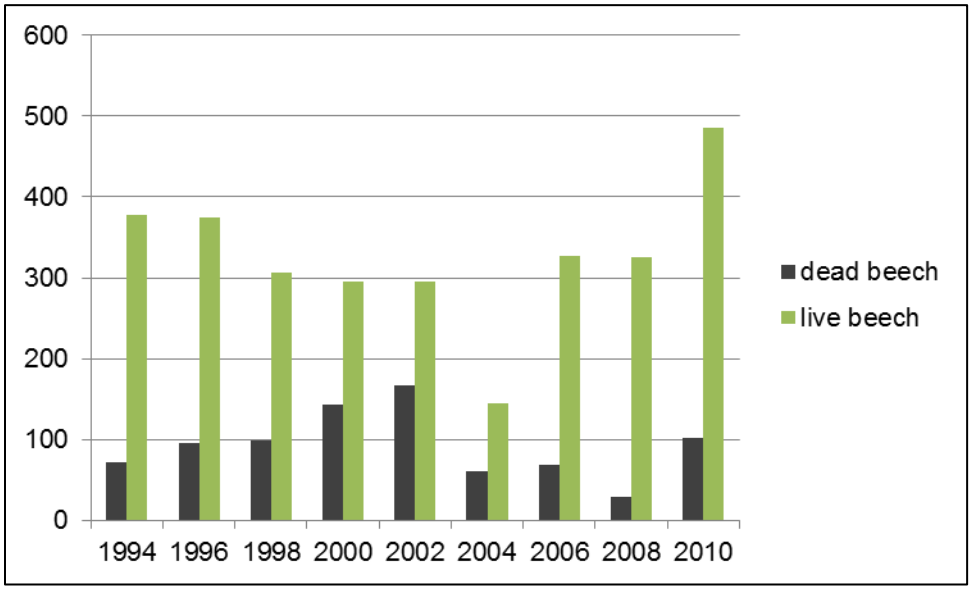

Figure 4. Number of live and dead American beech larger than 3.5 cm in diameter ar breast height in ten monitoring plots.

Figure 5. Over story American beech mortality within the Forney Ridge American beech plot reached 100 percent by 2002. Dense *Rubus* (blackberry) emerged then root sprouted beech saplings followed.

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