Fire Management Options for Controlling Woody Invasive Plants in the Northeastern and Mid-Atlantic U.S.

Spring 2002 prescribed fire in Scotch Broom. Photo by J. Richburg

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September 2004

Executive Summary

Alteration of natural habitats by woody invasive plants is a concern for land managers throughout the northeastern United States. Invasive species – both native and exotic – can adversely impact plant communities and alter fire regimes. Although there is some information on the impacts of invasive species on habitats in the Northeast, few studies have addressed best management practices for controlling or eliminating these species and no studies have evaluated their impacts on fire regimes.

Woody species utilize stored, below-ground carbohydrate reserves to survive dormancy and disturbance. These reserves naturally fluctuate over the course of a year: declining in the spring during flushing of leaves and elongation of shoots, and increasing during the growing season when excess photosynthate is produced. We evaluated the effectiveness of applying treatments at different points during this annual cycle in reducing spout vigor for seven woody invasive species: Gray Dogwood, Common Buckthorn, Multiflora Rose, Japanese Barberry, Morrow's Honeysuckle, Scotch Broom, and Catbrier.

To have the maximum effect on the depletion of below-ground carbohydrate reserves, treatments (cutting and/or prescribed fire) should be timed to periods of low reserves - immediately after leaf-out or after the growth of sprouts following another disturbance. Dormant season treatments have little impact on reserves, although they are successful at reducing the amount of above-ground live biomass.

For the species that we studied a single treatment, whether applied during the dormant or early growing season, appears to decrease root reserves for less than one growing season. Although this study was not able to determine the minimum number of treatments required, we (Patterson unpublished data) have found that annual summer mowing for five years can virtually eliminate a clonal shrub - Black Huckleberry - from pine-oak woodlands. Reserves can be further depleted by treating multiple times during the same growing season, although multiple years of treatments will still be required. More than one treatment within a growing season can

be especially effective so long as the time between treatments is long enough to allow sprouts to regrow and further deplete reserves.

In the northeastern U.S. woody invasive species can be categorized into two general types of fuels for fire: 1) species that present a fire hazard and 2) those that do not increase the fire hazard of an area. Most species we studied are in the second category. Species like Japanese Barberry, Morrow's Honeysuckle, and Common Buckthorn generally invade areas that rarely burn. These exotic species generally do not increase the threat of fire in the untreated condition. Treatments to control these species can increase the fuel load and potential fire behavior, but usually not enough to present a hazard. In fact, mechanical treatments that leave slash may allow the use of prescribed fire as a treatment in units that otherwise would not burn. An ideal treatment scenario would include cutting early in the growing season followed by burning later in the season but before resprouting plants have fully recovered their root reserves. This forces the plants to resprout again and further deplete their reserves. If the second treatment occurs in mid-to-late summer, plants will enter the fall/winter dormant season with substantially reduced potential for vigorous growth the next spring.

Fire dependent communities susceptible to invasion by native and exotic species do occur in the northeastern U.S. Examples include barrens vegetation on sandplains and ridgetops. Some of these communities have been invaded by woody species that can increase fire behavior with or without treatment. Examples include Scotch Broom and Catbrier in coastal grasslands. We found that without treatment both species burned during the growing season, with intensities that made control difficult. Treatments we evaluated include sickle-mowing, which left fuels that allowed subsequent treatment with prescribed fire, and grinding with rotary mowers which compacted fuel beds to the point that application of a subsequent prescribed fire treatment was not possible. Custom fuel models developed for treated fuel beds effectively predicted behavior observed in these prescribed fires. We conclude that carefully applied cutting and prescribed fire treatments, applied in tandem or alone, can reduce the fire hazard in invaded fuel beds.

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Introduction

Worldwide, invasive species, both plants and animals, are considered second only to habitat destruction as the most important threat to rare species and natural communities (Randall 1996, Westbrooks 1998, Myers & Bazely 2003). Among the threats posed by invasive species are alterations to fire regimes, including increased (or decreased) fire intensity and/or severity relative to natural conditions. Non-native species are especially detrimental and are increasingly recognized as problems in natural landscapes, although native invasive species can also have negative impacts (Mitchell 2000). The relationship between invasive plants and their influence on fire frequency and/or fire behavior has been studied for a few species [most notably Cheatgrass (*Bromus tectorum*) in the Great Basin], but the impact of invasive species on fire regimes is generally anecdotal or not known (D'Antonio 2000). Other impacts of invasive species, which often interact with native, non-invasive species to cause alterations to fire regimes, include direct competition with native species for resources, alteration of ecosystem processes (including nutrient cycling, primary production and decomposition), changing of local or regional hydrological characteristics, and, in the case of non-native species, degradation of gene pools through hybridization with native species (Randall 1996, Gordon 1998).

Invasive plants can increase fire occurrence and effects in non-fire dependent communities or they can reduce fire's role in fire-dependent communities (D'Antonio 2000). An example of a plant that increases fire frequency is Cheatgrass in the Great Basin (Pimentel 2000, Miller & Tausch 2001, Myers & Bazely 2003, Brooks et al. 2004). This non-native grass has invaded native habitats of sparse vegetation resulting in decreased fire return intervals (i.e. more frequent fire) where there was previously almost no natural fire. The Cheatgrass creates a positive feedback by creating homogeneous fine fuels that support frequent fires detrimental to native species but favorable to its own persistence. In other areas, invasive species can increase the fire behavior of an already fire dependent ecosystem making it difficult for managers to safely use fire in the system. Catbrier's (*Smilax rotundifolia*) invasion of grasslands in the northeastern United States is an example which we describe in our present work. Fire adapted invasive species, such as Melaleuca (*Melaleuca quinquenervia*), can also make the application of

prescribed fire difficult as their populations may greatly expand following a fire (Myers et al. 2001).

Invasion by non-native species can also make fuel beds less flammable. D'Antonio (2000) describes the invasion of Hawaii Volcanoes National Park by the tree *Myrica faya* which has decreased fire frequency in areas previously dominated by non-native grasses. This is similar to the invasion of northeastern U.S. pine barrens by Black Locust (*Robinia pseudoacacia*) causing a reduction in the flammability of that system. Van Wilgen and Richardson (1985) used fire simulation models to determine which fuel characteristics of invasive plants have the biggest impact on fire behavior. They found that in fynbos shrublands of southern Africa fire behavior was reduced due to densely-packed fuels despite the fact that fuel beds invaded by exotic species had a higher density and biomass per unit area. They speculate that the reduction in understory plants after invasion slows or precludes the spread of fire except under extreme conditions. Fire behavior and intensity can be increased, however, in the invaded areas under extreme conditions (i.e., high winds, high temperatures and low humidity) due to increased fuel loads (van Wilgen & Richardson 1985). Our review of existing literature suggests that more research is necessary to more clearly determine the influence that invasive species, both native and exotic, have on fuels and fire regimes.

Invasive species may also affect the options managers have for fire use. Prescribed fire may be a useful tool for controlling or eliminating invasive species. But fire can also favor the establishment of some invasive plant species, so it is important to understand the biology and ecology of the species targeted for control. In the northeastern U.S. woody invasive shrubs, trees, and vines are difficult to control once established due to their ability to resprout after natural disturbances or attempts to remove them. These species occur in a variety of habitats from grasslands (native or formerly kept open for agriculture and grazing) to wooded tracts (impacted by natural disturbances such as fire, wind, ice storms, and insect and disease outbreaks or anthropogenic disturbances such as timber harvesting and road building) (Hunter & Mattice 2002). Control methods, such as brush-cutting, burning, or herbicide application, can effectively kill above-ground biomass, but loads of available fine dead fuels may subsequently increase and as a result increase fire hazard. Other control methods, such as mowing with rotary mowers or

brush-hogging, can effectively preclude fire use by compacting fuel beds to the point where they will not burn. The effectiveness of control with just one application of any of the above methods is low when treating woody species that are able to resprout from stumps or below-ground roots or rhizomes. Successful control may be possible, however, with repeated treatment, especially when timed to the phenology of carbohydrate reserves in below-ground resources. In the work reported here, we investigate this hypothesis with respect to several invasive species common in the Northeast.

Physiological basis for control

As resource managers have recognized the problems woody invasive species create, programs to control species have been initiated. Complete removal is often difficult due to the ability of most woody invasives to reproduce vegetatively. Many methods, such as cutting or burning, kill above-ground stems, but dormant buds and carbohydrate storage in below-ground structures allow plants to resprout and persist on a site. Herbicide use may be effective but may be difficult to apply over large areas without impacting non-target species and may also not kill the below ground root systems entirely, allowing resprouting. This ability to survive disturbances (ranging from mild herbivory to storm damage and severe burning) by sprouting works well for woody species that often have an extended juvenile phase (Del Tredici 2001). A key component of this survival strategy is to store enough carbohydrates underground to support growth of new shoots and leaves that will, once formed, be able to photosynthesize and supply the plant with carbohydrates.

Carbohydrate reserves, or total nonstructural carbohydrates (TNC), provide the energy resources for developing new shoot, root and foliar growth prior to the development of photosynthesizing tissues. From an evolutionary perspective, this ability to store reserves for later use has allowed plant species to grow in previously uncolonizable areas. The amount of TNC in roots varies over the course of a year with stored reserves being depleted during periods of leaf-out or resprouting and gradually replaced once the plant is able to produce excess photosynthate. There may be a gradual reduction caused by maintenance respiration during dormant periods (such as during the winter in temperate regions).

The amount of stored reserves can impact the health and recovery of a species following disturbance. The more reserves, the better an individual will be able to survive stress; whereas depleted reserves may result in plant death (Gregory & Wargo 1986, Kozlowski 1992). Cook (1966) and McConnell and Garrison (1966) report that for woody plants stem elongation and rate of growth in the spring is proportional to the amount of carbohydrate reserves, and that the timing of removal of above-ground biomass during the natural cycle of TNC depletion and recovery affects the success of regrowth. Since this early work, many researchers have investigated the effects of frequency, timing, and extent of defoliation on carbohydrate reserves of a variety of trees and shrubs (Fitzgerald & Hoddinott 1983, Gregory & Wargo 1986, Kays & Canham 1991, Renaud & Mauffette 1991, Erdmann et al. 1993). Removal during the winter dormant season will have less impact on regrowth than removal during the growing season when reserves are reduced (Kays & Canham 1991, Johansson 1993). Late-season defoliation can cause a decrease in carbohydrate reserves which can impact the vigor of the individual at the beginning of the following growing season (Gregory & Wargo 1986, Loescher et al. 1990).

Carbohydrate storage in roots varies depending on reproductive strategy, with plants that resprout following disturbance having generally larger storage roots and more reserves than those that rely more on seed production (Bowen & Pate 1993). Resprouters also have lower growth rates indicating that the storage of resources may be at the expense of growth rate (Bowen & Pate 1993, Sakai et al. 1997). For some species it can take several growing seasons for starch reserves to be replenished following disturbance (Bowen & Pate 1993). Knowing the patterns and timing of starch storage and depletion of invasive woody shrubs and vines compared to non-invasive native vegetation may aid our understanding of why these species are successful invaders. Highly invasive species may be better suited to surviving certain stresses due to their ability to grow quickly and perhaps acquire large reserves and withstand additional stress.

Knowledge of carbohydrate depletion and recovery of invasive species has implications for management strategies to control them. Non-native and native shrubs and vines have invaded a variety of northeastern U.S. habitats including mature woodlands, shrublands, and grasslands. Natural areas managers are increasingly trying to control woody invasive species using a variety of management techniques such as cutting to remove above-ground biomass,

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prescribed burning, and application of herbicides (Randall & Marinelli 1996). In many cases, control methods are used based on the anecdotal success of the technique on the target or another similar species. In some instances, historical control techniques like dormant season mowing are used even if proven ineffective over the long term. Continued use of such techniques is often encouraged out of concern for other ecosystem properties/components (e.g. nesting bird species; Jones & Vickery 1997). Herbicides are considered one of the most effective control techniques, but are inappropriate for use in watersheds protecting drinking water supplies, and in natural areas supporting rare plant species that might be adversely impacted by broadcast sprays. The objective of our work is to provide managers with non-chemical control methods based on the carbohydrate reserve dynamics of woody plants while not increasing potential fire behavior or hazard.

Impacts of control on fire behavior

Woody shrubs have been shown to generate extreme fire behavior (Van Wilgen & Richardson 1985, Miller 1994). Miller (1994) describes three properties of shrubs that may cause this: 1) shrubs often have a high chemical content - that is, they are more volatile than many other fuels; 2) shrubs often have a high percentage of dead stems; and 3) stands of shrubs have a near ideal ratio of fuel to air (i.e. packing ratio) within their canopy. Treatments to control woody invasive shrubs can influence fire behavior by changing the amount and arrangement of fuels, particularly by changing the percentage of dead stems and their packing ratio.

Fuel loading, fuel size class distribution, surface area to volume ratio, packing ratio, fuel continuity, and fuel bed depth are all important factors that describe fuel beds. These properties, along with heat content and live fuel characteristics, are identified by Miller (1994) as being the most important determinates of fire behavior. The amount of live and dead fuel, usually expressed in tons per acre or kilograms per square meter, is known as fuel loading. Fuel loadings are often divided into size classes. Fuel size-class distribution is an important determinant of fire behavior. A fuel bed made up solely of large particles will not burn as rapidly or intensely as one made up of small, fine fuel particles. Fires usually ignite and spread

in fine fuels, which are defined as fuels less than 0.25 inches (0.6 cm) in diameter (Miller 1994). A physical characteristic of fine fuels is a large surface area to volume ratio. A fuel item with a large surface area to volume ratio can quickly dry and heat to the point of ignition. The surface area to volume ratios of fuels in grasslands are high. Shrubs, with their larger diameter stems have lower surface area to volume ratios.

The proportion of the fuel bed that is occupied by fuel is defined as the packing ratio (Burgan & Rothermel 1984). A fuel bed with no fuel has a packing ratio of zero, and a solid block of wood has a packing ratio of one (Burgan & Rothermel 1984, Miller 1994). A very tightly packed fuel bed (such as mulched or ground material) often will not burn well, because of a lack of available oxygen. Similarly, a very loosely packed fuel bed will often not burn well, because fuel particles are spread so far apart that heat is not transferred readily among particles (Miller 1994) even though oxygen is readily available. Every fuel bed has a theoretical optimum packing ratio (Burgan & Rothermel 1984).

The way fuel is distributed within a fuel bed influences the rate of spread of a fire. Fires spread best in continuously distributed fuels. Continuity of fuels can be thought of in both horizontal and vertical terms. Horizontal continuity is related to the horizontal distance between fuel particles, which is related to percent cover; whereas vertical continuity is related to the distance between surface and crown fuels (Miller 1994). The height above the duff of surface fuels is the fuel bed depth. Depending on the fuel size-class distribution in an area, a greater fuel bed depth can result in higher flame lengths.

Methods

Seven invasive shrub species (two native and five non-native) were studied at three locations (Figure 1). Three species (Gray Dogwood - *Cornus racemosa* Lam., Common Buckthorn - *Rhamnus cathartica* L., and Multiflora Rose - *Rosa multiflora* Thunb. Ex Murray) were located at the Montezuma National Wildlife Refuge (NWR), Seneca Falls, NY in old fields that were being maintained as grassland bird habitat. Morrow's Honeysuckle (*Lonicera morrowii* A. Gray) and Japanese Barberry (*Berberis thunbergii* DC.) occurred under closed

canopy forests in The Nature Conservancy's preserves in Sheffield, Massachusetts. This area is of conservation concern to The Nature Conservancy due to the number of rare plant and animal species located in the watershed. The woody vine Catbrier (*Smilax rotundifolia* L.) and a leguminous shrub Scotch Broom [*Cytisus scoparius* (L.) Link] both dominate many hectares of coastal grassland on Naushon Island, Gosnold, MA where they appear to decrease plant diversity and increase fire hazard as they form dense, nearly impenetrable thickets. All of these sites have used mechanical treatments and prescribed fire to control these species and, in the case of Naushon Island, to reduce the fire hazard presented by the invasive plants. As described in our original proposal, we had hoped to study four-to-five species at as many as six sites. We evaluated a variety of federally owned lands (from Maine to Virginia) to be included in this study, but either the invasive populations were not large and/or homogeneous enough, or the individual properties were not able to conduct prescribed fires (mostly due to not having approved fire plans). We therefore used five different sites at the three locations described above. These locations had suitable populations of 2-3 species each, and we were able to include seven species in this study.
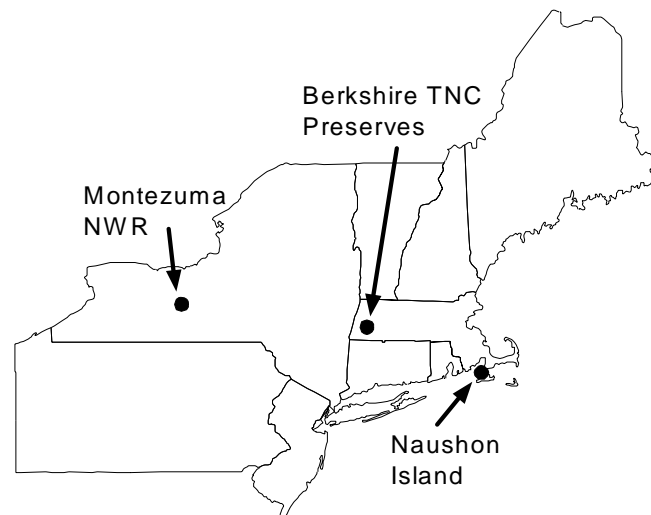

Figure 1. Locations of study sites across the northeastern United States.

Species selected for this study

Gray Dogwood is a medium sized shrub (1-5 m tall) that spreads vegetatively through a network of horizontal roots (Beoken & Canham 1995), with clones often forming dense thickets (Gleason & Cronquist 1991). It occurs in moist-to-wet habitats and, although native to the Northeast, has become invasive in old-field habitats of New York State. Maintaining old fields for grassland bird habitat requires preventing this and other woody species from dominating. Prescribed fire and mowing during the dormant season have had limited success in controlling Dogwood invasion, although recent treatments applied during the growing season have had some success (Mitchell 2000).

Common Buckthorn is a small tree, 6-8 m tall, which is native to Europe and Asia and has become naturalized in the eastern U.S. (Clark & Mattrick 1998). Individual Buckthorn plants are easily overlooked during late-spring and summer, as they do not possess showy flowers or fruits. They are conspicuous in the early spring and late fall though, because they leaf out earlier and hold their leaves longer than native species (Clark & Mattrick 1998). Control efforts have included hand-pulling smaller plants and cutting larger ones followed by herbicide application to stumps. Stems vigorously resprout after cutting. Little is known regarding the longevity of seeds banked in the soil.

Multiflora Rose has a growth form similar to a fountain with long, slender recurving branches (Dirr 1990) which may climb neighboring vegetation. It has a high growth rate and can grow 0.6 m or more per year to a maximum height of 1-3 m and a spread of 3-5 m. Multiflora Rose is native to Japan and Korea and escaped from cultivation in the U.S. after its introduction in 1868. It was originally promoted by the USDA as a living fence and was distributed to farmers for this purpose (Weatherbee 1994). Birds, which eat its abundant fruits, disperse seeds to pastures and open woods, whether disturbed or otherwise. Because the branches bear stout thorns, Multiflora Rose is not browsed and spreads rapidly once established. Control using repeated cutting and herbicide application has worked in some areas (Randall & Marinelli 1996). Rose rosette disease (RRD), which is endemic to North America and spread by mites, appears to be a successful biocontrol agent for Multiflora Rose. In portions of the Midwest, RRD has

nearly eliminated Multiflora Rose populations. RRD is not present yet in New England, but is expected to spread across the Midwest and into New England in the next 10 + years (Amrine *et al*. 1990, Epstein & Hill 1999).

Morrow's Honeysuckle is a multi-stemmed shrub, 2-4 m tall, which will form dense thickets shading out ferns, grasses, and wildflowers (Clark et al. 1998). Like other species of exotic honeysuckles, it produces large quantities of berries which are eaten by birds resulting in the spread of seeds into un-invaded areas, particularly young forests and floodplains (Weatherbee et al. 1998). As with other woody invasives, hand pulling and cutting followed with herbicide application to the stumps have been successful in managing some populations (Randall & Marinelli 1996).

Japanese Barberry is a dense, spiney shrub of rounded form that is usually broader than tall at maturity. Individuals may be nearly 3 m tall, although 1-2 m is more common, with widths of 1-2.5 m (Dirr 1990, Gleason & Cronquist 1991). It is one of the first shrubs to leaf out in the spring. This native of Japan has invaded pastures, woodlands, ledges, and floodplains in the northeastern U.S. (Weatherbee et al. 1998). Japanese Barberry has been controlled by hand-pulling or digging, herbicide application to sprouts after cutting, and prescribed fire (Randall & Marinelli 1996).

Catbrier is a native species that has become locally invasive in coastal areas of New York and New England. It is a thorny vine that climbs across the landscape covering shrubs and small trees, eventually shading out anything below and in some cases breaking branches due to its weight. It spreads by seeds and sprouting from the roots. It is flammable and acts as a ladder fuel (bringing fire into the canopy) increasing the intensity and spread of fire. Catbrier is resistant to most herbicides (Carey 2004).

Scotch Broom is native to Europe and was planted in New England before 1920. It occurs from Nova Scotia, west to New York, and south to Georgia with several populations in New England. It also occurs in the Pacific Northwest and central California where it is a particular problem in rangelands. It produces prolific, long-lived seeds, can sprout from the root

crown after a disturbance that injures or kills above-ground stems, and forms large thickets that displace native vegetation. Scotch Broom is highly flammable and increases fire intensity where it co-occurs with fine fuels which can carry fire into the low canopies where the needle-like leaves will ignite, even when green.

Site descriptions

Montezuma National Wildlife Refuge (NWR) is located in Seneca Falls, Tyre, and Montezuma in Cayuga, Wayne, and Seneca Counties in the Finger Lakes Region of central New York. The refuge is primarily managed as habitat for migratory birds – both waterfowl and upland grassland species. Its 2,860 hectares are located in a matrix of agricultural land and provides habitat features that cannot occur in highly managed agricultural fields. Many of the open grasslands on the refuge are rapidly succeeding to shrublands and forests. Refuge managers use a variety of methods including prescribed fire and mowing to retard or reverse succession at key sites. We worked at two of these: the Lay Road field (near the Esker Brook trail) and the Clark Ridge field (off of Wood Marsh Road) (Figure 2). The Lay Road field had been managed with a mixture of mowing and some prescribed fire, but was dominated by shrubs and small trees at the beginning on this project. The field was dominated by 1.5-2 meters tall Gray Dogwood, grasses and goldenrods (*Solidago* spp.). Other shrubs include Common Buckthorn, Blackberry (*Rubus allegheniensis*), Red-osier Dogwood (*Cornus sericea*), and honeysuckle (*Lonicera* sp.). Poison Ivy (*Toxicodendron radicans*) and Black Swallowwort (*Cynanchum nigrum*) are common. The Clark Ridge field is similar to the Lay Road site, although the Gray Dogwood and other shrubs tended to be taller at 2-3 meters. Other shrubs and trees found at this site include Common Buckthorn, Blackberry, Multiflora Rose, and some small White Ash (*Fraxinus americana*).
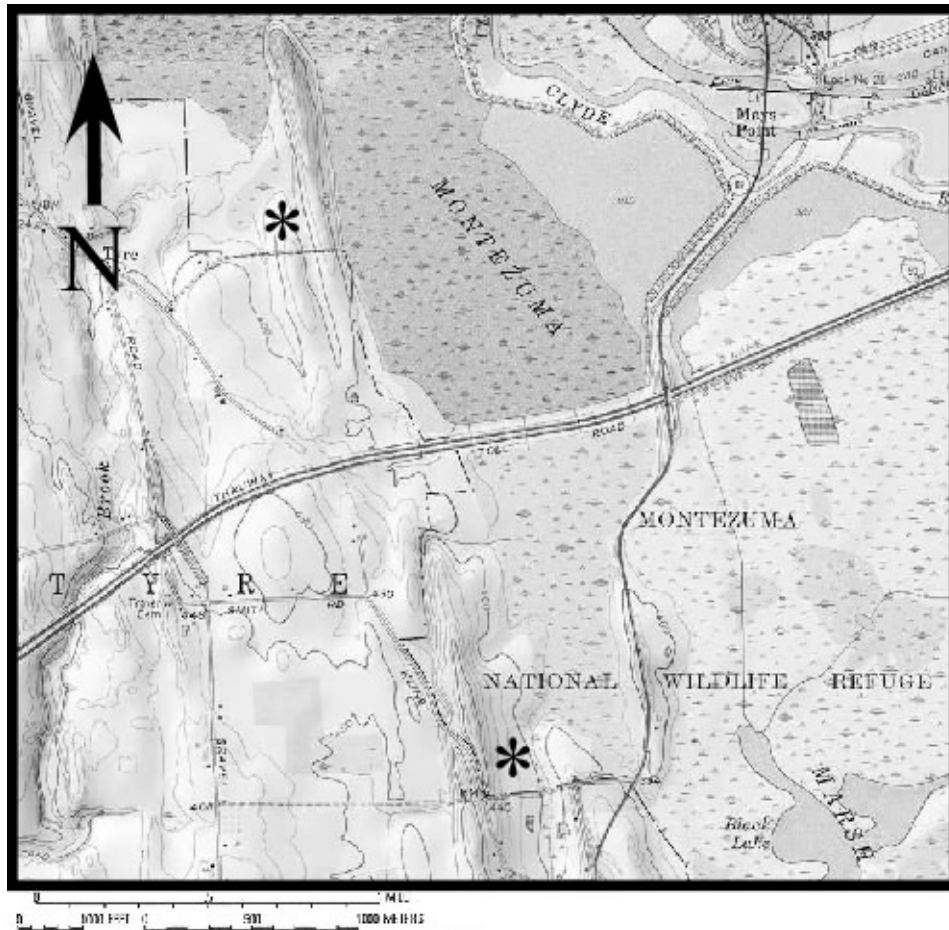
Figure 2. Locations of study sites at Montezuma National Wildlife Refuge. Clark Ridge is north of the NY Thruway (running across the center of the figure) and Lay Road is to the south.

In the Berkshire region of western Massachusetts we established two sites on land owned by The Nature Conservancy (Figure 3). The first site, the Bartholomew tract, is a mature deciduous forest dominated by Sugar Maple (*Acer saccharum*), Black Birch (*Betula lenta*), and White Ash. The understory is dominated by Japanese Barberry, in some cases with more than 80% cover. The second site, the Bear Rock Stream tract, is a forested swamp dominated by White Ash and Red Maple (*Acer rubrum*). There is a dense shrub understory dominated by Morrow's Honeysuckle. Japanese Barberry, Multiflora Rose, dogwood (*Cornus racemosa* and *C. amomum*), and Winterberry (*Ilex verticillata*) are common. The Nature Conservancy is managing both sites as buffer lands for rare plant and animal habitats and started an intensive program to eradicate non-native species at the upland site in 2003. The Conservancy is interested in utilizing fire where practicable to control invasive species and/or to maintain habitat structure.
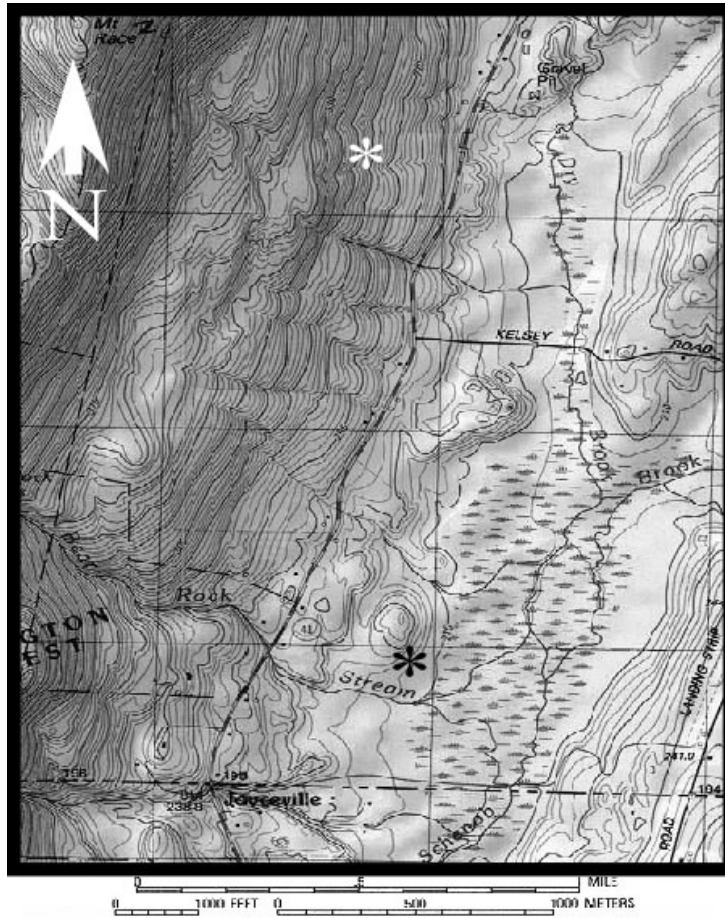
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Figure 3. Locations of two study sites owned by The Nature Conservancy in Sheffield, Massachusetts. The Bartholomew site indicated with the white asterix, the Bear Rock Stream site with the black asterix.

The Protected Field is located in the north-central portion of Naushon Island south of Woods Hole on Cape Cod, Massachusetts (Figure 4). The sandy soils of this site support a maritime grassland community that was invaded by the shrubby vine Catbrier and the non-native shrub Scotch Broom. Where these species occur, they often dominate with nearly 100% cover. Both species burn intensely, even when green, and thus threaten human resources on the island. Naushon Island is privately owned, and land managers are interested in managing the island to support important natural communities (such as sandplain grassland) and for fire hazard reduction.
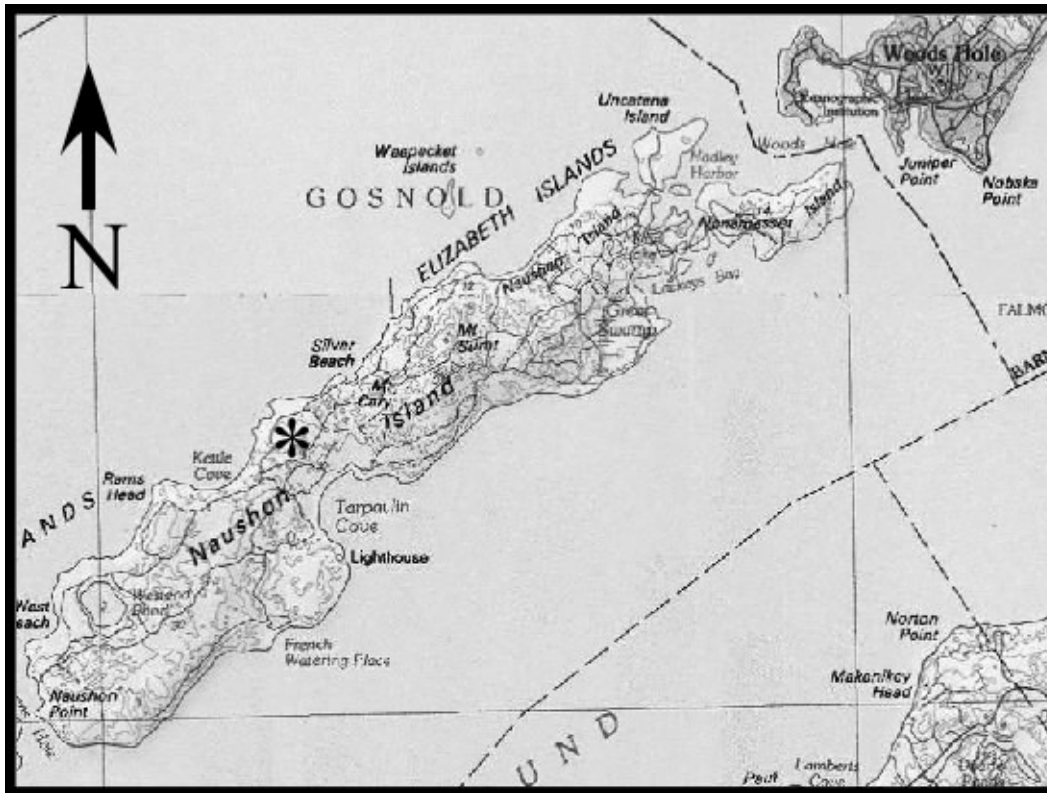
Figure 4. Location of the Protected Field (*) on Naushon Island, Gosnold, Massachusetts.

Plot location and treatments

At each site (defined here as a location with one or more target species where we established study plots), four, 0.2 ha (40 m x 40 m) plots were located in areas with similar overstory and understory vegetation. The four plots were randomly assigned to one of four treatments: 1) untreated control, 2) dormant season burn (or cut if unable to burn), 3) growing season cut followed by a burn in the same season, and 4) growing season cut followed by a second cut in the same season. This treatment regimen varied somewhat from that described in our proposal but provided an opportunity to compare growing season cutting without burning to a cut and burn treatment (treatment 4 vs. 3). Initial treatments were applied during the summer of 2001 and spring of 2002. All growing season treatments received a second season of cutting during 2002 (see Table 1 for treatments and dates). In addition, at Montezuma National Wildlife Refuge, a fifth plot was established to compare mowing with a mulching machine with brushcutting. Two prescribed fire treatments, a spring 2003 burn at Montezuma NWR and a

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2004 early summer burn at Naushon, were subsequently applied to observe and record fire behavior in those fuel beds. Treatments were differentially applied at each site based on availability of equipment and personnel, and weather factors.

Table 1. Treatment protocol (all treatments were carried out in the summer unless specified otherwise).

Plot #	2001 treatments	2002 treatments	2003/2004 treatments	Total # treatments
Montezuma NWR – Lay Road				
Lay - 1	-	-	-	0 (control)
Lay - 2	Mow, burn	Mow, mow	-	4
Lay - 3	Cut, burn	Mow	-	3
Lay - 4	Mow	Mow	-	2
Lay - 5	-	Spring cut	Spring burn '03	2
Montezuma NWR – Clark Ridge				
Clark - 1	Cut	Cut	-	2
Clark - 2	-	-	-	0 (control)
Clark - 3	-	Spring cut	-	1
Clark - 4	Cut	-	-	1
Bartholomew Property – Berkshires				
Bart - 1	-	Spring burn	-	1
Bart - 2	-	-	-	0 (control)
Bart - 3	Cut, burn	Cut	-	3
Bart - 4	Cut	Cut	-	2
Bear Rock Stream Property – Berkshires				
Bear - 1	-	-	-	0 (control)
Bear - 2	Cut, burn	Cut, cut	-	4
Bear - 3	-	Spring cut	-	1
Bear - 4	Cut	Cut, cut	-	3
Naushon Island				
Nau - 1 & 5	Cut, burn	Cut (5 only)	-	2 or 3
Nau - 2 & 7	-	Spring burn	-	1
Nau - 3 & 6	Cut	Cut (6 only)	-	1 or 2
Nau - 4	-	-	-	0 (control)
Nau - 8	-	-	Burn '04	1

Vegetation sampling

The plant community composition of each plot was determined by sampling the entire plot with approximately 300 points distributed on a 2 x 2 meter grid, with an allowance for an edge buffer without points. Presence/absence of species were recorded at each grid point and used to determine abundance (as percent cover calculated from the percent of points that intersected each species). We sampled all plots (except the Montezuma NWR Lay Road plot #3) in 2001 prior to application of treatments. In 2002 and 2003, all plots were resampled to determine differences in community composition following treatments. Treated plots were allowed to grow for at least three months before resampling.

Total non-structural carbohydrates and biomass

Root collection: Although root collection varied from that outlined in our proposal, the changes resulted in more roots being collected over a greater time period at more plots. The proposal stated that three samples per plot would be collected every two weeks, but we found that the variability of TNC among three samples was too great. Therefore we modified the sampling regimen to be four-to-six samples per plot approximately every four weeks. In addition, we also collected samples from all plots (not just the control and cut/burn plots) and a final set of samples in October 2003 (Year 3).

Sections of roots of the study species were collected from each plot approximately once a month during the growing season (except during the several-week period after treatment until above-ground sprouts were identifiable). Root samples were collected from different plants from each plot at each sampling date. For some Gray Dogwood and Catbrier it was impossible to determine the extent of an "individual plant" due to the clonal growth of these species. To ensure that samples for these species were independent of one another, root sections were collected from roots near widely separated stems. Except for Multiflora Rose and Common Buckthorn, which had too few individuals per plot, root samples were only collected once from a given stem during the study. Root sections approximately 1-1.5 cm in diameter and ±10 cm long were collected with small garden shovels, weed tools, and hand clippers. Each sample was

placed in a plastic bag in the field, put on ice and frozen until processed. In the lab roots were washed, cut, and dried at 70° C for at least 24 hours. They were then ground in a Wiley Mill to pass a 40-mesh screen. Ground samples were stored in a freezer until processing.

Total non-structural carbohydrate determination: The ground root material was placed in a 70° C drying oven for at least one hour prior to sampling for total non-structural carbohydrates (TNC). Ten milligrams of ground material was placed in a test tube (three replicates per root sample) along with five units of amyloglucosidase in 4 ml of phosphate buffer, then incubated in a 55° C water bath for 22 hours. After incubation, a 1 ml aliquot of extractant combined with Nelson's alkaline-copper reagent and Nelson's arsenomolybdate reagent were mixed and measured colormetrically at 540 nm in a spectrophotometer. (Haissig & Dickson 1979, Westhafer et al. 1982). The resulting TNC value was calculated as grams of TNC per gram of root expressed as a percentage.

Post-treatment biomass: To determine above-ground response of plants within the treatments, we harvested the target species from three-to-five, 40 x 40 cm plots which were randomly placed in each of the treatment plots (see Table 2 for sampling dates) at all of the sites except Clark Ridge (Montezuma NWR) due to time constraints and the Scotch Broom plots (Naushon) due to too few resprouts. In addition to the weight of the dried biomass (divided into leaf and stem factions) of each 40 x 40 cm plot, the heights and numbers of sprouts within these plots were also measured (except for the Catbrier plots at Naushon due to deer browse of the sprouts).

Analysis: Each site was evaluated as an independent experiment for the species at the site. Analysis of covariance (ANCOVA) was used to determine if there were significant differences in TNC levels between plots (treatments) with time as the covariate (SYSTAT 10.0). Since the treatments were not replicated, sampling times were used as "replicates" for each treatment. To test the significance of the treatments over time, two sets of ANCOVA's were run: 1) 2001 & 2002 data only, and 2) all data (2001-2003). All treatments were performed during 2001-2002 (with the exception of a dormant season burn at Montezuma NWR in April 2003). TNC was sampled on 6-8 sampling dates during 2001 and 2002 to determine TNC phenology

with and without treatments. It was sampled once at the end of the growing season of 2003 to determine TNC recovery after one growing season without treatments. Graphical analysis was used to display the extent of depletion following treatments compared to controls. Since the phenology of TNC within the roots of plants is cyclical, a wave form equation ($y = a + b * \sin^2((2\pi*x)/d + c)$ was fit to the data from the untreated plot (control) for each species (CurveFit2D, ver. 5.01). To determine if the TNC of treated plots departed from those of the control, expected TNC for the treated plots was calculated using the equations derived from control data. A single value t-test of the residual (observed-expected = 0) was used to determine if the treated plots differed significantly from the control.

Table 2. Dates in 2003 when biomass samples were collected from 40 cm x 40 cm randomly placed quadrats.

Plot #	Treatments	Destructive harvest
Montezuma NWR – Lay Road		
Lay - 1	Control	-
Lay - 2	Mow, burn, mow, mow	August 11
Lay - 3	Cut, burn, mow	August 11
Lay - 4	Mow, mow	August 14
Lay - 5	Spring cut, spring burn	August 14
Bartholomew Property – Berkshires		
Bart - 1	Spring burn	August 20
Bart - 2	Control	-
Bart - 3	Cut, burn, cut	August 20
Bart - 4	Cut, cut	August 20
Bear Rock Stream Property – Berkshires		
Bear - 1	Control	-
Bear - 2	Cut, burn, cut, cut	September 21
Bear - 3	Spring cut	September 21
Bear - 4	Cut, cut, cut	September 21
Naushon Island		
Nau - 5	Cut, burn, cut	September 25
Nau - 6	Cut, cut	September 25
Nau - 7	Spring burn	September 25
Nau - 8	Control	-

Differences in the heights, weights, and number of sprouts among treatment plots are shown diagrammatically. No statistical analysis was done due to the small sample size and the lack of replication. Vegetation composition of sites and plots, pre- and post-treatment, were summarized and compared graphically and in tables.

Fuels

Fuel load determination was as described in the proposal with the exception of sampling fewer subplots per plot at both Montezuma NWR and the Berkshire Nature Conservancy sites. Additional and more intense sampling was completed for Catbrier (a highly flammable species) on Naushon Island, as described below.

Fuel sampling at Lay Road & Clark Ridge (Montezuma NWR), Bartholomew & Bear Rock Stream (Berkshire Nature Conservancy sites), and for Scotch Broom (Naushon Island): Plots were sampled for fuel load using a stratified-random method. Each plot was divided into four quadrants (NE, NW, SE, and SW). At least one 40 cm x 40 cm plot was harvested and a 50 ft (15.2 m) planar-intercept line (Brown 1974) measured from each quadrant. Bear Rock Stream plot 2 was sampled more intensively (three planar-intercept lines and two harvest plots per quadrant), because the fuels were judged to be more heterogeneous than on the other plots.

Harvest plots were placed through the random toss of an object within each quadrant. Downed woody fuels, standing dead stems, and litter were clipped from each plot and dried in an oven at 70° C to yield an oven-dry weight for each fuel component.

Planar-intercept lines were located in each quadrant by randomly selecting an azimuth and running a tape measure out along that azimuth. Fuels intersecting a theoretical plane rising four feet (1.2 m) above the measuring tape were counted. One-hour fuels were counted for at least the first ten feet (3 m), and 10- and 100-hour fuels were counted for the entire 50 ft (15.2 m) length. For each 1000-hour fuel intersect, fuel particles with a diameter greater than three inches (7.6 cm) were measured for diameter and recorded as being sound or rotten. Duff depth was measured at 20 and 40 ft (6.1 and 12.2 m); and fuel depth [defined as the highest dead fuel

encountered on a one foot (30 cm) section of the plane], height of the shrub layer, and litter depth were recorded at 15, 30, and 45 feet (4.6, 9.1, and 13.7 m) along each line. Where the shrub layer was clearly arranged in high and low strata, measurements were recorded separately for each stratum.

Using calculations outlined in Brown (1974), we estimated the dry weight of each fuel component in tons per unit area, although harvest plot (40 cm by 40 cm) estimates of mass were typically used for custom fuel modeling. Fuel bed depth, depth of downed woody fuels, and litter depth all are important parameters in custom fuel modeling.

Fuel sampling Catbrier (Naushon Island): Catbrier was sampled more intensively because of its unique condition of vertically continuous, flammable one-hour fuels throughout the fuel bed, and its potential for extreme fire behavior (Ohman in preparation). Nine quadrats (each 1 m^2) of Catbrier were sampled within the Protected Field area of Naushon Island (outside treatment plots but in areas with similar structure and abundance of Catbrier). From these plots, all rooted fuels above the duff layer were cut using a gas-powered hedge trimmer. This tool allowed the viney Catbrier stems to be cleanly cut without snagging and pulling on stems outside of the sample quadrat. Stems, leaves, and litter were collected from each 1 m^2 quadrat. In the lab, stems were sorted by species into live and dead (for Catbrier and other woody species), dried at 70°C, and weighed.

Fuel moisture sampling: In advance of each burn, fuel moisture was sampled. Live leaves and woody stems of shrubs, and herbaceous materials (e.g. grass) were collected from throughout the burn area and placed into sealed plastic bags. Live fuels and litter were later brought to the lab where they were dried and their moisture content calculated. Where dead, downed woody material was abundant, its fuel moisture was determined using a protometer.

Fire behavior observations: Flame length and rate of spread were sampled by placing iron poles with horizontal arms at one-foot (0.3 m) intervals along the expected path of the head fire. The posts were placed a measured distance – usually at 5 to 10 or 20 feet (1.3 to 2.6 or 3.9m) apart. By observing the average length of flames as they reached the pole and by

measuring the time it took the head fire to travel the distance between the poles, we determined flame lengths and rates of spread. In many cases, photographs were taken as flames encountered the iron poles (or other objects whose height was known) to allow for subsequent confirmation of our observations. The 2004 Naushon Island burn was video-recorded which allowed us to later analyze more accurately flame length and rate of spread

Results

Response of total non-structural carbohydrates to treatments

With the exception of Japanese Barberry, analyses of covariance of total nonstructural carbohydrates (TNC) indicated significant differences between plots (treatments) for each species at each site during the period from 2001-2002, After one year without treatments (2003), only three species remained significantly impacted by the treatments (ANCOVA with 2001-2003 data, Table 3). The TNC sampled in October 2003 showed that for all plots and species, TNC had recovered nearly to control levels or in some cases above control levels by that date (Figure 5). Treatments did significantly affect the amount of TNC stored in the roots of the species evaluated for a few months to nearly one year, but these differences did not persist after one growing season without treatment.

Table 3. ANCOVA p-values for treatment and time effects for two multiple year models. (Bold indicates a significant value, $p < 0.05$. * = interaction term is significant, $p < 0.05$).

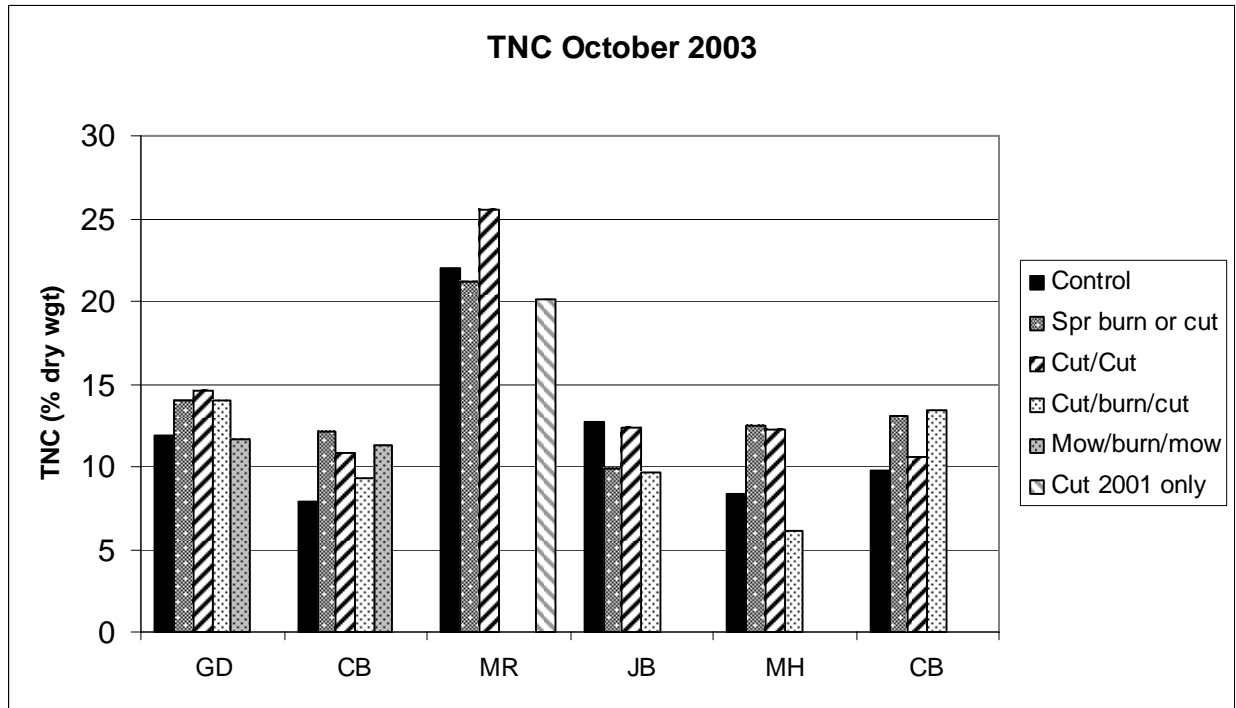| Species/site	Treatment		Time	
	2001-2002	2001-2003	2001-2002	2001-2003
Gray Dogwood / Lay Road	**0.045**	0.143	**0.000**	**0.016**
Common Buckthorn / Lay Road	**0.028**	**0.027**	0.059	**0.025**
Multiflora Rose / Clark Ridge	**0.029**	0.153	**0.017**	0.259
Japanese Barberry / Bartholomew	0.315*	0.332	**0.026***	**0.025**
Morrow's Honeysuckle / Bear Rock Stream	**0.000***	**0.000**	**0.038***	0.909
Catbrier / Naushon	**0.002***	**0.008***	0.574*	**0.001***

TNC October 2003

Figure 5. Total non-structural carbohydrates (TNC) sampled in October 2003 for all species and treatments. Gray Dogwood (GD), Common Buckthorn (CB), Multiflora Rose (MR), Japanese Barberry (JB), Morrow's Honeysuckle (MH), and Catbrier (CB). Treatments are listed in Table 1. All except the spring treatments were applied during the growing season.

Gray Dogwood:

Although there was some year-to-year variation, TNC of the control plot plants followed a normal cycle of depletion in the spring followed by replenishment during the growing season for both 2001 and 2002 (Figure 6). Treatments applied during the study included a combination of mowing, brushcutting, and burning (see Table 1). In 2001, two different growing season cut treatments were applied: mow and brushcut. Dogwood TNC stores appeared to have been replenished from their spring lows (to some extent) in the brushcut plot and the multiple mow plot prior to this first treatment (in mid-July and mid-June respectively), but not in the mow/burn plot (mowed on June 23rd). Yet these treatments appear to have caused a reduction in TNC compared to the control plants (Figure 6). A second treatment (prescribed burn on August 24th) within that growing season resulted in Dogwood TNC in the two burn plots (mow/burn & cut/burn) not recovering to control levels by the end of the first growing season. The mow only plot (mowed just once on June 23rd) did recover to control TNC levels by October 2001.
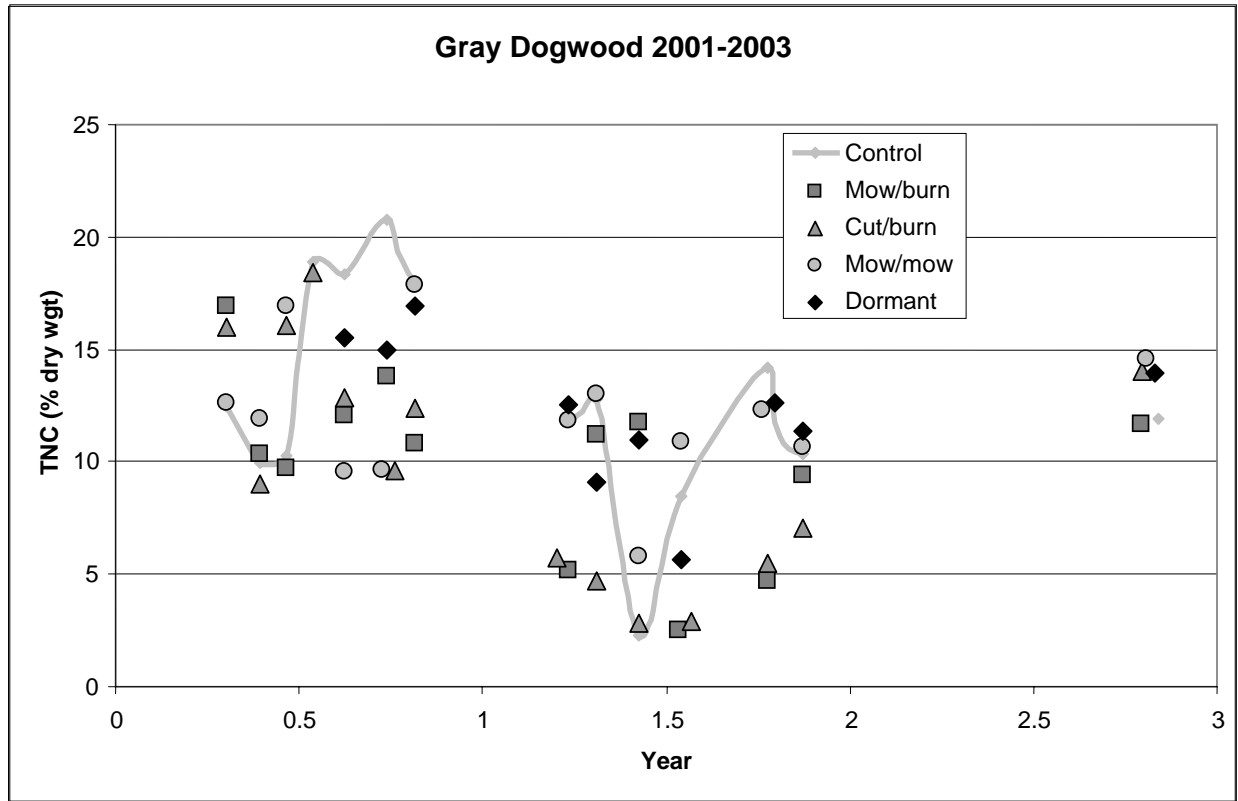
21

Figure 6. Total non-structural carbohydrates (% dry weight) for Gray Dogwood from 2001 - 2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

During the second year (2002), a new plot was treated with a dormant (April 24th) cut, and the 2001 growing season treated plots received either one or two mowing treatments (mow/burn mowed on June 13th and July 25th, cut/burn and mow/mow mowed on July 25th). The dormant plot plants depleted their reserves earlier than the control plot, but quickly recovered to control levels. The mow/mow plot followed the control curve, even after a second mowing. The mow/burn and cut/burn plots remained lower than the control until November when the mow/burn plot recovered to the control level. Although the cut/burn plot remained lower, it was replenishing its reserves after being mowed. When tested with ANCOVA, treatment effects were significant for 2001-2002 (p=0.045). In the spring of 2003, the dormant season plot (previously cut in spring 2002) was burned. This plot's TNC values were close to control levels prior to the spring burn and were again similar in October 2003. An ANCOVA completed using

the entire data set (2001-2003) indicated a non-significant treatment effect (p=0.143), but a significant effect of time (the covariate) (Table 3).

The wave form equation derived from the Gray Dogwood control data captured much of the variation in the data (r^2=0.65, p=0.012) and was therefore a suitable equation to test the relationship between the control and treatment plots. Observed TNC values were generally lower than expected for the two summer treatments that included burning (mow/burn and cut/burn) (Figure 7). T-tests of these residuals (mow/burn and cut/burn) were significant (p=0.056, 0.025 respectively), indicating that the TNC of these treatments departed from the expected TNC from the derived equation for Dogwood. Residuals from the growing season
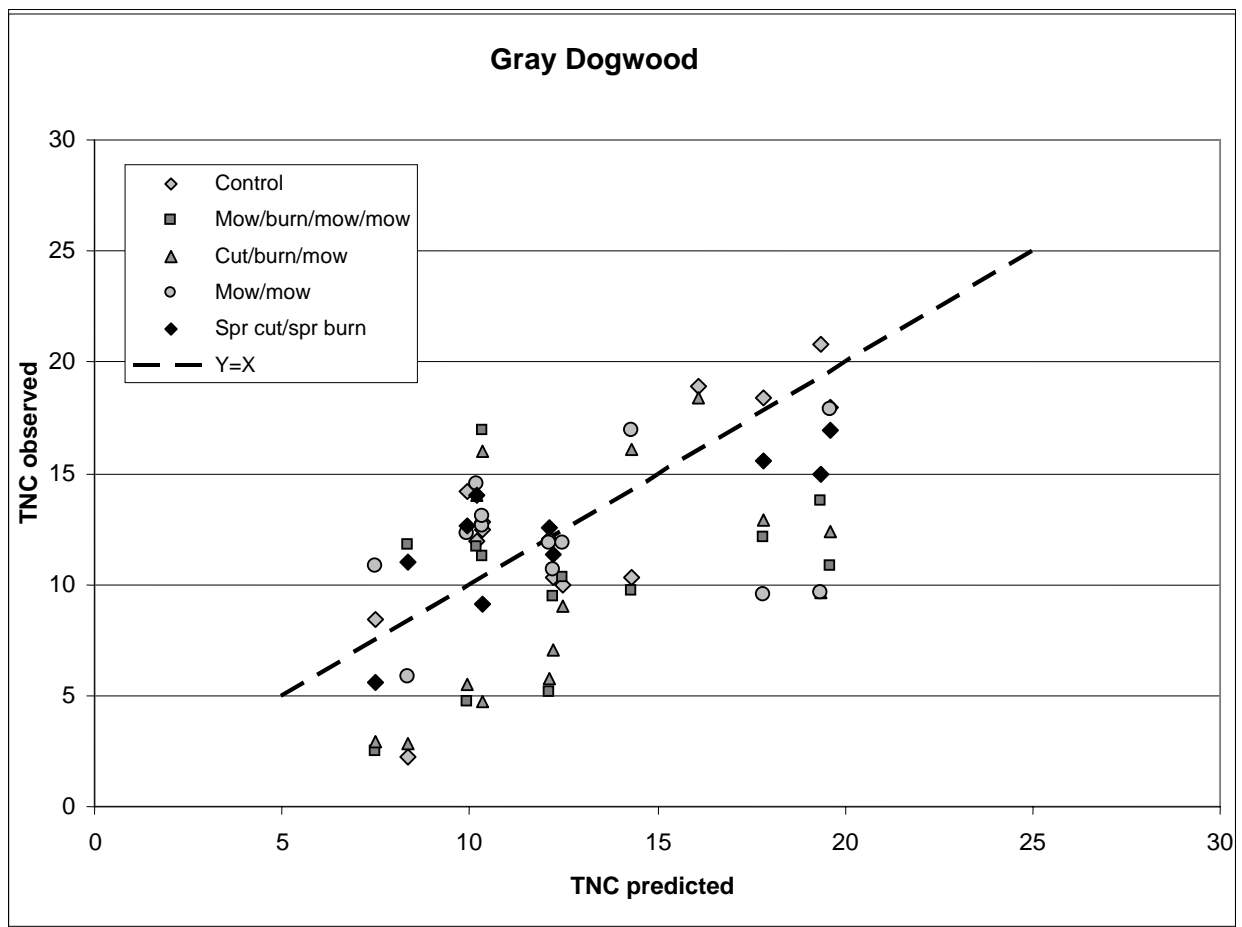

Figure 7. Plot of observed versus predicted TNC for Gray Dogwood. Predicted values from the equation derived from the control data points.

mow only and the dormant season treated plots were not significantly different from zero (p=0.665, 0.665 respectively).

Common Buckthorn:

Similar to Dogwood, Common Buckthorn also depleted its reserves in the spring and replenished them during the summer for both 2001 and 2002, although the replenishment phase appears to be shorter in Buckthorn. Treatments for this species were the same as those described above for Dogwood as both species were sampled from the same plots (see Table 1). With the exception of the mow/mow plot (which was initially higher than the control), Buckthorn TNC levels for the other plots were comparable to those for the control plot prior to treatment. In 2001 all summer treatments resulted in reduced TNC. The dormant cut treatment (on April 24th)
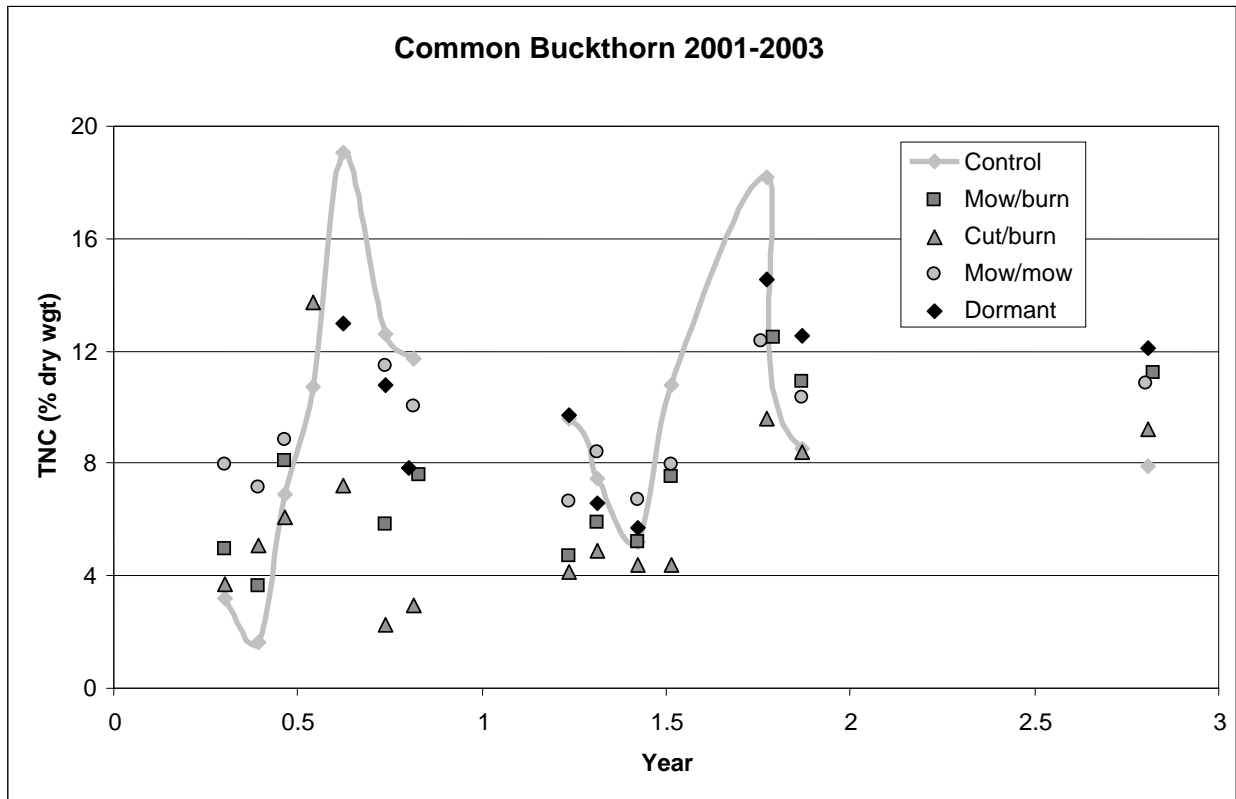

Figure 8. Total non-structural carbohydrates (% dry weight) for Common Buckthorn from 2001 -2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

had little impact on TNC during 2002, while the treatments that were applied during the growing season appeared to have kept TNC from replenishing until the end of the growing season. After the second-year (2002) treatments (including a dormant season cut), TNC was significantly reduced (ANCOVA for 2001-2002, p=0.028). No treatments were applied to any plot after the spring of 2003, and the ANCOVA for 2001-2003 was also significant (p=0.027), although TNC levels of all plots exceeded the control in October, 2003 (Figure 8).

The wave form equation derived for Buckthorn significantly fit the control data (r^2=0.58, p=0.030). Comparison of dormant-treatment observed TNC to those predicted by the derived equation indicate a nearly perfect fit (t-test p=0.981, Figure 9). The only treatment that resulted in a significant departure from the derived equation was the cut/burn treatment (t-test p=0.010) where TNC was generally lower than predicted (Figure 9).
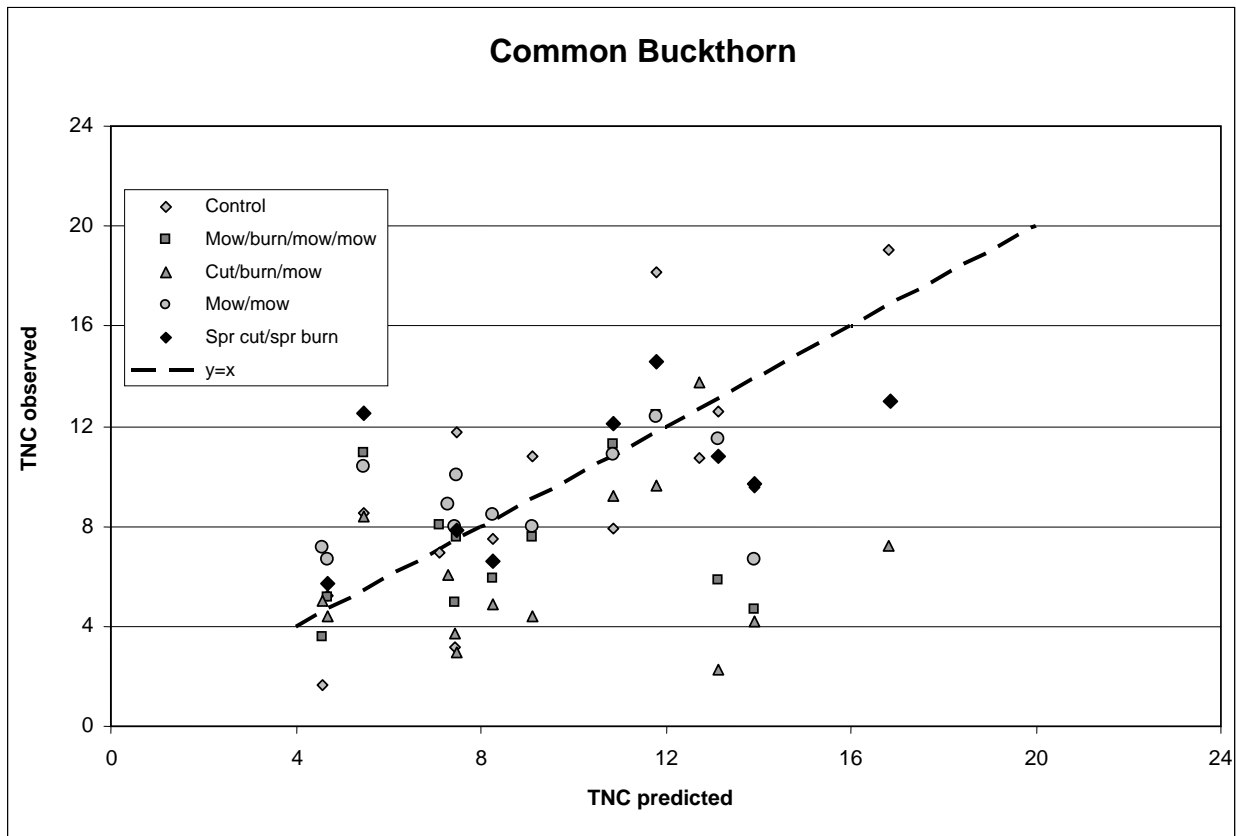

Figure 9. Plot of observed versus predicted TNC for Common Buckthorn. Predicted values from the equation derived from the control data points.

Multiflora Rose:

TNC for Multiflora Rose was depleted and replenished during the growing season in the control plot, although the depletion was generally smaller than in the other species (Figure 10). Cut treatments were applied to two plots in the early summer of 2001 (cut/cut July 13th, cut once July 17th), and only temporarily reduced TNC levels. The dormant season treatment was applied in the spring of 2002 (April 23rd) and TNC was temporarily depressed. Another plot was cut for a second time in the summer of 2002 (August 13th). Both plots that were cut during the growing season had TNC levels well below the control until the end of the 2002 growing season when the cut-once plot replenished to that of the control plot level. The ANCOVA for 2001-2002 was significant (p=0.029). By October 2003, however, even the multiple cut plot recovered to above the control TNC level. Overall, TNC was not significantly affected by the treatments across the three years of the study (ANCOVA for 2001-2003 p=0.153).
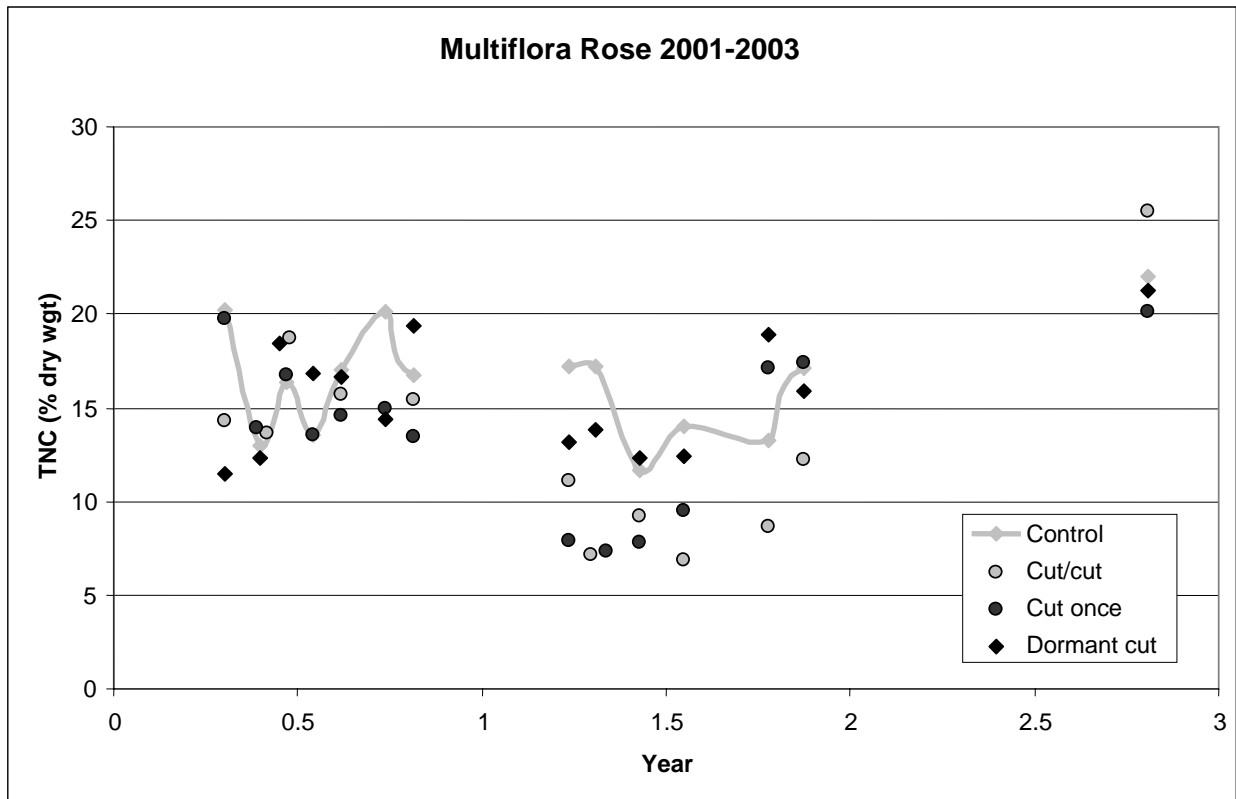

Figure 10. Total non-structural carbohydrates (% dry weight) for Multiflora Rose from 2001 - 2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

The wave form equation derived for Multiflora Rose did not significantly fit the control data (r^2=0.30, p=0.292). The residuals from all treatments were also non-significant, although the multiple-cut plot appeared to generally be lower than predicted (Figure 11).
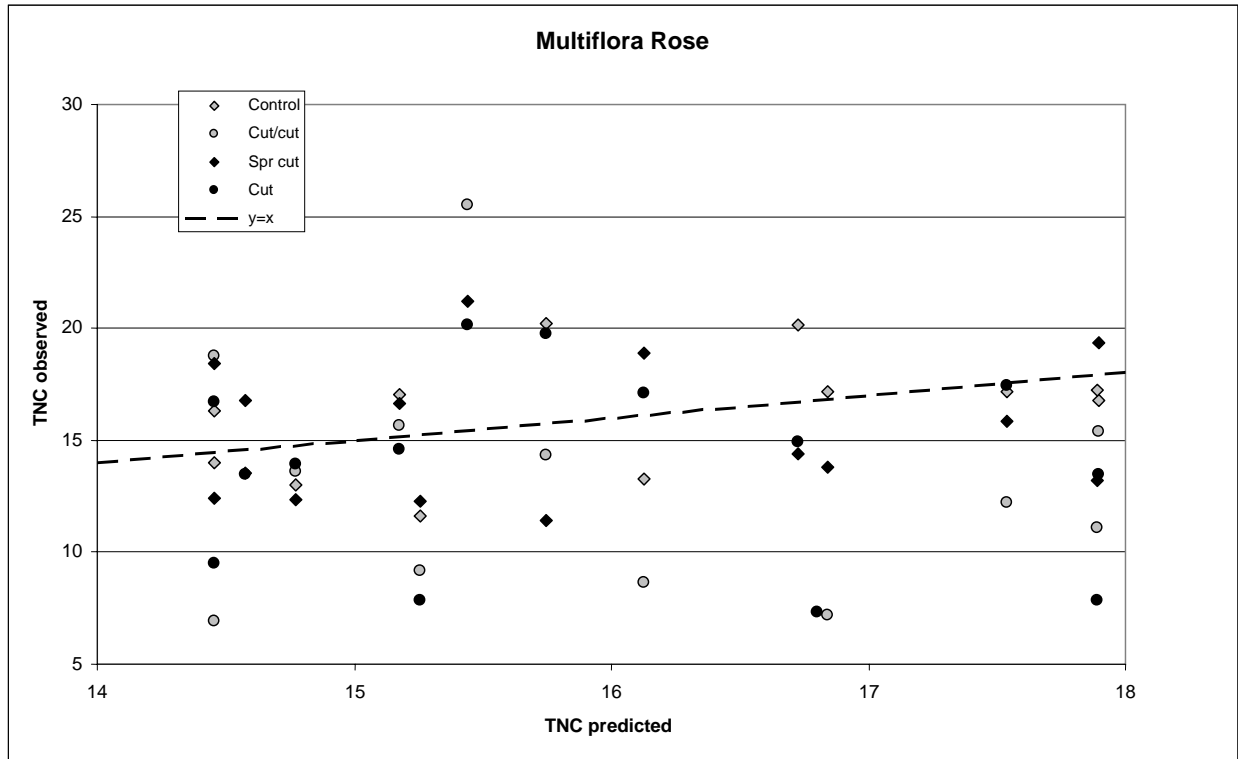

Figure 11. Plot of observed versus predicted TNC for Multiflora Rose. Predicted values from the equation derived from the control data points.

Japanese Barberry:

In 2001 TNC levels for Japanese Barberry (control) appear to have been depleted in the spring (prior to our first sampling of roots), and then recovered, but were also unexpectedly depleted later that same growing season (Figure 12). This second depletion of reserves may have coincided with the depletion of reserves due to cutting treatments, but we cannot know if depletion in the treated plots was due to treatments or the unknown factor affecting the control plot. All TNC levels were very similar throughout 2001, with TNC levels in the growing season cut plots temporarily higher than the control during the unexplained depression in the later. A burn was attempted during August 2001, but the fuels were too sparse to carry a fire. A second

attempt at burning was successfully completed after leaf-fall in November 2001. In 2002 there was the expected single depletion of TNC in the control plants, and all treated plots remained depleted throughout the growing season. A "dormant" season prescribed fire was accomplished in early April, at which time the Barberry had already leafed out while the native species had not. Although TNC appears to be significantly reduced in 2002, the ANCOVA of the 2001-2002 data was not significant (p=0.315). After one growing season without treatments, any depleted TNC in the treated plots returned to levels comparable to those of the control (ANCOVA of 2001-2003 data, p=0.332).
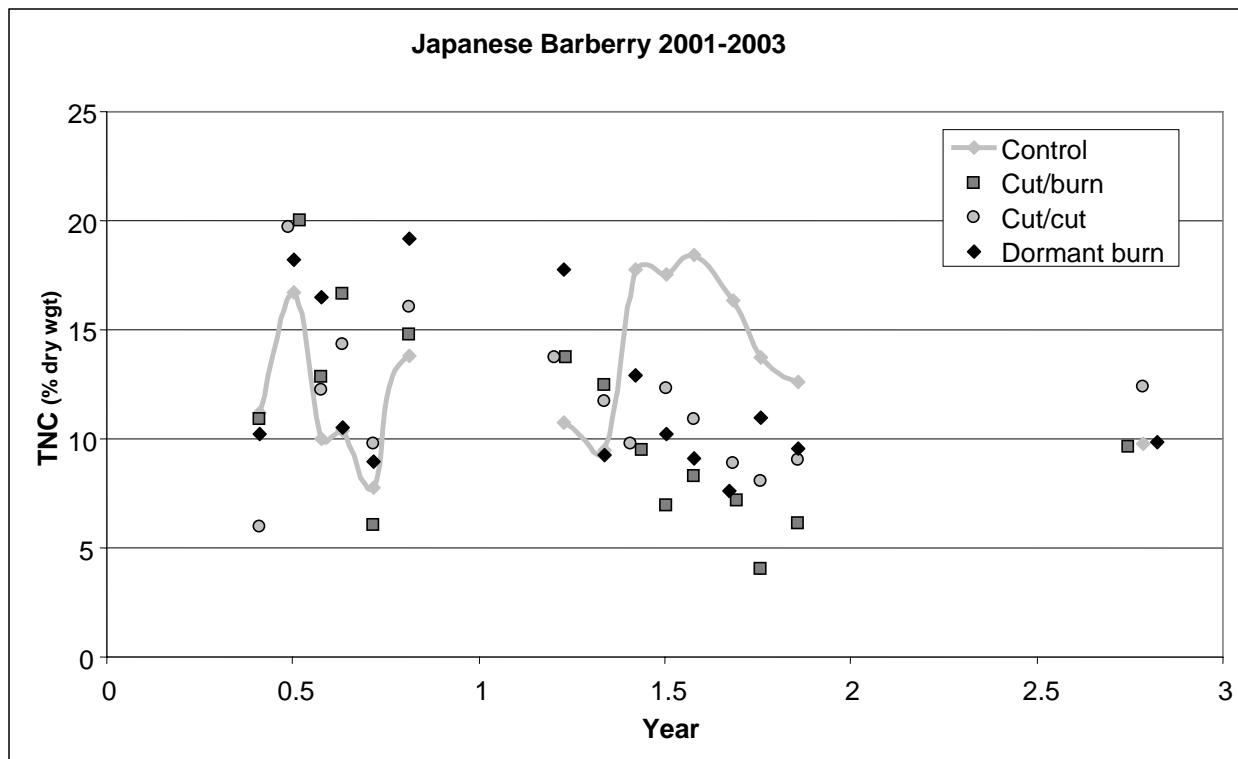

Figure 12. Total non-structural carbohydrates (% dry weight) for Japanese Barberry from 2001 - 2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

Although the derived wave form equation for Barberry appears to explain much of the variation in the data, it is not significant (r^2=0.40, p=0.122). Comparisons of the treatment

residuals were also not significant, although the growing season treatments generally appeared to be lower than predicted (Figure 13).
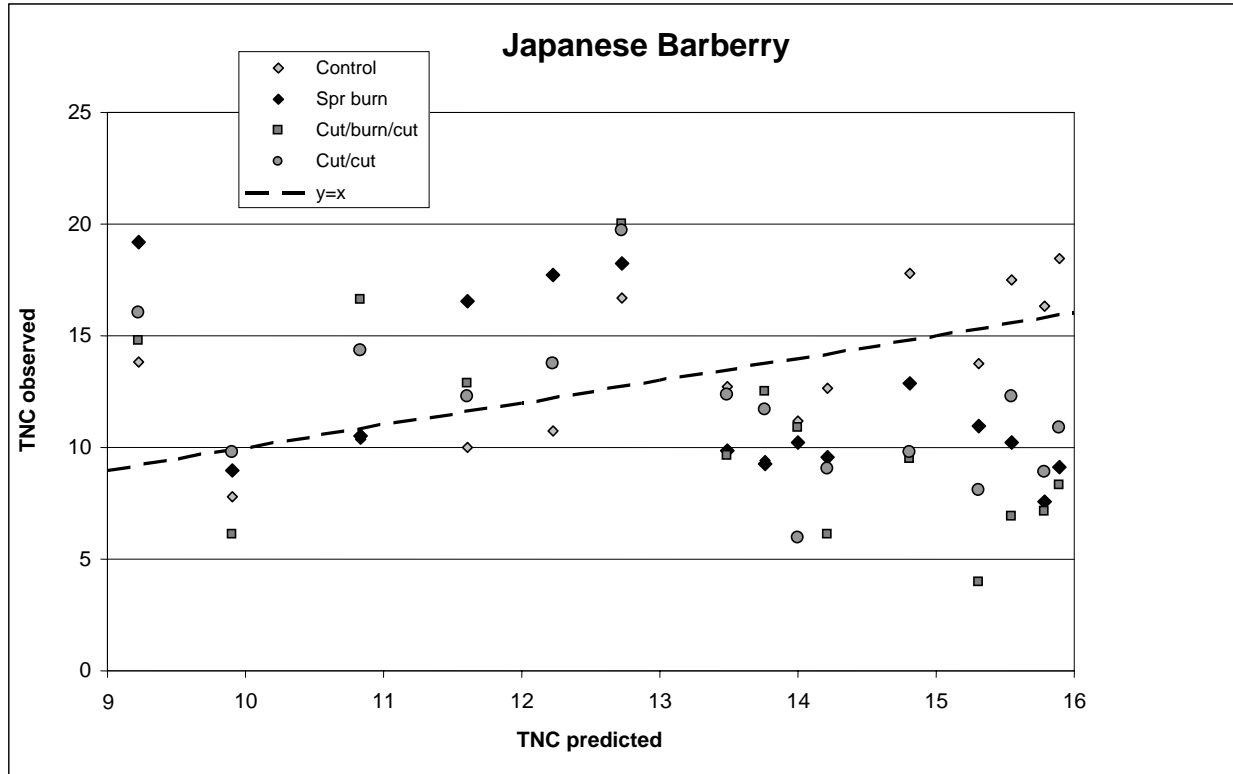

Figure 13. Plot of observed versus predicted TNC for Japanese Barberry. Predicted values from the equation derived from the control data points.

Morrow's Honeysuckle:

The TNC results indicate that Morrow's Honeysuckle depletes its reserves earlier than we were able to capture with our sampling, but in both 2001 and 2002 TNC levels in the control plants followed the expected trend of low values in late spring followed by replenishment (Figure 14). Changes to TNC following treatments in 2001 did result in significant depletions, with all treatment values lower than in the control. Additional treatments in 2002 produced additional significant depletions in TNC (ANCOVA for 2001-2002, p=0.000). Unlike the species listed above, TNC for treated Honeysuckle remained significantly different through

October 2003 (ANCOVA for 2001-2003, p=0.000), although some of this difference is likely due to the lower than expected TNC in the control plants. The cut/burn plot was treated a total of four times during the study - twice in each growing season (2001 and 2002) - and remained depleted through the end of 2003.
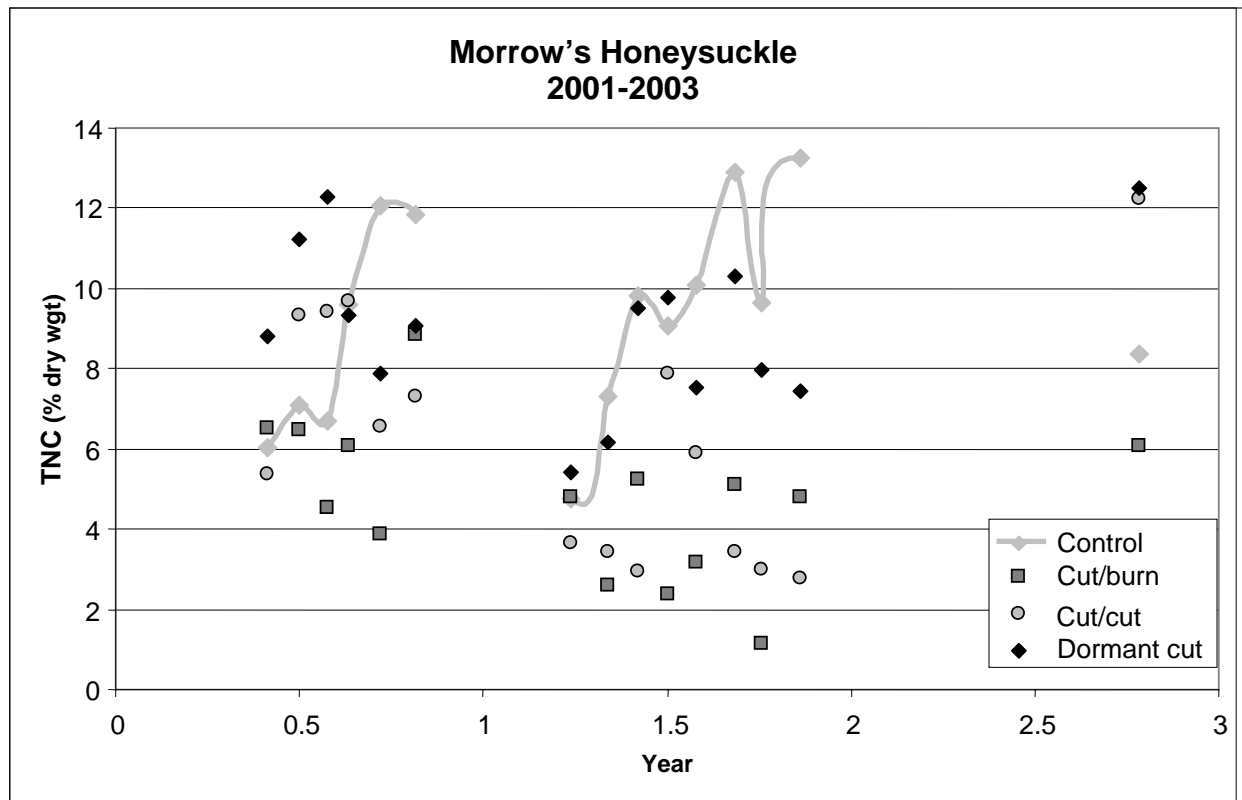
Figure 14. Total non-structural carbohydrates (% dry weight) for Morrow's Honeysuckle from 2001 -2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

The wave form equation derived for Honeysuckle significantly fit the control data (r^2=0.72, p=0.002). Comparisons of the residuals from the two summer treatments (cut only and cut/burn) were significant (t-test p=0.008, 0.000 respectively), indicating that the TNC of these treatments were lower than those predicted (Figure 15). Residuals of the dormant season cut plot were not significantly different (p=0.770).

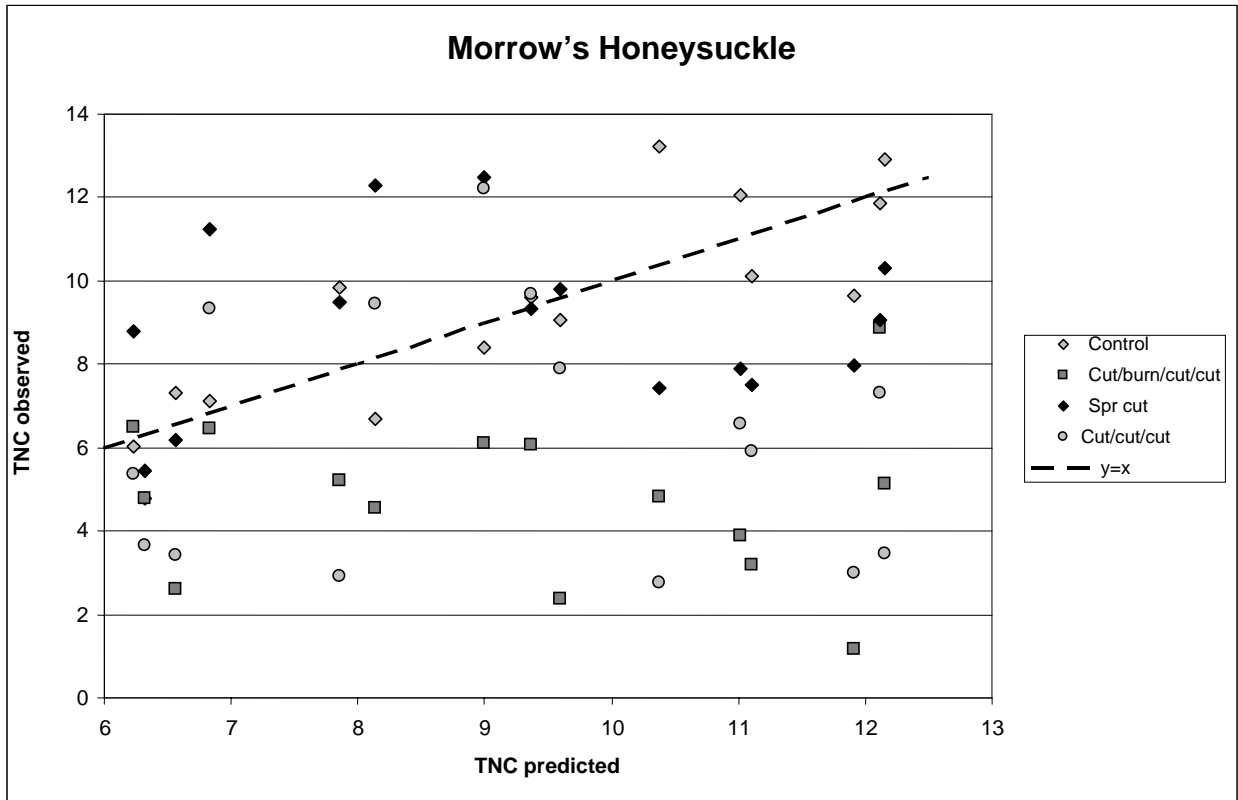Figure 15. Plot of observed versus predicted TNC for Morrow's Honeysuckle. Predicted values from the equation derived from the control data points.

Catbrier:

Catbrier has significantly lower TNC levels in control plants than the other six species we studied. In 2001 TNC levels in the control plot followed the expected depletion and recovery, but in 2002 the initial depletion in the spring was not followed by a strong recovery, perhaps due to an extended drought at the site (Figure 16, Henlin 2004). Graphs of the 2001 samples indicate large differences among treatments. TNC in both treatments applied during the growing season were depleted relative to the control, while the dormant treatment plot's TNC remained equal to or above the control prior to its treatment. The dormant season treatment (burn) was applied in the spring of 2002, and the growing season treated plots were cut again in that year. TNC in the dormant burned plot was depleted relative to the control for a few months before recovering to

the control level by the end of 2002. The growing season cut/burn plot also replenished TNC during 2002, even after being cut a second time on August 6th. The ANCOVA for 2001-2002 was significant (p=0.002). Unlike most species we studied, differences in TNC of Catbrier remained significant following one growing season without treatments (2001-2003 ANCOVA p=0.008). All of the treatment plots had TNC levels higher than the control in October, 2003.
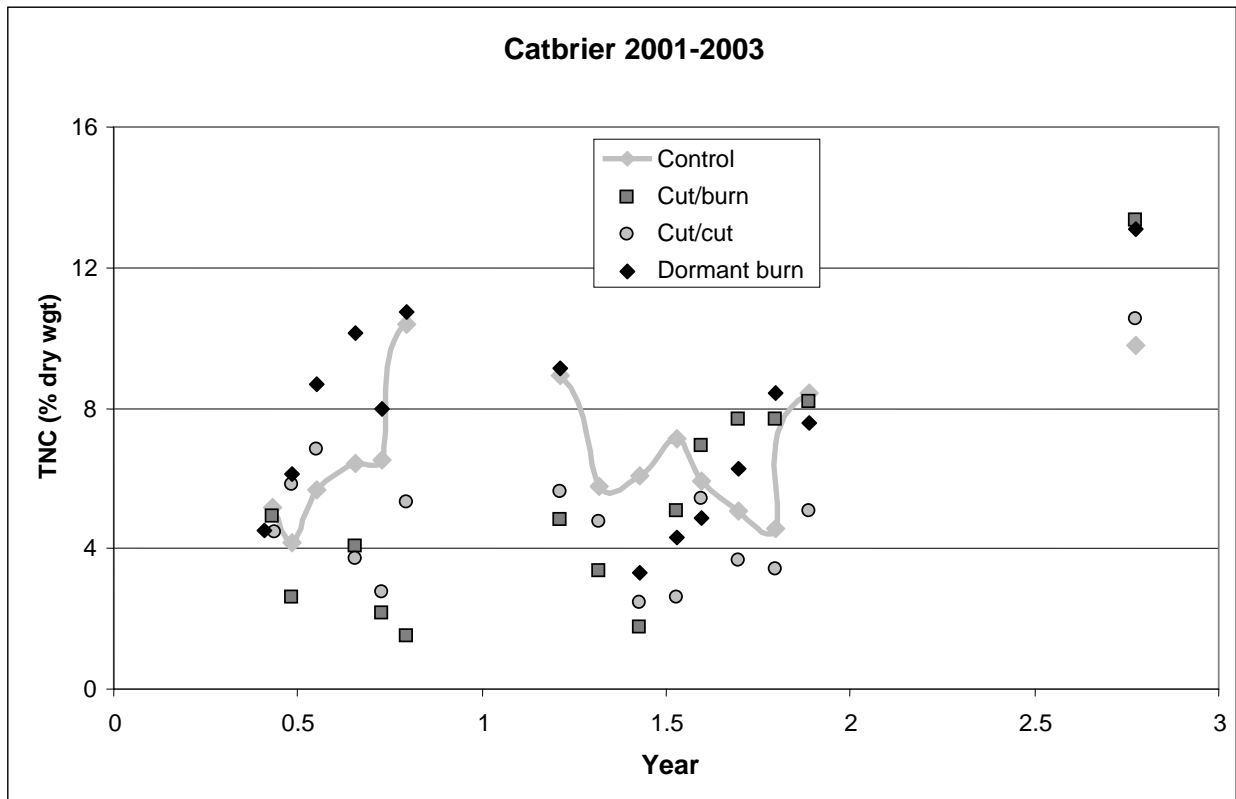
Figure 16. Total non-structural carbohydrates (% dry weight) for Catbrier from 2001 -2003. Overlapping symbols were offset along the x-axis. (Year 0-1 is 2001, 1-2 is 2002, and 2-3 is 2003). Treatments are listed in Table 1. All except the "Dormant" treatment were applied during the growing season.

The derived wave form equation for Catbrier did not significantly explain the control data (r^2=0.34, p=0.197). The observed minus. predicted TNC values from the summer cut only treatment significantly varied from zero (p=0.009), with observed levels generally lower than predicted (Figure 17).
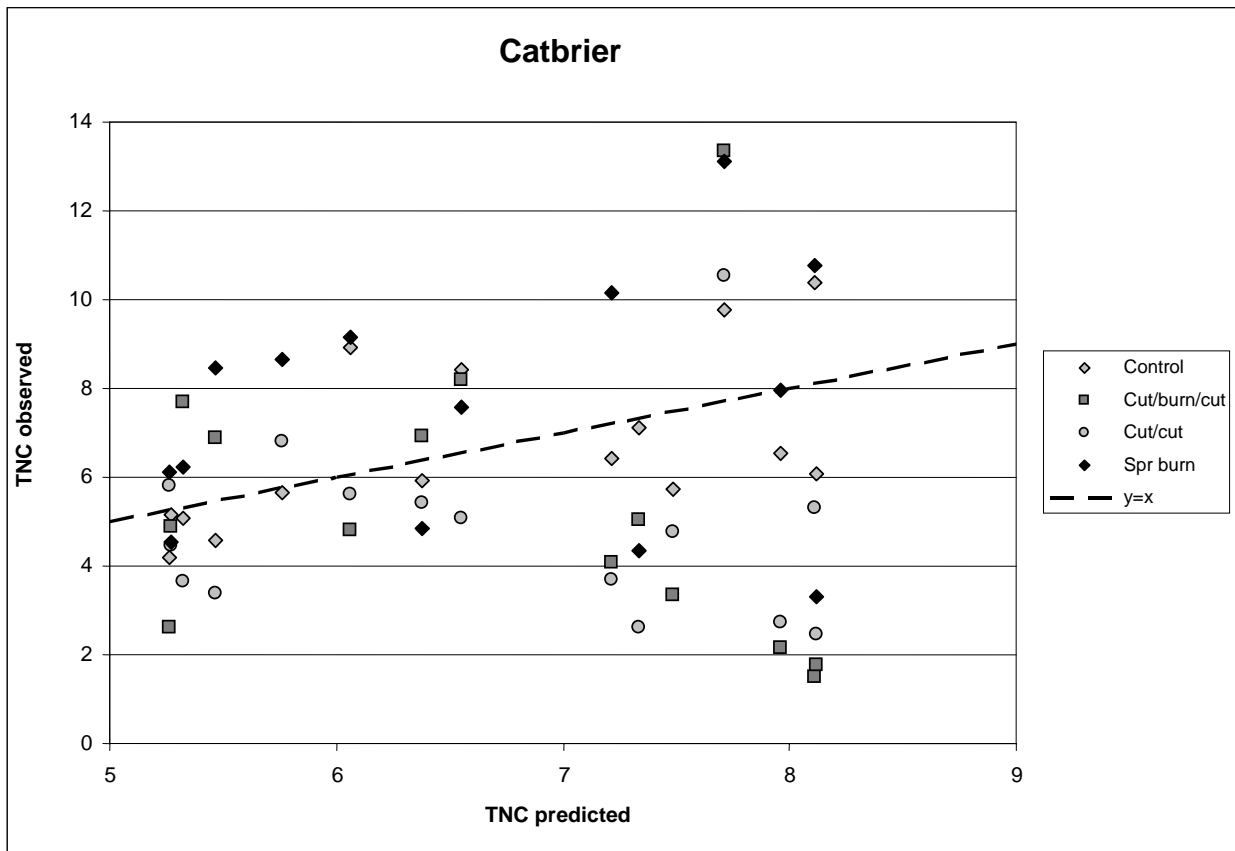
Figure 17. Plot of observed versus predicted TNC for Catbrier. Predicted values from the equation derived from the control data points.

Biomass production (vigor) following treatments

Heights of sprouts differed depending on species, treatment type, and site location. In general, dormant season treated plots had taller sprouts by late summer 2003 than the growing season treated plots (Figure 18). This was true for all species sampled except Japanese Barberry at the Bartholomew site. In this case, the repeatedly cut plot had taller, although not significantly (the 95% confidence intervals overlapped), sprouts at the time of harvest (Figure 18) than the dormant plot. Although some of the height difference may have been due to the differential amount of growing time since last treatment (Table 4), this was not the case across all species. In fact for Gray Dogwood and Common Buckthorn, the dormant plot sprouts were more than double the height of the other treatment plots' sprouts despite the fact that the dormant plot was

treated only four months before the samples were collected and the growing season plots had
more than one year to grow before sampling. The growing season treatments, cut and burn vs.
mow and burn vs. multiple cut, were generally similar in their sprout heights (overlapping 95%
confidence intervals) for Dogwood, and Barberry and Honeysuckle at Bear Rock Stream. In the
cut plot for Buckthorn, however, heights were greater than in the other growing season plots, but
much shorter than the dormant season plot.

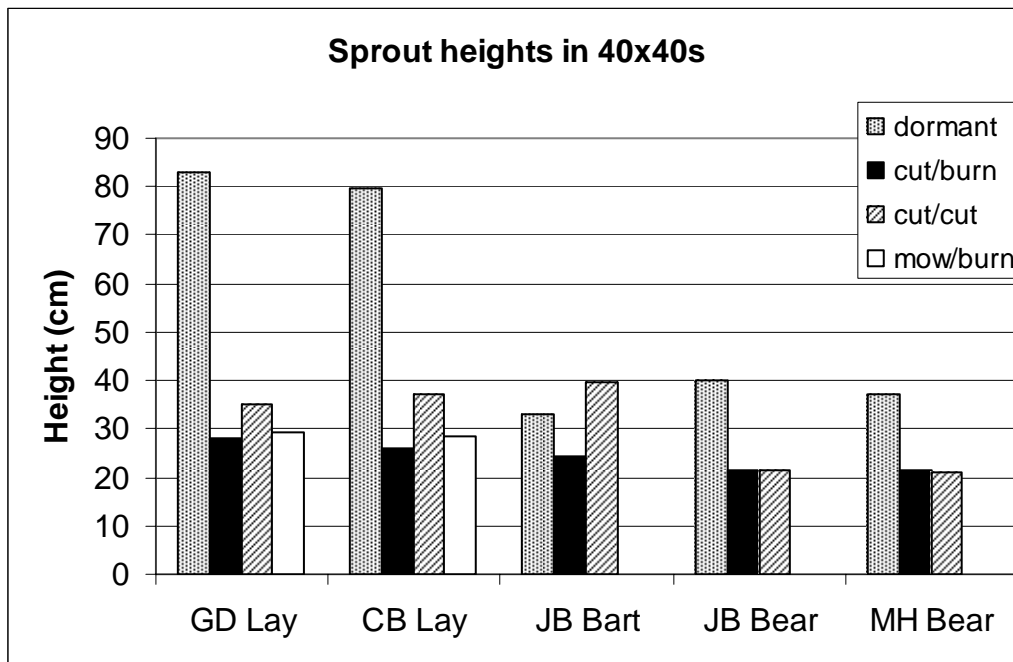Figure 18. Average height (cm) of sprouts collected in 40 cm x 40 cm harvest samples for plots
sampled at the end of the growing season in 2003. All plots except the "Dormant" treatment
were treated during the growing season. GD – Gray Dogwood, CB – Common Buckthorn, JB –
Japanese Barberry, MH – Morrow's Honeysuckle. Lay –Lay Road site, Bart – Bartholomew
site, Bear – Bear Rock Stream site.

Table 4. Dates of last treatment and collection of samples for height, numbers, and biomass of sprouts from 40 cm x 40 cm randomly placed quadrats.

Plot #	Treatments	Date of last treatment	Destructive harvest
Montezuma NWR – Lay Road			
Lay - 1	Control	-	-
Lay - 2	Mow, burn, mow, mow	July 25, 2002	August 11, 2003
Lay - 3	Cut, burn, mow	July 25, 2002	August 11, 2003
Lay - 4	Mow, mow	July 25, 2002	August 14, 2003
Lay - 5	Spring cut, spring burn	April 25, 2003	August 14, 2003
Bartholomew Property – Berkshires			
Bart - 1	Spring burn	April 19, 2002	August 20, 2003
Bart - 2	Control	-	-
Bart - 3	Cut, burn, cut	July 25, 2002	August 20, 2003
Bart - 4	Cut, cut	July 25, 2002	August 20, 2003
Bear Rock Stream Property – Berkshires			
Bear - 1	Control	-	-
Bear - 2	Cut, burn, cut, cut	July 24, 2002	September 21, 2003
Bear - 3	Spring cut	April 12, 2002	September 21, 2003
Bear - 4	Cut, cut, cut	July 24, 2002	September 21, 2003
Naushon Island			
Nau - 5	Cut, burn, cut	August 6, 2002	September 25, 2003
Nau - 6	Cut, cut	August 6, 2002	September 25, 2003
Nau - 7	Spring burn	April 5, 2002	September 25, 2003
Nau - 8	Control	-	-

Numbers of sprouts were counted in each 40 cm x 40 cm harvest plot. Although the dormant season plots tended to be taller, for most species they had fewer or the same number of sprouts compared to the growing season plots (Figure 19). All treatments of Common Buckthorn, except for the dormant treated plot, had exceptionally large numbers of sprouts compared to the other species.
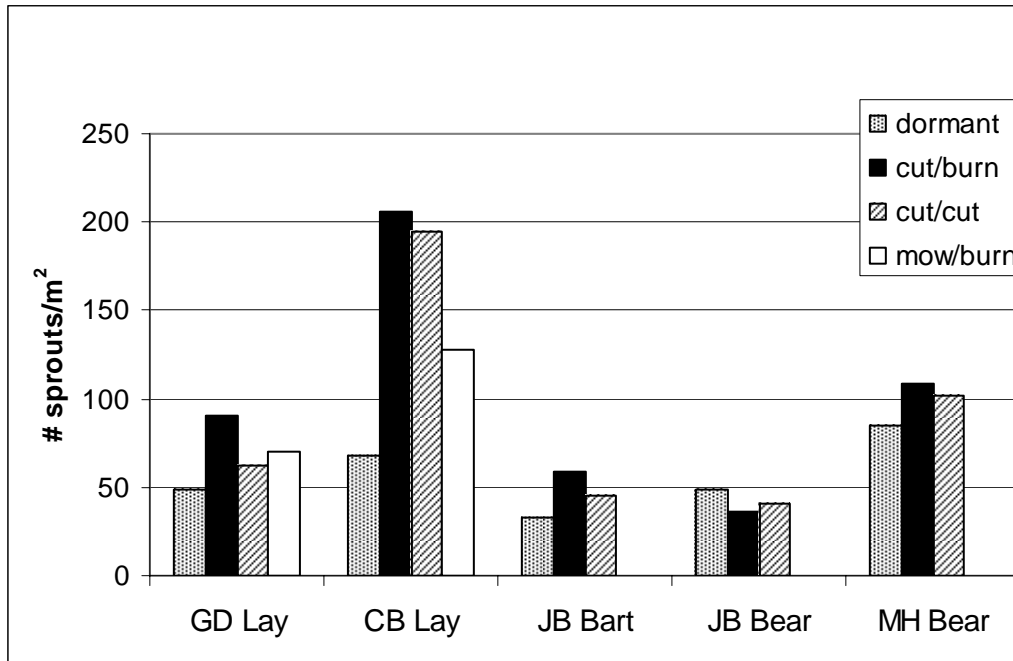
Figure 19. Numbers of sprouts per square meter for plots sampled at the end of the growing season in 2003. All plots except the "Dormant" treatment were treated during the growing season. GD – Gray Dogwood, CB – Common Buckthorn, JB – Japanese Barberry, MH – Morrow's Honeysuckle. Lay –Lay Road site, Bart – Bartholomew site, Bear – Bear Rock Stream site.

Like the height data, the amount of biomass was generally greater in the dormant season treated plots – in some cases more than an order of magnitude (Figure 20). This trend was the same whether looking at stem biomass, leaf biomass, or the two combined. The difference in biomass between the different treatments seems related more to the type of treatment than the amount of growing time since last treatment. This is especially noticeable for Dogwood and Buckthorn where the dormant season treated sprouts weigh much more than the growing season treated sprouts even though they only grew for several months before harvest compared to more than one year. Growing season treated plots that had more treatments generally had less biomass accumulation than those treated fewer times, although this trend does not appear to be significant.
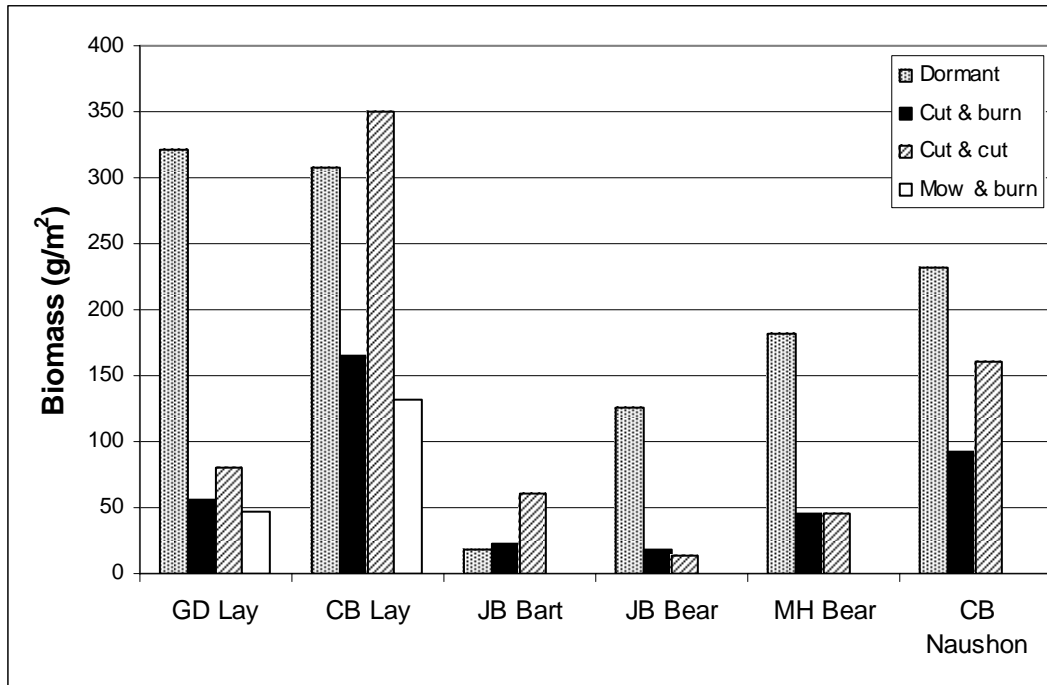
Figure 20. Biomass (g/m^2) of sprouts for plots sampled at the end of the growing season in 2003. All plots except the "Dormant" treatment were treated during the growing season. GD – Gray Dogwood, CB – Common Buckthorn, JB – Japanese Barberry, MH – Morrow's Honeysuckle. Lay –Lay Road site, Bart – Bartholomew site, Bear – Bear Rock Stream site, Naushon – Naushon Island.

Vegetation composition pre- and post-treatment

Lay Road: In 2001 prior to treatment, the most common species (and their average percent cover across all plots) were: Gray Dogwood (72%), goldenrod (36%), Poison Ivy (36%), Blackberry (20%), and a variety of grasses (80%). Average richness (# species) of plots in 2001 was 33. Following all treatments, the cover of Dogwood decreased (to 20-30%) while richness increased (Table 5). In general, cover of woody species decreased whereas that of herbs increased.

Table 5. Species richness pre-treatment (2001) and post-treatments (2002 and 2003).

Site / plot	2001	2002	2003
Lay Road (Montezuma NWR) target species Gray Dogwood & Common Buckthorn			
Lay 1 (control)	35	32	42
Lay 2 (mow/burn)	31	NA	54
Lay 3 (cut/burn)	NA	54	53
Lay 4 (mow)	29	46	46
Lay 5 (dormant cut/burn)	35	38	57
Bartholomew Property (Berkshires) target species Japanese Barberry			
Bart 1 (dormant burn)	18	14	18
Bart 2 (control)	19	20	23
Bart 3 (cut/burn)	15	14	19
Bart 4 (cut)	18	11	19
Bear Rock Stream Property (Berkshires) target species Morrow's Honeysuckle			
Bear 1 (control)	39	46	45
Bear 2 (cut/burn)	55	43	41
Bear 3 (dormant cut)	49	55	49
Bear 4 (cut)	42	52	48
Naushon Island target species Catbrier			
Nau 5 (cut/burn)	10	9	9
Nau 6 (cut)	6	6	9
Nau 7 (dormant burn)	6	6	8
Nau 8 (control)	4	3	2

Bartholomew Site: Japanese Barberry dominated the understory of all plots in 2001, prior to treatment, with an average cover of 70%. No other species had a cover value above 10% in these Barberry thickets. Following treatment, Barberry cover decreased significantly to less than 5% in the plots that were burned, but only decreased by half (to 30% cover) in the plot that was cut during the growing season. Unlike the Lay Road site, richness values did not change post treatment (Table 5).

Bear Rock Stream Site: Morrow's Honeysuckle dominated the understory in nearly all of these plots with an average cover among plots of 50%. No other species had cover as great as the Honeysuckle prior to treatment. Following treatment, Honeysuckle cover decreased by 80% in the growing season treated plots, but only by 20% in the dormant season treated plot. Richness values varied from year to year in both the control and treated plots, which may be due more to the time of sampling at this rich site than the type of treatment applied (Table 5).

Naushon Catbrier Plots: Catbrier dominated these plots with an average cover of 85% (three plots had > 90% cover, the fourth had 56% cover). Species diversity was low with ten or fewer species prior to treatments in 2001 (Table 5). Following treatments, Catbrier cover decreased by 75% in the burned plots, but only by 50% in the cut plot. Richness numbers did not change, although in the cut plot and the dormant burn plot there may be a few additional species present.

Effect of treatments on fuels and fire behavior

Fuels treatments fell into three categories: 1) cutting with saws, 2) grinding with rotary mowers, and 3) prescribed fire. Individual plots received one or more of these treatments, or were left as untreated controls. We report our results here in English units, as these were used to develop custom fuel models with outputs in English units and are what virtually all fire managers in the United States work with. All treatments impact the availability of fuels for subsequent fires, most notably in the effects they have on consuming (and/or producing) dead fuels, altering fuel bed depths, and changing the packing ratios of fuel beds. Different mechanical treatments had different effects on fuels (Table 6).

Table 6. Fuel bed characteristics for untreated (control) and treated plots by species and treatment. Fuel loads calculated from 40 x 40 cm harvest-plots. NA = no data available.

Fuel Type	Treatment	1-hr Woody (tons/acre)	1-hr Non-woody (tons/acre)	10-hr Woody (tons/acre)	Fuel Bed Depth (ft)
Gray Dogwood	None	0	0.2	0	0.3
	Cut	3.2	1.6	2.9	0.7
	Grind	3.2	1.6	2.9	0.5
Japanese Barberry	None	0.5	2.8	0.9	0.8
	Cut	1.6	1.5	1.5	0.7
Morrow's Honeysuckle	None	NA	NA	NA	NA
	Cut	1.4	1	0.3	0.4
Catbrier	None	3.3	3.6	0	3
	Cut	6	3.6	0	1.2
	Grind	6	3.6	0	0.5
Scotch Broom	None	0.3	3.5	0	0.8
	Cut	1	1.7	4.8	0.8

The effect that fuels treatments had on fire behavior depended on the treatment and the fuel type. Grinding treatments were only applied to Gray Dogwood and Catbrier fuel types. Fires burning in these fuels were irregular with low rates of spread and flame lengths. This made direct measurement difficult, so fire behavior was not recorded directly. Subjective observations of fire behavior were made as fires burned into areas that had been mowed (Table 7). The Gray Dogwood plot that had been ground was burned in August 2001 at the Lay Road site (Montezuma NWR). This fire burned irregularly, with flame lengths averaging one foot with low rates of spread of 1-2 feet/minute. Fire behavior in Catbrier fuels that had been ground was not measured directly but instead was observed in conjunction with a June 2004 growing season burn in untreated Catbrier fuels. A fire break surrounding the Catbrier control plot had been ground and a head fire was allowed to burn freely into it. Intensity of the fire dropped dramatically as it reached the 10-foot-wide break, and in our opinion it would not have continued to burn as a running head fire if the break had extended for several more feet. The fire which had been burning with 20-foot flame lengths at nearly 40 feet per minute died completely when it entered a previously burned grass fuel bed.

Where fires carried actively through the fuel bed on control and cut plots (either in the growing or dormant season), burning reduced the available fine (1-hr) fuel loads to near zero until leaf litter and other fine fuels had a chance to accumulate in subsequent seasons. In two cases (Japanese Barberry and Morrow's Honeysuckle), growing season burns did not carry across even the cut plots – fire behavior parameters (flame length and rate of spread) were zero – so these plots were burned later during the dormant season (Table 7). For the two other study species (Multiflora Rose and Common Buckthorn) fuels generated from cutting these species were sparse and patchy, and their fuel characteristics and associated fire behavior were not measured. (Table 7).

Table 7. Flame length and rate of spread for head fires (or backing fire where indicated with BF) in untreated (control), cut, and grind plots. NA = data not available – observations not made.

Fuel Type	Treatment	Season	Flame Length (ft)	Rate of Spread (ft/min)
Gray Dogwood	No cut	Dorm	1	6
	Cut	Dorm	3	10
	Cut	Grow	2	3
	Grind	Dorm	1	3
Japanese Barberry	No cut	Dorm	1	NA
	Cut	Dorm	1	3
	Cut	Grow	0	0
Morrow's Honeysuckle	No cut	Dorm	0	0
	Cut	Dorm	1	1
	Cut	Grow	0	0
Catbrier	No cut	Grow	18	37
	Cut	Grow	10	NA
	Grind	Grow	3	NA
Scotch Broom	No cut	Dorm	20	NA
	Cut	Grow	3 BF	3 BF

The June 2004 Catbrier burn was aggressively ignited using a head fire. An adjacent plot burned in March 2002 was used as a fire break. Here we were able to directly compare the fire behavior in an untreated plot with that in a plot that was burned two years before (Table 7). In the untreated fuels, fire behavior was extreme. The fire was allowed to burn into the neighboring, previously burned plot which had very sparse fuel – only a very shallow layer of leaf litter, Bracken Ferns, and succulent, young Catbrier stems were present. The fire reached the March 2002 plot as a flanking-fire and immediately died. If a single ignition source such as a burning ember had fallen into this previously burned plot, no more than a smoldering duff fire could have resulted. We are not sure how long it would take fuels to accumulate enough to support a surface fire in previously burned or ground Catbrier fuels, but it would be longer than the three years we have had to observe fuel accumulation in this study.

Two Scotch Broom plots were burned. The first was a cut plot burned in August 2001 under very dry conditions. Because of the potential for extreme fire behavior, including spotting, a backing fire was used. The backfire moved slowly (1-2 feet per minute) against a steady wind

and produced flame lengths that averaged two to three feet. A second Broom burn plot was not cut and was burned in April 2003. Scotch Broom occurs patchily in the plot and thickets are separated by areas of grass and sedge. Fire behavior in the thickets was extreme, with flame lengths exceeding 20 feet. Fire behavior in the grass areas separating the shrubs behaved as predicted by standard fuel model 1 (short grass) with flame lengths of 1-2 feet.

Discussion and Management Implications

Invasive woody species can alter the composition, structure, and fuels of important habitats (Gordon 1998, Mack & D'Antonio 1998, Myers & Bazely 2003, Brooks et al. 2004). By timing treatments to periods when the invasive species is most vulnerable, control efforts may be more effective and efficient. Woody species utilize reserve carbohydrates to support sprouting following dormancy or injury. The amount of reserves influences the ability of an individual to successfully sprout. The greater the reserves, the better the species will be able to sprout and grow new shoots which support leaves to meet energy needs. Our results show that dormant season treatments have little influence on carbohydrate reserves beyond the immediate use of reserves to support sprouting. This use of reserves appears to be comparable to annual spring flushing of new growth. Reserves of the dormant season treated plants were replenished by the end of the growing season following the treatment – a period of only a few months. All treatments changed the structure of the target species by reducing their abundance within the plots by as much as 75%, but the replenishment of TNC reserves in the dormant season treated plants provided the resources necessary to support vigorous sprouting in all of the species in this study. The rapid growth rate of many of these species will lead to the areas becoming similar to pre-treatment stature and composition within just a few years.

Growing season treatments on the other hand, had a greater influence on the replenishment of reserves, although there is also a recovery that appears to take place once sprouts have been formed. The initial treatment applied in the growing season was attempted when reserves were thought to be at their lowest. This timing was not the case for all species studied, as later indicated by TNC processing with some species (i.e. Gray Dogwood, Multiflora Rose, and Japanese Barberry) having recovered reserves prior to at least some treatments.

Multiple treatments in a growing season do result in depressed TNC which can be further depleted if treated again the following year. For the species we studied, two years of treatments did not deplete TNC reserves enough to prevent resprouting, although sprouting in TNC depleted individuals was less vigorous than those with more TNC (e.g. dormant season treated individuals). For several species (e.g. Morrow's Honeysuckle, Catbrier) TNC levels increased rapidly following sprouting leading to some replenishment of TNC prior to the application of a second treatment.

Numbers, height, and amount of biomass of sprouts are related to the amount of underground root reserves and the length of time since treatment. If above-ground biomass is removed when TNC reserves are high (i.e. during the dormant season), the individual plants produce large numbers of sprouts and leaves to replenish the reserves that were utilized. Plants that had their above-ground biomass removed during the early growing season (or following a second treatment) prior to the recovery of TNC reserves produce much smaller sprouts (both in height and total biomass), which therefore increases the amount of time required to replenish reserves. For the three-year period of this study, our results indicate that sprout growth following growing season treatments does not equal that following dormant treatments, even when given more time to grow following treatment. For Gray Dogwood and Common Buckthorn, the results are striking, with sprout growth being much greater in the dormant treated plots four months post-treatment compared to growing season treated plants that had more than a year to grow (at least double the amount of time in the "growing season") (Figure 18). For other species, even though their heights, number of sprouts, and biomass differed less between the dormant and growing season treated plots, our results indicate that growing-season treated plants were not able to recover as quickly as the dormant season plants. For Japanese Barberry and Morrow's Honeysuckle at the Bear Rock Stream Site, the dormant-season treated plants had more than twice the biomass of the growing-season treated plants; a result that cannot be explained solely by the difference in amount of growing time before harvest. For Barberry at the Bartholomew property, however, there was a different result, with the dormant season burn and the growing season cut and burned plots producing less biomass than the plot that was cut during the growing season. This reduced production of biomass in the cut and burned plot is not unexpected, however, as it had one more treatment than the plot that was just cut (three

treatments vs. two treatments). But the small amount of biomass produced by the dormant treated Barberry is lower than expected and may be the result of burning this species during an usually dry year (Henlin 2004).

In addition to a difference in sprouting response due to timing of treatments, there is also species-to-species variation, perhaps dependent on where on the plants sprouts originate (how many buds were damaged by the treatment), the age of the individuals, and in the amount of reserves required for growing new sprouts. Gray Dogwood, Catbrier, and Common Buckthorn generally produced more biomass following all treatments than the other species in the study. Dogwood and Catbrier are both clonal species, and therefore may have been able to acquire TNC from portions of the clone outside of the treatment plots. The large sprouting response of Buckthorn might be due to the greater below-ground biomass of this species compared to others in our study. Although we did not measure it directly, we assume that the Common Buckthorn plants had large root systems due to their larger stems and root diameters than other species of similar age (Richburg, pers. obs.). This additional root mass, along with the larger stumps, may explain why Buckthorn treated in the growing season was able to produce many more sprouts and more biomass than Gray Dogwood, even though their TNC concentrations were both depleted. The amount of below-ground carbohydrate reserves is influenced not only by the concentration of reserves in the roots, but also in the amount of root material . The large root system of larger above-ground stems can produce more sprouts than the smaller root system of smaller plants (Kramer & Kozlowski 1960). It is important to note, however that the above-ground sprouts may not be able to support the entire biomass underground resulting in some decrease in live underground biomass (Lauenroth & Gill 2003).

Effect of treatments on fuels

With mechanical treatments, live fuels, which reduce fire behavior by acting as a heat sink, are felled and allowed to dry and therefore become a potential heat source. Fuel bed depths are also altered. The effect depends upon the fuel and the treatment method. Cutting brings fuels that are not available prior to treatment closer to the ground where they can interact with surface fuels (litter and thatch) and increase fuels available to burn. Grinding has an effect

similar to cutting, but lowers fuel bed depth even further often to the point where packing ratios are increased far beyond the optimum. This reduces the likelihood that surface fires will burn continuously through affected fuel beds. With Gray Dogwood and Catbrier we found that grinding eliminated fire as an option for a second treatment for more than two years.

Burning has the effect of consuming all available fuels if they are horizontally continuous and can carry fire. The amount of fuel consumed depends upon weather, fuel moisture, fuel arrangement, and ignition strategies. A fire under damp conditions is likely to burn off only the litter layer resulting in a small decrease is fuel load. Live shrub stems are usually top killed, however, and these increase the load of dead woody material that might burn in subsequent burns. Conversely, an aggressively applied prescribed burn conducted under dry conditions could consume not only litter, but most 10-hour and aerial fuels and even the duff layer resulting in a situation where the stand is unlikely to have fuels sufficient to carry a fire for some time.

Evaluating potential fire behavior with custom fuel models.

Custom fuel models (CFM) were developed for several species/treatment combinations. Given the difficulties associated with comparing fire behavior observed in plots with different treatment histories burned at times when environmental conditions may have differed among plots, CFMs allow evaluation of predicted (rather than observed) fire behavior with environmental conditions held constant.

Gray Dogwood:

We found that the CFM predicts the unique fuel conditions of untreated Gray Dogwood monocultures during dormant season well. Three standard fuel models (6, 8, and 11) were used for comparison. Fuel model 6 (dormant brush) over-predicts fire behavior in this example and fuel model 8 (closed timber litter) under-predicts (Table 8). In the growing season both the CFM and SFM 11 (light slash) predicted fire behavior well.

Table 8. Observed fire behavior in cut and uncut dormant and growing season Gray Dogwood fuels compared to standard (SFM) and custom fuel model (CFM) predictions.

Fire Behavior	Observed	CFM Predicted	SFM 8 Predicted	SFM 6 Predicted	SFM 11 Predicted
Dormant uncut					
Flame length (ft)	1	1	1	3	0
Rate of spread (ft/min)	6	5	1	10	0
Dormant cut					
Flame length (ft)	3	4	1	3	0
Rate of spread (ft/min)	10	7	1	7	0
Grow cut					
Flame length (ft)	2	2	1	5	2
Rate of spread (ft/min)	3	6	1	22	4
Grow grind					
Flame length (ft)	1	1	1	3	2
Rate of spread (ft/min)	3	3	1	11	2

The fire behavior resulting from burning a plot (cut or uncut) during the dormant season is well represented by both the CFM and standard fuel model 6. SFM 11 was also evaluated for both conditions, but BEHAVE predicted that fires would not spread. The fire behavior resulting from burning in the growing season is well represented by both the CFM and SFM 11. The utility of using a CFM in an experimental setting, even when a standard fuel model predicts well, is that fuel parameters are easier to tailor to unique conditions.

SFM 6 could be used by managers to accurately predict potential fire behavior in the dormant season – it is usually best to use a fuel model that over-predicts fire behavior rather than one that under-predicts. SFM 8 under-predicts both flame length and rate of spread, especially in cut plots during the dormant season and should not be used. SFM 11 could be used by managers to accurately predict potential fire behavior in the growing season.

Catbrier:

A CFM for Catbrier during the growing season performed well. Standard fuel models 4 (chaparral) and 7 (southern rough) were also used for comparisons with observed fire behavior. Both SFMs under-predicted observed fire behavior (rate of spread and flame length) by a wide

margin (Table 9). The fire behavior predictions produced by standard fuel models 4 and 7 would not be acceptable for use in Catbrier monocultures. We were especially interested in the difference between observed fire behavior and the SFM 4 predictions. Never before have we seen a situation where SFM 4 under-predicts observed fire behavior to that extent.

Table 9. Observed fire behavior in Catbrier fuels compared to standard (SFM) and custom fuel model (CFM) predictions. NA – data not available.

Fire Behavior	Observed	CFM Predicted	SFM 4	SFM 7
Growing no cut				
Flame Length (ft)	18	16	7	4
Rate of Spread (ft/min)	37	54	18	14
Growing cut				
Flame Length (ft)	10	12	7	4
Rate of Spread (ft/min)	NA	NA	18	14
Growing grind				
Flame Length (ft)	3	6	7	4
Rate of Spread (ft/min)	NA	NA	18	14

Morrow's Honeysuckle:

A custom fuel model constructed for a dormant season burn of a cut plot in Morrow's Honeysuckle did not predict the minimal fire behavior any better than standard fuel models (Table 10). In this situation, SFM 8 or 5 (brush) would allow a manager to understand the fire behavior that was likely to occur in this plot. Fuel and fire behavior data were not gathered for other Honeysuckle plots, because these plots were not likely to carry fire.

Table 10. Observed fire behavior in cut, dormant season Morrow's Honeysuckle fuels is compared to standard (SFM) and custom fuel model (CFM) predictions. There is no substantive difference in the accuracy of the CFM, SFM 8 or SFM 5.

Fire Behavior	Observed	CFM	SFM 8	SFM 5
Flame Length (ft)	<1	2	0.4	0.8
Rate of Spread (ft/min)	1	3	0.3	1.1

Japanese Barberry:

        Custom fuel models were constructed for three different Japanese Barberry treatments. Generally, these custom fuel models did not perform any better than standard fuel models (Table 11). Other seasons and treatments were not evaluated because the plots were not likely to carry fire or because of missing data.

Table 11. Observed fire behavior in cut dormant season Japanese Barberry fuels is compared to standard (SFM) and custom fuel model (CFM) predictions. The Barberry CFM predicts fire behavior well in the dormant season, but over-predicts in the growing season. NA – data not available.

Fire Behavior	Observed	CFM	SFM 8	SFM 5
Growing cut				
Flame Length (ft)	0	2	0.4	0.6
Rate of Spread (ft/min)	0	3	0.3	0.8
Dormant cut				
Flame Length (ft)	1	2	0.2	0.4
Rate of Spread (ft/min)	3	2	0.3	0.5
Dormant control				
Flame Length (ft)	1	2	0.4	0.6
Rate of Spread (ft/min)	NA	3	0.2	0.5

Scotch Broom:

        Because of the patchy nature of the untreated Scotch Broom fuels we sampled, it is difficult to predict fire behavior with fuel models.

Comparing predicted and observed fire behavior

        To evaluate the effectiveness of CFMs and standard fuel models, we compared predicted fire behavior to observed fire behavior using the environmental parameters that existed at the time of the fire. We found that custom fuel models, when all the fuel types that were modeled were put together, very accurately predicted flame length of prescribed fires (Figure 21). The fact that correlation coefficient (R^2) is 0.93 and that observed values nearly equal predicted values suggest that CFMs can be a powerful tool.
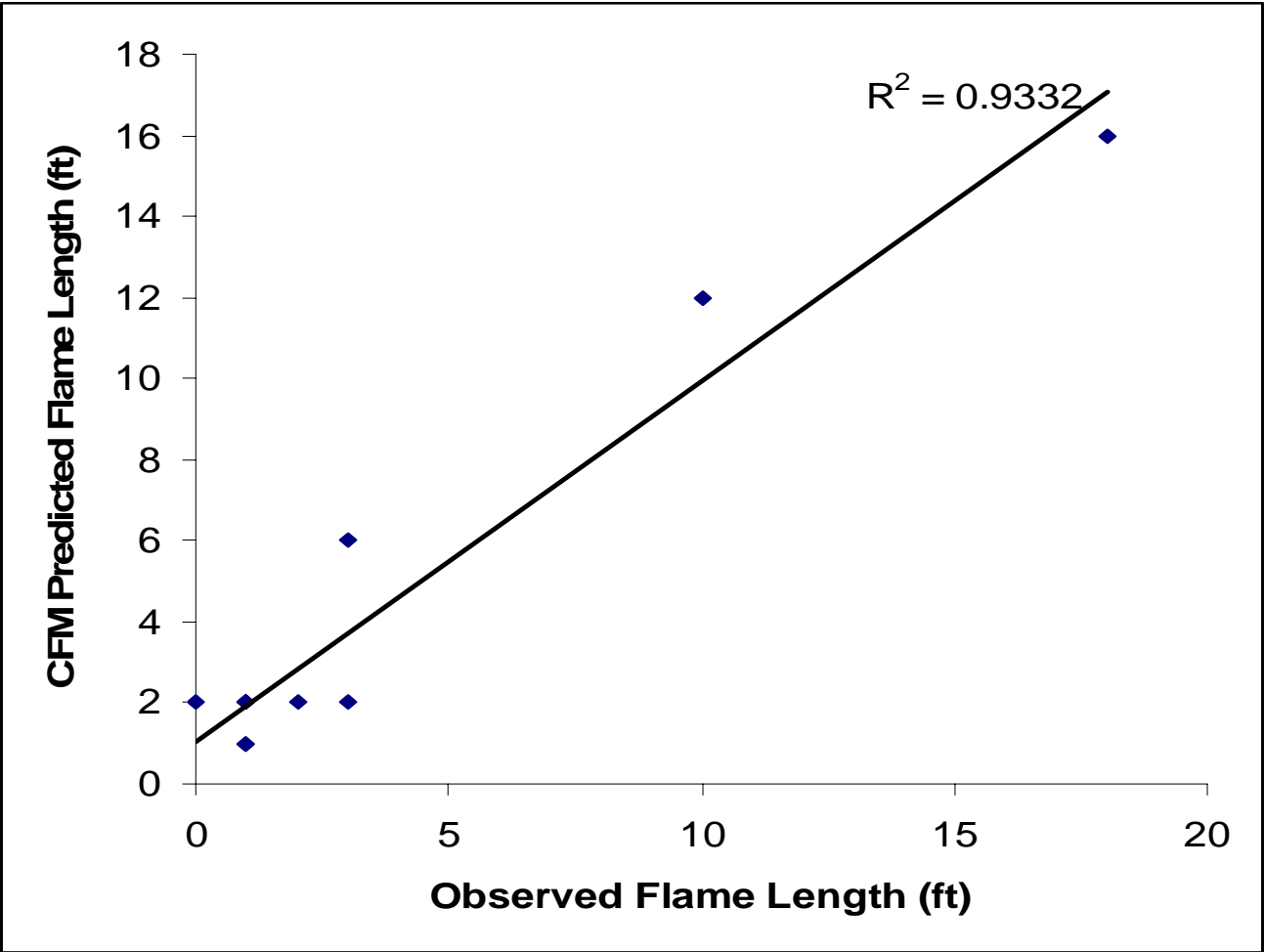
Figure 21. Predicted (CFM) flame lengths vs. those observed on a variety of species/treatment combinations. See Tables 8-11 for input data.

Management Recommendations

Cutting and prescribed fire can be useful tools in the management of many northeastern U.S. woody invasive plants. To increase the effectiveness of any management technique, it is important to understand the physiology of the target individual. When using cutting and/or prescribed fire to control woody invasive species, treatments should be applied during the growing season to have maximum effect on the ability of plants to resprout. During the growing season below-ground food reserves are depleted and plants are forced to use what reserves they have at a time when they would normally be replenishing those reserves. Within the growing

season, treatments should be timed to periods when reserves are lowest, such as immediately after leaf-out or after the growth of sprouts following another disturbance. Reserves may also be influenced by periods of lower than normal precipitation (Henlin 2004). Any treatments that can take advantage of dry years may have a greater impact on control of target species.

Dormant season treatments have little impact on root reserves, although they are successful at reducing the amount of above-ground live biomass. Due to the early leaf-out of some invasive species (e.g. Japanese Barberry and Morrow's Honeysuckle) treatments can be applied in what is considered to be the dormant season (i.e. before leaf out of most deciduous native species), but is, physiologically, the early growing season for these two exotic species.

A single treatment, whether applied during the dormant or early growing season, appears to decrease root reserves for less than one growing season. To affect a lasting control of these species, multiple years of treatments are necessary. Although this study was not able to determine the number of years required for the species we studied, Patterson (unpublished data) has found that annual summer mowing can eliminate Black Huckleberry (*Gaylusaccia baccata*) after five years.

Reserves can be further depleted by treating multiple times during the growing season, although several years of treatments will still be required. Multiple treatments within a growing season should allow enough time between treatments for new sprouts to grow and further deplete reserves. In our study, Gray Dogwood, Common Buckthorn, Multiflora Rose, and Catbrier grew sprouts and began to replenish reserves within four weeks after treatment. Japanese Barberry and Morrow's Honeysuckle took longer to begin replenishment of their reserves, but only by a few weeks. In areas with lengthy growing seasons (but also with a dormant season), such as the mid-Atlantic states, treatments might be repeated three or more times in a growing season. The limit to the number of treatments applied will depend on how quickly the target species can resprout, and the period of time over which it will continue to resprout before becoming dormant. Generally, treatements should first be mechanical and then involve a prescribed burn to remove slash. Any additional treatments would again have to be mechanical, as a prescribed

burn would remove fine fuels with little prospect for sufficient fuel recovery within the same season to allow a second burn.

In the northeastern U.S. woody invasive species can be categorized into two general types of fuels for fire: 1) species that present a fire hazard and 2) those that do not increase the fire hazard of an area. The majority of problem woody invasive species in this area fall into the second category. Species like Japanese Barberry, Morrow's Honeysuckle, and Common Buckthorn generally invade areas that burn infrequently. These exotic species generally do not increase the threat of fire in their untreated conditions. Treatments to control these species can increase the fuel load and potential fire behavior, but usually not enough to present a hazard. Prescribed fire can then be used as an effective tool to reduce slash, or to clear out thick brush to make additional control methods easier to apply.

Fire dependent communities do occur in some areas of the northeastern U.S. including pine barrens, sandplains and ridgetops. Some of these communities have been invaded by woody species that can increase fire behavior with or without treatment. Carefully applied cutting and prescribed fire treatments, applied in tandem or alone, can reduce the fire hazard presented by the invasive plants.

Specific recommendations for species included in this study:

To control Gray Dogwood in grassland habitats, we suggest a series of multiple growing season cuts along with an early burn to remove slash. Dogwood can form large clones by spreading with underground rhizomes. For treatments to be successful, managers must either treat entire clones or isolate a portion of the clone from its surviving, above-ground stems (by cutting connecting roots with a trenching tool). Multiple treatments over the course of more than two years will be necessary to eliminate this species, as it rapidly recovers root reserves by producing new stems. Common Buckthorn is similar to Dogwood but it can produce a greater density of stump sprouts than the other species in this study. Buckthorn, along with Japanese Barberry, Morrow's Honeysuckle, and Multiflora Rose, leafs out much earlier than native species. Therefore an early spring treatment following root carbohydrate depletion in these

species is possible prior to depletion of native species' reserves. Some of these species can also hold their leaves until early fall, and therefore may need to be cut even into September or October. We have found that sprouts from growing season treatments often retain green leaves late into the fall (in the absence of killing frosts), probably reflecting an extended effort on the part of the plants to restore depleted reserves. The type of treatment (mowing, cutting, burning) will depend somewhat on accessibility of equipment, cost of control, and the species present. While mowing may be more cost effective, it might not be useful in an area with native woody species that a manager does not want to loose. Using hand-held brushcutters may be more useful in that situation as the operator can selectively cut the target species.

Gray Dogwood does not represent a fire hazard in the untreated condition. Fires will rarely carry beneath uncut stands, because the heat generated by the sparse litter layer and surface fuels is insufficient to ignite canopy leaves. Cutting does not create a hazard but rather allows fire to at least burn through and consume the "activity" fuels. In this instance, cutting increases the dead fuel load by killing live stems and by reducing the distance between the surface litter fuels and the fine stems in the shrub crown. Fuels are more available and fires burn more completely. Grinding increases packing ratios to the point where growing season fires carry only under conditions that preclude prescribed burning. Our recommendation for initial treatments of Dogwood is to cut stems with a sickle mower or brush cutters early in the growing season, and to burn the resulting slash in late July or early August, effectively top-killing plants twice in the same growing season. Our results support those of Mitchell (2000) who also worked at Montezuma NWR.

Multiflora Rose and Common Buckthorn typically invade old fields and thatch from grass fuels can be used to carry through slash created from cutting treatments, which are practical with Buckthorn but much more difficult with Rose. As with other species, grinding would preclude subsequent burning until fine fuel loads recovered, again limiting the opportunities for two fire treatments in a growing season.

In the rich woods of the Berkshires, fine fuels are quickly decomposed. This presents problems for utilizing prescribed fire as an invasive plant control method. Morrow's

Honeysuckle and Japanese Barberry will not burn in the growing season without cutting in advance. Even then, in the wooded stands we worked in at Sheffield, surface litter loads were so low that burning following treatment was impossible. Although cutting or grinding may be desirable to reduce sprouting in Honeysuckle, treatment of activity fuels with broadcast burning is not only unnecessary, it is virtually impossible. Piling of slash and burning the piles with follow-up treatment of stumps with herbicides is a more practical method for controlling sprouting. Fuel treatments are not likely to be needed for activity fuels generated by the cutting of Barberry. We were unable to ignite activity fuels during the growing season. Dormant season burning was accomplished in treated and untreated Barberry fuels.

Scotch Broom did not effectively resprout following cutting or a dormant season prescribed fire. Many seedlings, presumably from soil-banked seed, grew following treatments, even after a severe growing season burn that left exposed mineral soil. One way to potentially reduce the success of seedling growth would be to cut during the growing season, but not burn the plot until the following growing season. In this way, some seedlings would potentially be killed by the fire. Cutting Broom can have the effect of making the patchy fuel bed more continuous, if the slash from shrubs is scattered adequately. Subsequent burning can be accomplished more safely than burns in untreated fuels. As with other species, grinding would preclude subsequent burning in the short run.

Catbrier differs from other fuels in our study because it presents an extreme fire behavior risk in the untreated condition. Untreated Catbrier will burn intensely as a crown fire during both the dormant and growing season. Treatments to this fuel that result in further compaction can reduce the fire hazard of Catbrier stands. Due to its green stems and extensive root system, root reserves are quickly replenished following disturbance. Deer browse prevented sprouts in our treated plots from growing much above 15 cm during the course of the study, but reserves recovered rapidly even with this continued disturbance. Although some of the recovery in reserves in spite of treatments may be the result of only a portion of the clone being treated, this is likely not the only reason, as nearly the entire clone was treated with our cut and burn plot and reserves recovered in that plot as in the others. Therefore, multiple treatments that do not kill stems to ground level may not be effective for this species.

Cutting and grinding treatments are helpful in reducing fire behavior in Catbrier stands.

Fire behavior likely to result from the various treatment scenarios we evaluated is summarized in

Table 12. Cutting reduces fuel bed depths, but the packing ratio remains near-optimal. Fires

burn, although with somewhat reduced intensity. Grinding increases the packing ratio above the

theoretical optimum to the point where rates of spread drop dramatically. Fires may fail to carry

though treated fuel beds except under drought conditions when the threat of ground fires is high.

Cutting is difficult in untreated stands, however, so we recommend growing season burns (when

spotting potential is reduced) in untreated stands followed by annual growing season mowing of

resprouts. As with Gray Dogwood, entire clones must be treated to effectively drain root

reserves.

Table 12. Prescribed burns in Catbrier should be considered carefully before application.
Risk is presented as a number between 0 (low risk) – 25 (highest risk) - roughly correlating with
our observed flame lengths (ft). Plus (+) indicates increased risk of spotting for dormant season
burns.

Treatment	Season	Risk	Acceptable
Grind	Grow	0	Yes
	Dorm	2 +	Yes
Cut	Grow	5	Yes
	Dorm	10 +	No
None	Grow	20	No
	Dorm	25 +	No

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