EFFECTS OF TIMBER HARVEST AND PRESCRIBED FIRE ON WILDLIFE HABITAT AND USE IN THE OUACHITA MOUNTAINS OF EASTERN OKLAHOMA

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CHAPTER I

INTRODUCTION

The oak-pine (Quercus spp.-Pinus spp.) forest is the largest timber type in the eastern United States (Lotan et al. 1978). Shortleaf pine (P. echinata) is a major constituent and has the widest geographic range of the southern pines (Lawson and Kitchens 1983). It occurs in 22 states from New York to Missouri and south to the Gulf states (Williston and Balmer 1980). The highest concentrations of this species are found in the Interior Highlands of Arkansas and eastern Oklahoma (Sternitzke and Nelson 1970). Shortleaf pine is the predominant native pine in Oklahoma; loblolly (P. taeda) naturally occurs in a limited area (Little 1981). In spite of its prevalence and importance, a research void exists in management of the oak-shortleaf pine type (Komarek 1981, Murphy and Farrar 1985).

The oak-pine forest is a fire subclimax association and will succeed to a oak-hickory (Carya spp.) climax in the absence of fire (Bruner 1931, Little and Olmstead 1931, Braun 1950, Oosting 1956). Frequent fire can shift forest community composition in the Ouachita Mountains from an oak-pine mixture to pine dominance (Little and Olmstead 1931).

Although fire is considered a major determinant in shaping the oak-pine ecosystem (Garren 1943, Oosting 1956), our understanding of fire ecology in the Ouachita Highlands is limited to inferences from other similar forest types (Lotan et al. 1978), qualitative descriptions (Little and Olmstead 1931), and effects of fire in young pine plantations (Nickles et al. 1981).

Wildlife research in this region has largely centered on wildlife use and habitat quality of managed pine stands on National Forest and industrial forest landholdings. Habitat quality of managed pine stands for white-tailed deer (*Odocoileus virginianus*) has been evaluated in the Ouachita Mountains (Segelquist and Pennington 1968, Fuller 1976, Reeb and Silker 1979, Fenwood et al. 1984, Jenks et al. 1990). Some work has been done on eastern wild turkey (*Meleagris gallopavo silvestris*) use of extensive commercial forest lands in the Ouachita Mountains region (southeastern Oklahoma--Bidwell 1985, Bidwell et al. 1989; southwest Arkansas--Wigley et al. 1985, 1986).

Much of the forested land base in southeastern Oklahoma is in oak-pine or oak-hickory forest types (Hines and Bertelson 1987). Qualitative generalizations and inferences from managed pine forests are not adequate to address the effects of oak-pine forest management and fire on wildlife population dynamics in the Ouachita's. Forest succession dynamics and fire ecology in the Ouachita Mountain region must be understood by wildlife managers to develop management strategies from an ecosystem perspective.

Forest Habitat Manipulation To Benefit Wildlife

The effects of forest management and various silvicultural systems on wildlife habitat quality have been studied widely in the southeastern United States (See Chapter II). To increase management effectiveness, research should be conducted on the manipulation of forest ecosystems specifically to benefit target wildlife species (Ripley 1980). Wildlife managers manipulate plant succession to increase carrying capacity for a given species by providing essential life requisites (Yoakum et al. 1980), especially those that limit the population (Dasmann 1964). But population responses to habitat manipulation are difficult to quantify (Ripley 1980).

Ripley (1980) indicated that long-term studies in poor oak-pine habitats would be an excellent place for an investigation on population response to habitat manipulation. For such a study to be successful, one must possess knowledge of how management techniques will affect carrying capacity (Macnab 1985). Implicit assumptions include understanding ecological relationships of the system and how manipulation will impact these relationships (Macnab 1983).

An Integrated Research And Management Approach

Wildlife research typically deals with a species' biology, population dynamics, habitat, or the related effects of current land use. Such studies give us descriptive knowledge based on inductive or retroductive scientific methods (Romesburg 1981). Although quantitative analyses are evident in wildlife science, actual testing of hypotheses are sorely lacking (Macnab 1983, Romesburg 1981). Caughley (1980) concluded that most large mammal studies generate a large mass of information which amounts to "nothing much." Romesburg (1981) indicated that a partial solution to the apparent groping for scientific knowledge in environmental science fields is to use a problem oriented approach similar to that used by medical researchers. While an argument can be made that a knowledge base is necessary (Gill 1985), wildlife professionals need to design research that tests ecological assumptions (Macnab 1983, Romesburg 1981).

Wildlife managers can play a vital role in answering ecological questions through deductive management-oriented research (Macnab 1983). Management problems and practices can be set up in experimental settings and various factors manipulated and statistically tested to determine if a hypothesis is supported. This approach is applicable to habitat manipulation practices commonly used, albeit in an inductive manner, by wildlife managers (Macnab 1983). With a little scientific rigor in setting up controls, replicates, and testable hypotheses, much knowledge could be gained that is now lost or at best applied locally in an intuitive way. Many of our ecological assumptions may be tested by combining the research tool of hypothesis testing, through appropriate experimental design, and the practical experience of wildlife managers. The roles of wildlife research and management will then be seen as fusing together rather than as disjunct in purpose and scope (Macnab 1983).

The Present Study

The Oklahoma Department of Wildlife Conservation began using fire and timber harvest in 1977 to improve habitat conditions for white-tailed deer. Forest openings created through commercial pine timber harvest and maintained with prescribed fire were used to provide additional forage in years of mast shortfall. Selected residual hardwood trees were released for crown development and increased mast production by using single stem injection of herbicide to kill competing trees. In essence, site retrogression was induced through timber harvest and maintained with periodic prescribed fire.

Retrogression of forested sites as a wildlife management strategy was untested and needed further development. Questions existed as to whether or not this strategy was beneficial for deer. The required frequency of prescribed fire necessary to maintain early successional stages was unknown. The Pushmataha Forest Habitat Research Area was set up in 1982 with these and other questions in mind. The experimental development and testing of retrogression as a deer management strategy offered an opportunity to fill a number of research voids. Assuredly, wildlife managers would benefit from additional management strategies, but our understanding of forest succession dynamics, fire ecology, and effects of forest management practices could be extended within a research setting.

My study was designed to (1) evaluate the wildlife management strategy of site retrogression through timber harvest and periodic prescribed fire and (2) evaluate the effects of fire on plant succession on oak-pine sites. I compared retrogressed sites maintained in an earlier sere with periodic prescribed fire with the traditional forest management practices of regeneration clearcutting, initial rough reduction burns, and later hazard reduction burns to reduce fuel loads. Effects of clearcutting and hazard reduction burns have been studied extensively and provide a basis of comparison.

Objectives

1. To determine effects of timber harvest and periodic prescribed fire on soil chemical properties and litter dynamics.

2. To determine oak-pine community response to various levels of overstory removal and various rotation cycles of prescribed fire.

3. To evaluate critically and compare induced retrogression through timber harvest and periodic prescribed fire with regeneration clearcutting, hazard reduction burns and untreated controls. Specific hypotheses were:

   a. H_o: Nutrient response of selected deer browse on treated areas = that of untreated areas.

   b. H_o: Cervid plant utilization on treated areas = that of untreated areas.

   c. H_o: Forage production on treated areas = that of untreated areas.

   d. H_o: Deer, elk (Cervus elaphus), and rabbit (Sylvilagus floridanus) use of treated areas = that of untreated areas.

4. To determine effects of rainfall on treatment responses.

The remainder of this chapter introduces the rest of the dissertation and provides an outline of format. Chapter II reviews the current literature pertinent to this study. Chapter III provides a detailed description and location of the study area. Chapter IV gives experimental layout, techniques used for gathering data, sampling protocol, methods for sample analysis where appropriate, and data analyses. The remaining chapters are formatted for submission to *Forest Ecology and Management* and the *Journal of Wildlife Management*. They are complete as written and do not need supporting material. The first manuscript is: Chapter V, "Effects of timber harvest and prescribed fire on soil chemical properties in the Ouachita Mountains," formatted for submission to, *Forest Ecology and Management*. The remaining chapters are formatted for submission to the *Journal of Wildlife Management*: Chapter VI, "Nutrient response of selected deer browse to timber harvest and fire in Oklahoma Ouachita Mountains," Chapter VII, "Effects of fire and timber harvest on vegetation in Oklahoma Ouachita Mountains," and Chapter VIII, "Wildlife use of oak-pine habitats altered by fire and timber harvest."

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CHAPTER II

LITERATURE REVIEW

Supplemental Forage

The basic premise behind manipulation of game habitats is that something is limiting within a particular species' range that a manager can correct. Much of wildlife management's philosophy behind habitat manipulation arose from agricultural schools of thought. If the farmer intensifies his efforts and refines his technique, greater production is realized. Wildlife managers often have the same goals in mind (Larson 1969).

The use of supplemental forage clearings in forested settings has long been recommended for management (Leopold 1933). Handy and Scharnagel (1961) described in detail the agricultural methods used to establish cultivated food plots only to have them end up similar to permanent pastures. Miller (1965:173) flatly stated that wildlife openings were the "basic ingredient of stable game populations." However, censusing methods were inadequate to measure population response to such treatments (Handy and Scharnagel 1961). Permanent openings provided loafing, nesting, and feeding areas (Miller 1965). Larson (1967) provided unusual insight into the utility of management practices geared toward supplementing forage by recommending that these techniques be evaluated on the basis of objective criteria.

The value of providing supplemental forage has been shown in forests of limited productivity (Segelquist 1974). However, during late fall and winter deer (Odocoileus virginianus) selected appreciable amounts of other foods (browse and herbage) only when hard mast was unavailable (Segelquist and Green 1968, Harlow et al. 1975). Oak (Quercus spp.) mast was substantially higher in nutritional quality than other available forage. Adequate nutrition could be provided without hard mast, but only in unique situations (Harlow et al. 1975). Although Goodrum et al. (1971) found that total mast failure never occurred during their 20-year study, their results may not be applicable to oak-pine (Pinus spp.) habitats in mountainous terrain. Mast shortfalls have been reported in the Ozark Plateau region of Arkansas (Segelquist 1974).

Winter mortality of deer, decreased productivity, and summer fawn mortality have been related to mast failures (Segelquist et al. 1969, 1972; Logan 1972). The Ozark and Ouachita Mountain regions lack an adequate understory forage base and a suitable evergreen winter browse (Segelquist and Pennington 1968; Segelquist et al. 1969, 1972). One approach to this problem was to establish forage clearings and honeysuckle (Lonicera japonica) plantings (Segelquist and Rogers 1974). The greatest use of these clearings occurred when mast was scarce. In deer enclosures where supplemental clearings was provided, mortality was less in years of mast failure than on control areas (Segelquist and Rogers 1974).

Cultivated forage openings have been criticized widely by wildlife managers (Larson 1967). Managers criticisms were cost inefficiencies, concentration of wildlife and increased chances for disease transmission, untested use as a management practice, and cultivated openings generally provided little benefit (Larson 1967). Long term studies on nutrient-limited oak-pine habitats could provide some answers as to the utility of forest habitat manipulation for the expressed purpose of increasing carrying capacity. Forested habitats that are nutrient limited support fewer animals and presumably a population response to manipulation would be easier to detect than in more productive areas (Ripley 1980).

Many recent studies on effects of clearcutting on wildlife have reported substantial increases in forage production, even on relatively poor sites (McComb and Rumsey 1981, Conde et al. 1983a, Waldrop et al. 1985). The implications are obvious. Maintaining clearcuts in an unregenerated state with periodic prescribed fire may be a more cost effective management tool than cultivated forage openings. It may be that cultivated forage clearings are useful and can be economically justified. Problems still remain with concentrating wildlife and the potential for disease transmission on cultivated clearings.

Clearcutting

Regeneration clearcutting has received more attention than any other method of stand regeneration. Davis (1970) aptly defended clearcutting and even-aged management systems for forest management from an economic and efficiency standpoint. Oliver (1981) and others have indicated that clearcutting approximated natural disturbance that leveled large areas, because the subsequent stand that developed was even-aged. Clearcutting was the preferred method of regeneration in the east (McQuilkin 1970) because plantation grown pine produced substantially more fiber in shorter time periods than unmanaged tracts (Hurst and Warren 1980). Loblolly pine (P. taeda) was favored over shortleaf pine (P. echinata) because shortleaf pines' growth and yield pattern was considered unsuitable for pulpwood rotation (Williston and Balmer 1980).

Effects on Plant Succession

The effects of clearcutting varied with the intensity of site preparation, vegetation control methods, and the species replanted (Hebb 1971, Stransky 1976, Dickson 1981). Across the South, numerous studies showed that 1-3 years after clearcutting, there was a marked increase in herbaceous, graminoid, and woody understory forage production (western Arkansas and eastern Oklahoma, Ouachita Mountains [Fenwood et al. 1984]; west central Arkansas, Ouachita Mountains [Kuroda 1984]; western North Carolina [Harlow 1967]; South Carolina Piedmont [Cushwa and Jones 1969]; Georgia Piedmont [Atkeson and Johnson 1979]; central Florida sandhills [Beckwith 1964]; Florida sandhills [Umber and Harris 1974]; north Florida flatwoods [Moore et al. 1982; Conde et al. 1983<u>a</u>,<u>b</u>]; Florida flatwoods [Swindel et al. 1983]; northwest Florida sandhills [Hebb 1971]; southwest Georgia [Buckner et al. 1979]; east Texas [Schuster 1967, Halls and Alcaniz 1968, Stransky et al. 1974, Stransky 1976, Stransky and Halls 1978]; interior flatwoods Mississippi [McKee 1972, Perkins 1973, Hurst and Warren 1980]; and North Carolina pocosin [Hazel et al. 1976]). Generally, annuals predominated after the first growing season, then in succeeding years grasses and herbs were followed by perennial grasses with a distinct shrub component.

The successional progression described by Hebb (1971) was quite similar for all sites in the southern and eastern United States. The progression was: 1) the denuded site, 2) profusion of forbs and grasses, 3) dominance by relatively few species, and 4) shading out of understory by the developing overstory. Initially, species diversity was increased in southern and eastern studies.

Plant succession following clearcutting was affected by the intensity of site preparation (Moore et al. 1982) and prior land use (Harris 1980). Increased site preparation intensity caused more rapid successional change, and initiated earlier crown closure. In southwest Georgia, Buckner et al. (1979) found that herbaceous cover was increased more on chopped and burned sites than on less intensive site prepared areas; however, differences were not significant at the end of 3 years. Species diversity, cover and biomass response was lower on intensive prepared sites compared with less intensive methods, but differences disappeared after 2 years (Conde et al. 1983a,b; Lewis et al. 1984; Moore et al. 1982). Relative dominance of woody plants was decreased by intensive methods (Conde et al. 1983a,b; Moore et al. 1982). Forage response in the understory was less on previously cultivated sites (Harris 1980). Less intensive methods favored wildlife (White et al. 1975). The differences noted in some of the studies may be related to on site factors such as former vegetation, soil type, moisture regimes (Johnson et al. 1974) and former land use (Harris 1980).

Effects on Browse and Forage Production

In studies from Michigan to Maine and across the mid-south, browse production on clearcuts increased as much as three times that of untreated sites (Gysel et al. 1972, Sweeney 1980, McComb and Rumsey 1981, Monthey 1984, Waldrop et al. 1985). On clearcut hardwood sites fruit yield increased significantly 4 years after clearcutting hardwoods (Crawford and Harrison 1971, McComb and Rumsey 1981). However only on better sites could increased fruit production offset the loss of hard mast production in poorest years (Crawford and Harrison 1971).

Forage yields and fruit production were related to site preparation intensity. Forage yields and fruit yields increased on less intensively site prepared areas (Stransky and Richardson 1977, Stransky and Halls 1978). Mechanical site preparation resulted in less production due to the amount of soil disturbance (Stransky and Halls 1980). Burning increased nutrient quality in forage over mechanical site preparation and no site preparation (Stransky and Halls 1976). On intensively cultivated sites in Mississippi, Wolters and Schmidtling (1975) found that browse and forage yields were less than half of that on uncultivated areas. After 12 years browse production was equal on both treatments. When windrowing was used as part of the site preparation phase, plant species in windrows were different from areas between windrows and windrows generally supported more diverse wildlife (Perkins 1973).

On the other hand, sheared sites in Michigan produced more browse than less intensive methods because of increased sprouting from roots and stumps from the original hardwood stand (Gysel et al. 1972). In Texas, K-G blading and raking slash reduced production when compared to less intensive methods (Stransky 1976). The cost of site preparation on poor oak sites (site index less than 45) could not be justified when converting to red pine (*P. resinosa*) (Gysel et al. 1972).

Effects on Wildlife

As clearcut stands succeeded to later stages, there was a commensurate change in associated wildlife species (Johnson et al. 1974, Atkeson and Johnson 1979). The initial response of wildlife to clearcutting was immediate displacement. For example, squirrel (*Scirus niger* and *S. carolinensis*) use in southern Ohio initially declined by 44% after clearcutting (Nixon et al. 1980). Foraging guilds for various bird species were virtually eliminated (Webb et al. 1977). Initially, food production on site prepared areas favored seed eaters and herbivores (Buckner et al. 1979, Swindel et al. 1983). Small mammal use was unchanged while winter bird densities increased (Swindel et al. 1983). Cardinals (*Cardinalis cardinalis*) and Carolina wrens (*Thryothorus ludovicianus* were widely tolerant of conditions following clearcutting (Dickson 1981), typically these species were winter residents. Byford (1969) found that white-tailed deer (*Odocoileus virginianus*) continued using a clearcut area that was within their normal home range indicating their tolerance for a wide range of habitat conditions and disturbance. Deer activity became more concentrated on the clear-cut areas as food plants increased in abundance (Byford 1969).

Several southern studies found that in the first few years after clearcutting, with increased herb, grass and browse production, wildlife species such as small seed-eating mammals (Umber and Harris 1974, Atkeson and Johnson 1979), meadow lark (Sturnella spp.), bobwhite quail (Colinus virginianus), mourning dove (Zenaidura macroura), certain song birds and cottontail rabbits (Sylvilagus floridanus) were benefitted (Johnson et al. 1974). McComb and Noble (1982) found that bird and small mammal use increased in clearcuts the first year but small mammal use declined thereafter. Clearcuts with snags provided an important source of nesting habitat for eastern bluebird (Sialia sialis). Bluebirds were out-competed for nest sites in urbanized areas by English sparrows (Passer domesticus) and starling (Sturnus vulgarus) (Conner and Adkisson 1974).

Eastern wild turkey (Meleagris gallopavo silvestris) (Kennamer et al. 1980, 1981, Bidwell et al. 1989) and white-tailed deer (Umber and Harris, 1974) used early successional clearcut stages seasonally. Blair et al. (1977) indicated that although an abundance of forage was found on clearcuts, it was deficient in phosphorus and that this may be a limiting factor for deer in Louisiana. Halls and Alcaniz (1986) found that fruit and twig growth increased seven times in the open over what was found in a sawtimber stand.

Clearcutting and site preparation increased winter food availability for deer (McKee 1972). Deer diets were generally higher in nutritive value in clearcuts than in forests (Thill and Morris 1983). Initially, deer use of clearcuts may be limited to the edge (Waldrop et al. 1985). Deer use in one study increased on clearcuts but was limited to 100.5 m from cover (Tomm et al. 1981). As pine stands developed in height on previously clearcut sites, deer use of the central portion of the stand increased. Melchiors et al. (1985) found that all portions of large (128-276 ha) 4-5-year-old pine stands were used in southeastern Oklahoma. Some preference was noted for edge boundaries. However large contiguous clearcuts regenerated to pine are deficient in hard mast.

Use of clearcuts by deer was influenced by size, shape, interspersion with uncut mature timber, site treatment (Tomm et al. 1981), and age of the clearcut (Melchiors et al. 1985). Increased use was related to more available and nutritious forage in clearcuts (Thill and Morris 1983). Monthey (1984) was the only study that indicated deer were adversely affected by clearcutting. Deer use of clearcut areas may be modified by human disturbance. With high levels of human harassment deer use of clearcuts declined

(Tomm et al. 1981).

Fire

Annual burning in southeastern Oklahoma was common until 1926 (Bruner 1931, Little and Olmstead 1931). Records of annual burning date back to Nuttall's explorations into southeast Oklahoma in 1819. The Oklahoma Forest Service established its Southeastern Oklahoma Protective Unit in 1926 and until that time an estimated 1/3 to 3/4 of the upland pine-oak area of the Ouachita Mountains were burned each year (Little and Olmstead 1931).

Southeastern Oklahoma is unique because of the interspersion and juxtaposition of different habitat types. Oak-pine, oak-hickory (Carya spp.) and Cross Timbers vegetation types are in close proximity along the western edge of the Ouachita Mountains. Areas of relict tallgrass prairie exist in small interspersed pockets (Duck and Fletcher 1943).

Given the past fire history of southeastern Oklahoma and the interspersion of vegetation types, this section reviews fire literature pertinent to the 3 major vegetation types: oak-pine, oak-hickory and tallgrass prairie. Cross Timbers are considered to be an extension of the oak-hickory type with hickory becoming less important in the western extent (Bruner 1931, Oosting 1956).

Oak-pine or Southern Pine Forest

Fire has played a major role in the development and maintenance of the southern pine ecosystem (Komarek 1974, Garren 1943, Van Lear 1985). Fire in the oak-pine forest type results in pine dominance over oak to form a disclimax association rather than an oak climax association (Garren 1943, Oosting 1956). Many of the virgin stands of pure pine in upland habitats developed because of frequent fire (Garren 1943), and after timber harvest, a mixed oak-pine forest developed because of the lack of fire (Barrett 1962). In the absence of fire, succession progresses from oak-pine to a oak-hickory climax (Bruner 1931, Little and Olmstead 1931, Braun 1950, Oosting 1956). When the forest is harvested, succession is re-directed and the effects of fire may be masked or even highlighted (Oosting 1956, Barrett 1962). Succession is hastened to oak-hickory climax when selective pine harvest is practiced (Van Lear 1985).

Effects of Fire on Pines. Southern pines were generally tolerant of low intensity fires, especially after they reach the sapling stage (>2.4 m in height) (Garren 1943). Shortleaf pine was more fire tolerant than loblolly pine and was one of the few pines that sprouted following fire or mechanical injury to seedlings (Garren 1943, Wright and Bailey 1982). Over half of shortleaf seedlings (<2.4 m in height) subjected to injury will survive by sprouting

(Garren 1943).

Effects of fire on pines were well summarized by Wade and Johansen (1986), who resolved some of the apparent contradictions found in the literature regarding the effects of fire on growth rates of southern pines. Often results were not comparable because differences in burning season, fuel loads (and consumption), and fire intensity were not reported (Wade and Johansen 1986). However, Wade and Johansen (1986) concluded that re-introduction of fire into stands long excluded from fire may cause delayed mortality from stem girdling, because low intensity fires may smolder in the accumulation of sloughed bark and litter around the immediate bole of the tree. Tree mortality was related to bark thickness, moisture content of the tree (Martin 1963), diameter of tree, fire intensity and residence time (Cushwa and Martin 1969, Wade and Johansen 1986). Fire intensity determined largely the extent of bark char and crown damage (Cain 1984) and was primarily a function of fire type (backfire vs. headfire) (Fahnestock and Hare 1964) and season of burn (Waldrop and Van Lear 1984). The height of crown scorch was a geometric function of fire intensity in northern pines (Van Wagner 1973) and presumably southern pines as well. Thus, fire intensity could be used to predict the effects of fire on woody vegetation (Cain 1984). Strip headfires were the preferred burning technique in managed pine forests of the region because headfires were often sufficiently intense to cause excessive crown damage and backfires were too slow to burn large stands (Wade and Johansen 1986, Wade and Lunsford 1989).

Southern pines are fire resistant and usually will not die if terminal buds are not killed, even with total crown scorch. The likelihood of mortality could be high if buds were physiologically active and ambient temperatures were high. Active buds were more likely to receive lethal doses of heat because less heat was required to raise buds to lethal temperatures (Wade and Johansen 1986).

Studies of fuel consumption comparing headfires and backfires in pine forests showed conflicting results and did not aid our ability to predict or interpret vegetation response to fire type. Numerous field and laboratory studies showed that backfires consumed more fuel (Hough 1968, 1978, Wade and Johansen 1986). On the other hand, Davis and Martin (1960) and Fahnestock and Hare (1964) found that fuel consumption was greater when headfires were used. Residence times for both types of fire were often the same, and the base of the tree was subjected to the same amount of heat energy in both types of fire (Fahnestock and Hare 1964).

Frequency and Seasonality of Fire. Recommended burning frequency for maintenance of loblolly or shortleaf pine is related to the size of trees within the stand. Wright and Bailey (1982) indicated that after pine stands reach sapling size the initial burns are for hardwood control and thereafter should be conducted at 5- to 10-year intervals in loblolly stands and 2- to 3-year intervals in shortleaf pine stands. Komarek (1981a) recommended an overall 3-year burning cycle for established pine stands.

Fire in the dormant season tends to be less intense and has less effect on overall stand composition. Small hardwood and shortleaf pine may be top killed but will generally resprout (Komarek 1981a). Fire during the growing season has the potential to affect more change in composition because the ability to resprout was lowered because of reduced root carbohydrates (Garrison 1972).

Fire as a Forest Management Tool. Fire has been used as a forest management tool in the southeast since early settlement. Most research however, has dealt with shortleaf, loblolly, longleaf (P. palustris), and slash pine (P. elliottii) in Coastal Plain areas (Lotan et al. 1978, Wright and Bailey 1982, Murphy and Farrar 1985). Basic uses of fire as a forest management technique include: wildfire hazard reduction, control of competing vegetation (usually hardwoods), thinning and release of crop trees, disease control, site preparation (for both artificial and natural regeneration), to increase quantity and quality of forage for livestock grazing, and for managing and improving wildlife habitat (Williams 1977, Lotan et al. 1978, Crow and Shilling 1980, Van Lear 1985).

Hazard reduction burns were undertaken to reduce forest fuels. A thick rough, or litter layer can accumulate in just a few years and produce a high intensity fire capable of damaging overstory trees if ignited at the wrong time. Periodic burning controls fuel buildup. When fuel levels were lower the chances of high intensity fires were less in the event of accidental fires (Van Lear 1985).

One of the major problems in management of pine stands is competition from herbaceous growth and/or hardwoods, which may lower growth rates of southern pines (Nelson et al. 1981). Hardwoods are prolific sprouters, and compete more vigorously with pine seedlings over longer periods of time than early herbaceous growth (Grano 1970, Cain and Yaussy 1984, Cain 1985a, Van Lear 1985).

Burning for vegetation control may be done in conjunction with thinning (Clason 1984) or chemical control of competing hardwoods (Loyd et al. 1978, Cain 1985a) to enhance pine growth rates. Prescribed burning can slow growth rates of pines (Cain 1985b) and can be used to thin pines in overstocked stands (Nickles et al. 1981). Adequate hardwood control has been achieved using summer burns in Arkansas Coastal Plain (Grano 1970) and a combination of chemical control and prescribed fire in spring and summer head, flank, and back fires (Loyd et al. 1978). Pine growth response is dependant upon stand age, rate of hardwood reinvasion, and rainfall patterns. Older stands may not respond as markedly as younger stands to control of competing vegetation by the above methods. Cessation of burning allows hardwoods to reinvade (Cain 1985a).

In an east Texas study, 4 years of annual growing season (spring and late summer) burns in immature loblolly-shortleaf sawtimber reduced the hardwood understory more than dormant season (mid and late winter) headfires. Stems 2.5 cm to 5 cm in diameter were more effectively controlled than stems >11 cm in diameter (Ferguson 1961).

Similarly, hardwood stem kill was significantly greater in summer versus winter prescribed fire in Georgia's Piedmont, but stem kill was not different between backfires and strip headfires (Brender and Copper 1968). Brender and Copper's (1968) study was one of the few to quantify fire behavior and intensity with respect to effects on vegetation.

Effects of Thinning and Fire on Wildlife. Application of cultural treatments for even-aged pine management, such as site preparation (Stransky 1981), other mechanical treatments, thinnings, herbicide use, and prescribed fire for vegetative control have one objective, i.e., increased productivity of planation pines (Cain and Yaussy 1981, Nelson et al. 1981, Pienaar et al. 1983, Clason 1984, Cain 1985a). Thinnings (precommercial and commercial) have obvious benefits to residual overstory pine or hardwoods, but they also could enhance the value of the stand for wildlife by increasing forage (Blair 1960, 1971; Blair and Enghardt 1976; Blair and Feduccia 1977; Hurst and Warren 1980, 1982; Hurst et al. 1982). However, the possibility exists that heavy thinning could encourage the development of a hardwood mid-story (Blair and Enghardt 1976). A hardwood mid-story was the principle deterrent to forage production for deer. In order to maintain nutritional palatable deer browse, pine stands should be managed to allow moderate to high light transmission in the understory (Blair 1982). However, elimination of mature hardwoods within or adjacent to pine stands eliminates hard mast production. Hard mast is a critical food item of deer and other wildlife in fall and winter months (Harlow et al. 1975).

Fire was a common management tool in loblolly-shortleaf pine-hardwood forests of the Southeast for both cattle and wildlife (Lewis et al. 1982). Fire aided in improving forage by increasing palatability, nutrient content, digestibility, productivity and availability of grasses and forbs (Lay 1967, Komarek 1974, Reeves and Halls 1974, Lewis et al. 1982). Often the increases in productivity were dramatic (Oosting 1944, Lewis and Harshbarger 1976). Lay (1956) and Oosting (1944) also have documented plant species composition change as well as increased forage production after burning. The change in vegetation composition generally lasts 2- to 3-years. Exclusion of fire led to declines in ground cover herbaceous plants (Kucera and Koelling 1964, Lewis and Harshbarger 1976). Lewis and Harshbarger (1976) used seasonal and cyclic fire treatments and found that in all cases forage production was increased over unburned controls. On annual and biennial summer burns grasses became the dominant understory plants. Forage production on South Carolina loblolly pine sites was higher on annual winter burns, than on unburned, periodically winter burned or any frequency of summer burning (Lewis and Harshbarger 1976).

Fire in woodlands may actually promote sprouting of hardwoods and increase cover at the expense of forage production (Shrauder and Miller 1969). However, forbs and some grasses, such as the panicums (Panicum spp.), may be favored (Grelen and Lewis 1981). Frequent summer burns and both frequent and infrequent winter burns led to dominance by fire tolerant grasses that may not be utilized by white-tailed deer (Stransky and Harlow 1981).

Fire may negatively impact wildlife species that depend upon soft mast (e.g., blackberry [Rubus spp.], huckleberry [Vaccinium spp.]) (Lay 1956). Summer burning reduced shrubs and small hardwoods and changed understory and midstory composition. Although it was apparent that competing hardwood midstories could be detrimental to forage production, hardwoods were critical for some forms of wildlife. Hardwood mast was used by squirrels, deer, quail, blue jays (*Cyanocitta cristata*) and wild turkey among others. Hard mast (acorns, hickory nuts, etc.) may be reduced if frequent or large scale intensive fires are used (Landers 1987). The bark of hardwood trees harbor insects necessary for many insectivorous birds. The trees also provide cavities and nesting materials necessary for squirrels, bats, and cavity nesting birds. In mixed pine-hardwood stands most breeding birds were associated with the hardwood component. Canopy stratification was distinct in pine plantations with competing hardwood midstories (Dickson 1981). Noble and Hamilton (1975) found that as canopy strata increased so did the number and kinds of birds.

Fire may be the most important factor controlling abundance of forest birds. Aside from habitat structure, fire directly affects food availability for both seed-eating and insectivorous birds (Landers 1987, Komarek 1974). At ground level, litter dwelling invertebrates were reduced by fire in the short term. As succulent herbaceous regrowth occurs, herbivorous insects increased (Dickson 1981). These changes in the invertebrate community may affect breeding success of some birds because insects were a critical source of nutrients for many breeding birds (Landers 1987).

When fire reduced the midstory hardwood component in mixed pine-hardwood forests, structural complexity was reduced. Foliage gleaners tied to deciduous midstory and low shrubs were disadvantaged by periodic fire, but those that require pine stands or early successional habitats were favored. Those species dependent on heavy litter accumulations, vertical and horizontal structural diversity, edge or plant species diversity were generally disadvantaged (Dickson 1981, Landers 1987). Frequent fire can negatively impact cavity nesters by destroying snags. Burn intervals from 7- to 10-years may increase snags but they were generally of small size as large hardwoods were fire resistant (Conner 1981). The above discussion related mainly to mid-successional second growth stands. The long-term results of periodic fire in old-growth stands may result in a continual supply of trees with cavities and subsequently snags.

Periodic fire was required to maintain suitable habitat conditions for some bird species. The red-cockaded woodpecker (*Picoides borealis*) benefits from fire in mixed pine-hardwood stands because prevalent hardwood midstories create unsuitable habitat conditions (Ligon et al. 1986). Other birds were noted as fire followers [e.g., eastern bluebird (*Sialia sialis*)] (Ahlgren and Ahlgren 1960). Michael and Thornburgh (1971) noted increased bird numbers within pine-hardwood stands subjected to partial hardwood removal (reduced by 11%) and fire.

ADV. As previously mentioned, legumes increased in abundance and seed production following fire (Stoddard 1931, 1963). In open areas, panicums and paspalums (*Paspalum* spp.) were also increased. These species along with other grasses were important items in the diets of bobwhite quail, mourning dove (*Zenaidura macroura*), wild turkey, ruffed grouse (*Bonasa umbellus*) and other avian species (Landers 1987). Some parasites of galliform birds may be reduced by burning (Stoddard 1931). Burning during the nesting season may negatively impact ground nesting species as well as low shrub nesting species (Landers 1987). Birds of prey may be attracted to burned areas because small mammals, ground nesting and understory utilizing birds and herpetofauna become more susceptible to predation when cover is removed (Landers 1987).

Fire also affects many mammals. Small mammal survival in burned areas was dependent on the uniformity, duration, and intensity of fire, in addition to the animals mobility, and position in relation to soil surfaces (Wright and Bailey 1982) and litter structure (Landers 1987). During the first and second years post-burn, herbivorous and graminivorous species became dominant and insectivorous species declined. Many small mammals required early to mid-successional habitats, that was created or maintained by fire (Landers 1987). Fire may be an important factor in niche separation between gray squirrels and fox squirrels in Coastal Plain regions with mixed oak-pine forests, because fox squirrels readily used pine as a habitat component (Landers 1987, Kirkpatrick and Mosby 1981). Rabbits (*Sylvilagus* spp.) also were benefitted by fire (Landers 1987). Any benefit to small and medium size mammals also benefited mammalian predators (Landers 1987).

In general, advantages of fire in oak-pine forests included: (1) the ability to control and direct hardwood midstory development to achieve specific wildlife management objectives; (2) removal of litter for enhanced growing conditions; (3) increased forage palatability, nutrient content, digestibility; and (4) increased herbage production and availability (Lay 1967, Komarek 1974). Seasonal use of fire allowed the manager to shift plant community composition to favor management objectives whether they be wildlife or livestock oriented. Timber production, livestock, and specific wildlife species could be benefitted by modifying season of burning and using deferred grazing schedules with winter supplementation.

Effects of Fire and Overstory on Forage Quality.

There is a high potential for immediate nutrient release from burning forest floor litter (Curtis et al. 1977). Burning generally increased the nutrient content and palatability of forage (Lay 1967). DeWitt and Derby (1955) found burning to increase crude protein and decrease ash in forage. Lay (1957) also reported an increase in crude protein and in phosphorous on burned versus unburned pine-hardwood stands. However, Dills (1970) reported no response of nutritive values of woody plants to burning in Tennessee.

Lay (1967) found that the effects of fire persisted about 2 years. However, Wood (1988) reported that effects from hazard reduction burns appeared to be small and lasted only a few months. Wolters (1981), Hurst et al. (1982) and Hurst and Warren (1980) recommend thinning and burning together.

Although numerous studies have demonstrated a clear relationship between forage production and overstory basal area (BA) (e.g., Wolters 1973, Blair and Enghart 1976, Fenwood et al. 1984), results were quite variable with nutrient response and BA. Conroy et al. (1982) indicated that crude protein levels were unrelated to overstory BA in thinned loblolly pine plantations. But the range of BA was relatively narrow, and may not have been wide enough to detect a meaningful relationship. Fenwood et al. (1984) found that phosphorous, crude protein, calcium, and TDN of composited understory forage samples showed no apparent relationship to BA or stand age in Oklahoma and Arkansas shortleaf pine stands.

Species composition changes in response to changes in residual overstory BA. Therefore, comparisons of treatment effects and relationships of nutrient levels to overstory cover using composited samples may not be valid. Nutrient response data from Fenwood et al. (1984) indicated that overall nutrient changes under differing pine stand BA's was minimal.

Evidence suggests that nutrient response of the same plant species was related to canopy cover. Increased canopy cover in young longleaf (P. palustris) and slash (P. elliotii) pine stands increased protein and phosphorous content but decreased nitrogen-free extract (Wolters 1973). Fiber content increased under shade and offsets gains in protein and phosphorous because of reduced digestibility (Blair et al. 1983). Total available nutrients were greater when more light reached the understory because of reduced fiber, increased digestibility, and increased forage production (Blair 1982, Blair et al. 1983). In the Edwards Plateau of Texas, crude protein and phosphorous levels were lower in open areas as well (Valentine and Young 1959).

In contrast, Halls and Epps (1969) found crude protein and phosphorous values to be greater with less overstory cover, but calcium levels were lower. Fuller (1976) reported that nutrient response varied by plant species, part, and season on Gulfwest Coastal Plain sites in Oklahoma and that Ca:P ratios were the only parameter that consistently differed between clearcut and selectively cut shortleaf pine stands. However, comparison of Fuller's (1976) data for the same season of collection, with that from Halls and Epps (1969) revealed similar findings with the exception of crude protein. Crude protein had no consistent relationship over the range of plant species analyzed. Fire histories of sites studied by Fuller (1976) and Halls and Epps (1969) were not documented and may have influenced findings.

Contradictions in the literature on the relationship of nutrient response to fire and overstory characteristics may be related to the manner in which the studies were conducted. Fire history or stand characteristics were not documented adequately enough to make valid comparisons. Composited samples of all plants in a quadrat were used in some studies while separate species were used in others, which further confounds comparisons of relationships between fire, overstory, and nutrient levels of forages.

Variability of nutrient responses in plants were related to plant species and phenology (Fuller 1976), overstory characteristics (Blair et al. 1983, Halls and Epps 1969), site characteristics, season of collection, possibly rainfall, and the presence or absence of fire (Lay 1967, Lewis et al. 1982). Site characteristics were apparently less important than the above factors (Reeb and Silker 1979). Although several studies on forage quality have demonstrated changes in nutrient levels because of habitat manipulation, none have looked at targeting management efforts to raise forage quality for deer during critical fall stress periods.

Oak-hickory Forest

The oak-hickory forest, an association of the eastern deciduous formation, occurs as a wide band around most of the margin of the deciduous forest formation (Braun 1950, Oosting 1956). This association occurs throughout the Piedmont and Coastal Plain regions in an ever widening arc into Texas. At the western extent in Texas and Oklahoma, the oak-hickory forest becomes savannah-like, intermingles with tallgrass prairie, and is known as the Cross Timbers. The oak-hickory forest is more or less continuous, extending north from the Cross Timbers into western Minnesota, then across to the New England states (Oosting 1956). On the southern end, this association is intermingled with the southern pine subclimax. The oak-hickory forest is considered as a more drought resistant part of the deciduous forest formation (Braun 1950, Oosting 1956). Much of the southern pine region can be considered as an oak-hickory association, but fire has caused a pine-dominated subclimax in local situations and generally in coastal plain areas (Oosting 1956). A detailed coverage of the nature and extent of this association is given by Braun (1950).

Oosting (1956) considered Cross Timbers as part of the oak-hickory forest in a transition zone. In Oklahoma, the Cross Timbers region is dominated by post oak (_Q. stellata_), blackjack oak (_Q. marilandica_), and occasional black hickory (_C. texana_). To the east and extending north into the Ozark Plateau, on more moist sites, northern red oak (_Q. rubra_), white oak (_Q. alba_), black oak (_Q. velutina_), mockernut hickory (_C. tomentosa_), and bitternut hickory (_C.

cordiformis) are some of the more important upland species (Bruner 1931).

Effects of fire in oak-hickory ecosystems have been largely overlooked in ecological and fire literature. Wright and Bailey (1982) did not mention fire in oak-hickory forest types, except to note that the natural role of fire in Cross Timbers was unclear. Neither did Chandler et al. (1983) mention the role of fire in oak-hickory community ecology other than in scrub oak habitats of the New England states. Ahlgren and Ahlgren (1960) discussed oaks only twice in the context of fire and soil relationships. Komarek (1981b) noted that we were in need of research on fire effects in hardwood types in general.

The oak-hickory forest is considered to be fire prone, with the primary fuel being oak leaves (Lotan et al. 1978). Lotan et al. (1978) considered most fires to be of low to moderate intensity with mortality limited to young trees. However, Anderson and Brown (1986) indicated that fires in this type were of high intensity. Both statements were true when taken in context. Anderson and Brown (1986) worked with grassland-forest ecotone areas and Lotan et al. (1978) made generalizations from more mesic portions of the oak-hickory forest type, that tend to form closed canopies.

Guyette and McGinnes (1982) used dendrochronology of red cedar (Juniperus virginiana) as a means of reconstructing fire history of an Ozark glade in southwest

Missouri. They discovered that from 1630 to 1870 fire occurred at an average interval of 3.2 years. Frequency dropped to once every 22 years after settlement and displacement of the Osage Indians.

Effects of Fire on Vegetation. Literature on fire in the oak-hickory forest is sparse, inconsistent, and frequently speculative. For the most part, fire in hardwoods has been dealt with in a negative context, i.e., advocating forest protection because of perceived relative intolerance of hardwoods to fire (Davis 1953). Otherwise the literature deals with either the subclimax southern pine region or the forest-prairie interface, with the emphasis on maintaining these respective subclimaxes (Garren 1943, Ahlgren and Ahlgren 1960, Kucera and Ehrenreich 1962, Kucera 1978). The classical climax succession model of seral stages progressing to an oak-hickory climax (in the absence of fire) is tacitly assumed in discussions relating to the oak-hickory forest association. More recent research indicates that the decline in Quercus spp. dominance may be related to the exclusion of fire (McGee 1980, 1986, Huntly and McGee 1981, Teuke and Van Lear 1982). Evidence from the Cumberland Plateau region of Tennessee and in north Alabama shows that fire intolerant, shade tolerant trees [e.g., yellow poplar (Liriodendron tulipifera), silver maple (Acer saccharum), white ash (Fraxinus americana)] were able to regenerate under dominant oaks and will express dominance in the advent of harvest of oaks or through progressive aging, senescence and mortality in the absence of periodic fire.

Wildfires were common in upland hardwood forests in the Southeast and may have affected stand composition (Garren 1943). Open park-like oak forests were present during the Indian Period in southern New England states and in the southern Appalachians, probably a result of recurrent fire (Niering 1978, Van Lear and Waldrop 1989). Historical records indicate that the Missouri Ozarks were open park-like stands intermingled with prairie in the seventeenth century. The area is now completely forested because of the elimination of fire (Beilmann and Brenner 1951).

In experimental burning of an oak-pine forest in Connecticut, Niering (1978) recreated park-like conditions, retaining larger stemmed oaks within the stand. Trees over 15 cm d.b.h. (diameter at breast height, 1.4 m above ground level) remained vigorous, except for occasional fire scars. Fire scars on the butt of hardwood stems were the most important means of entry for decay-causing fungi. As the tree ages, considerable merchantable volume could be lost because of spreading decay (Lotan et al. 1978).

Resistance to fire in oaks varied with age or bark thickness and species differences. Large-stemmed oaks showed a marked resistance to fire (Garren 1943, Kucera et al. 1963, Komarek 1981b, Sanders et al. 1986, White 1986). The time for the cambium of trees to reach lethal temperatures increased with bark thickness (Hare 1965) and bark thickness increased with age (Davis 1953). Many of the oaks were moderately resistant to fire (Davis 1953). Post oaks rated highest in resistance for the oak species given, but the relative fire tolerance of blackjack oak was not given (Davis 1953). Oak trees larger than 15 cm d.b.h. were top killed only with the extreme conditions of high air temperature and high fire intensity (Penfound 1968, White 1986). Oaks that were top killed sprout prolifically and produced coppice stands (Garren 1943, Penfound 1968).

Although Garren (1943) cited evidence that white oaks reproduce poorly on burned areas (by sprouts or acorns), Loomis (1977) noted successful re-establishment of a sapling white oak-red oak-hickory stand in Missouri after successive wildfires 13 years apart. The difference in these 2 studies may be fire frequency, but soil exposure due to fire may also be important in seedling establishment. Many hardwood species required mineral soil for seedling establishment and mineral soil exposure occurred naturally only with fire (Komarek 1981a). Recent research has emphasized oak regeneration by coppice or by controlling stocking of competing species with periodic fire (McGee 1980, 1986, Huntly and McGee 1981, Teuke and Van Lear 1982, Augspurger et al. 1986, Sanders et al. 1986).

Effects of Thinning and Fire on Wildlife. Thinnings and timber stand improvement were effective in enhancing understory forage production in hardwoods (Murphy and Ehrenreich 1965, Crawford 1971, Knierin et al. 1971, Beck 1983). Harlow (1985) found that forage values in thinned cove hardwood stands provided more than adequate nutrition to meet minimum requirements for white-tailed deer. Maxey (1976) found no significant difference in the number of greenbriar stems on areas receiving improvement cuts and thinnings. But this was probably related to high deer populations on the area. Beck (1983) indicated that thinning also improved ruffed grouse (Bonasa umbellus) habitat by increasing ground cover. Control of oak and hickory sprouts was recommended on poorer sites to favor species more palatable to deer (Crawford 1971).

Intensive cleaning of all but crop trees also increased forage production (Della-Bianca and Johnson 1965). Release efforts have been shown to increase acorn production (Harlow and Eikrum 1963) and release of suppressed hickories early on in a regenerating stand will put them in good position as mast producers later in the rotation (Nixon et al. 1982).

Some negative aspects of fire included potential reduction of hard mast (acorns) if intensive large scale fires were used. Home range displacement may be another problem (Landers 1987). Fire in woodlands may actually promote sprouting of hardwoods and thereby increase cover, but only at the expense of forage production (Shrauder and Miller 1969).

Tallgrass Prairie

Fire, at least late spring fire, was almost always followed by an increase in grasses relative to other plant growth forms, but the increase was more dramatic in higher precipitation areas where mulch accumulation suppressed growth in the absence of fire (Kucera 1978, Hulbert 1988). Unburned grasslands tended to stagnate and yields declined (Kucera and Ehrenreich 1962, Komarek 1965, Kucera 1978, Rice and Parenti 1978). Komarek (1965:190) noted the deleterious effects of fire exclusion was related to "mulching, smothering and disease harboring by heavy accumulation of dead plant growth."

Increased production was the result of increased nitrogen availability, warmer soil temperatures and increased surface light intensity which initiated earlier growth than on unburned areas (Kucera and Ehrenreich 1962, Peet et al. 1975, Knapp 1984, Hulbert 1988, Svejcar and Browning 1988). An important function of fire is the physical removal of standing dead vegetation (Hulbert 1969, 1988). A marked increase in grass production on annually burned tallgrass prairie, is likely in Missouri with big bluestem (Andropogon gerardi), little bluestem (Schizachyrium scoparium) and Indiangrass (Sorghastrum nutans) producing more numerous flower stalks and greater yields (Kucera and Ehrenreich 1962). In Oklahoma and Kansas, big bluestem (Peet et al. 1975, Hulbert 1988) and

Indiangrass also increase in production after burning (Hulbert 1988). Little bluestem increased in biomass and density after burning (Adams and Anderson 1978, Kucera 1978, Wright and Bailey 1982) except when soil moisture remained lower than normal (Anderson 1964, Box and White 1969, Adams et al. 1982).

In general, the advantages of fire in tallgrass prairie were control of woody plant invasion, removal of litter for enhanced growing conditions (Bragg and Hulbert 1976), increased forage palatability, and increased herbage production where soil moisture was adequate (Kucera 1978). Production was also strongly influenced by amount and distribution of annual precipitation and soil water-holding capacity (Sala et al. 1988).

Effects of Season, Frequency, and Type of Fire. Season and frequency of fire were major variables that affected species composition of grasses and forbs as well as productivity (Bragg 1982, Kucera 1978, Wright and Bailey 1982, Vogl 1974). Depending on local conditions and management objectives, fire in any season or frequency may be either beneficial or detrimental (Kucera 1978). The major effects of timing and frequency were moderated to the extent and intensity that the area was grazed (Kucera 1978). Comparisons of season and frequency were difficult because effects of fire differed yearly and locally. Therefore statements about frequency, in particular, were difficult to quantify with regard to maintaining grassland stability (Kucera 1978).

Effects of frequency of burning were related to litter accumulation, plant recovery and production up to time of burning. In the mesic tallgrass prairie, recovery, litter accumulation and production was more rapid (Kucera 1978). Grass production was generally maximized by burning at 2-year intervals (Vogl 1965). Kucera and Koelling (1964) found that a fire frequency range of 1- to 3-years was optimum in Missouri tallgrass prairie. In the second year, productivity was similar to 1-year burns but species diversity was increased. On areas burned every 5 years woody species encroachment occurred and productivity declined.

Seasonal timing may affect plant community species composition and productivity more than any other factor (Vogl 1974). Season of burn may have variable effects on forbs depending on soil moisture (Wright and Bailey 1982). Generally, late spring burns negatively impacted cool season grasses as they were actively growing (Wright and Bailey 1982). Warm season grasses were either dormant or had not expended much energy in the form of new growth (Vogl 1974). Comparatively, winter and early spring burns lowered bluestem yields (Anderson 1964). Soil and water losses were increased on winter and early spring burns before green-up and cover establishment (Anderson 1965). Winter burns generally increased forb component, whereas late spring burns reduced forbs (McMurphy and Anderson 1965, Towne and Owensby 1984).

Late summer fires have the potential to shift community composition from warm season grasses (e.g., big bluestem, little bluestem) to cool season grasses and forbs. This shift was caused by mortality to bunchgrasses and by changes in microclimate. Total herbaceous production was not reduced by late summer burning (Ewing and Engle 1988). Adams et al. (1982) noted a decrease in herbaceous production after both summer and winter burns but indicated that this may have resulted from low soil moisture because of below average rainfall during the study period. Summer was most likely the time of year when presettlement fires occurred (Komarek 1964, 1965, Bragg 1982).

Type of fire also impacted community composition. Spring backfires decreased tallgrasses, but spring headfires increased them. Forbs, conversely, were increased by spring backfires and decreased by headfires, but the magnitude of this change was small relative to effects of season of burn (Bidwell 1988).

Effects of season and frequency of burns on the plant community were moderated by the degree of herbivore utilization, because litter decreases proportionally with grazing use. With depleted fuel supplies, fire may become secondary to grazing intensity relative to plant community composition and production. If severely overused, site deterioration may occur and woody invasion may be accelerated because of absence of periodic fire and loss of competing herbaceous species that often accompany overgrazing (Kucera 1978, Wright and Bailey 1982).

Effects of Fire on Wildlife. Effects of fire on wildlife were indirect and operated to change habitat structure, food availability, quantity and quality (Komarek 1963, Wright and Bailey 1982). Fire may affect the total animal species and habitat complex. Interacting factors that change this complex included the plant community sere (i.e., the current stage of plant succession), the overall weather pattern (Wright and Bailey 1982), seasonal timing of the burn, soil properties, topography, animal niches, and characteristics of the individual fire (Landers 1987). Most species of wildlife require specific habitats and without some form of successional redirection or method of disturbance (such as fire) these habitats progressively change without most people ever noticing (Komarek 1963).

The intricacy of the wildlife habitat complex may be further illustrated by expanding Steuter's (1986) fire-bison grazing interaction hypothesis to include the greater prairie chicken (*Tympanuchus cupido*). In my hypothesis, the fire-bison interaction was expanded to explain how prairie chicken breeding habitat was historically provided in tallgrass habitats. Prairie chickens require sites with relatively stubby grass or grass/forb cover for booming grounds and breeding purposes (Manske and Barker 1987). The bison grazing pattern, migratory to some extent and concentrating on burned areas, would produce discontinuous fuels and modify fire return intervals. The resultant mosaic of vegetation would include bison impacted areas, particularly near watering sources or wallows, with vegetation shorter in height because of trampling and grazing effects from large herds and possibly short term community shifts based on fire return intervals. Adjacent sites in the vegetation mosaic with different fire return intervals would provide the taller vegetation required for brood rearing (Newell et al. 1987). Prairie chickens seasonally require a diversity of habitats with different heights and at different stages of growth (Christisen 1985). Historically, this vegetational mosaic could be produced in tallgrass prairie only by the type of fire-bison interaction proposed by Steuter (1986).

Burning during warm-season dormancy including the late summer dry season reduced shrubs and small hardwoods, thus changing understory and midstory composition. However, forbs and some grasses, such as panicums, may be favored which benefits most species of wildlife (Grelen and Lewis 1981). Fire in any season lowered soft mast production for 2- to 3-years (Lay 1956). Burning tended to benefit many gallinaceous birds through increased food supplies, improved brood rearing habitat, and nesting cover, unless burns were conducted during nesting season (Landers 1987). Fire increased production, palatability, nutrient content (primarily protein and phosphorous) (Lay 1957, 1967), and digestibility of forages for wildlife (Blair et al. 1977).

Frequent summer and winter burns may lead to dominance by fire tolerant grasses (e.g., bluestems) that could be detrimental to some forms of wildlife such as white-tailed deer (Stransky and Harlow 1981) and beneficial to other wildlife such as the greater prairie chicken (Manske and Barker 1987). Frequent summer burns reduced legumes which would be detrimental to bobwhite quail, while periodic winter burns tended to promote legumes (Grelen and Lewis 1981).

Late spring backfires have advantages over fall or winter burning because of reduced loss of food and cover for wildlife. Backfires tended to leave patches of standing herbaceous material that were beneficial to nesting birds (Bidwell 1988). Burning small areas in fall or winter in a patchwork fashion benefitted quail because of increased legume production over other seasons (Landers 1981). If burns were conducted immediately before warm-season tallgrass regrowth (early- and mid-spring), forb production may be increased at the expense of tallgrasses (Launchbaugh and Owensby 1978).

In general, the management advantages to use of fire in tallgrass prairie were control of woody plant invasion, removal of litter for enhanced growing conditions, increased forage palatability, and increased herbage production if soil moisture is adequate (Kucera 1978). Seasonal use of fire allowed the manager to shift plant community composition to favor management objectives whether they were wildlife or livestock oriented. Modification of season of burning and using deferred grazing schedules may allow for management to benefit livestock, prairie chickens, quail and other forms of wildlife.

Conclusions

Based upon the foregoing literature review, vegetation response to timber harvest and fire may be postulated for the present study area. Initially, the harvested and winter burned treatments would be similar to low intensity site preparation of clearcuts (Stransky and Richardson 1977, Stransky and Halls 1978). The clearcut treatment would be comparable to high intensity site preparation treatments (Stransky 1976). Rough reduction burns should cause a response similar to low intensity rough reduction burns elsewhere in mixed oak-pine habitats (Lay 1956, 1967; Grano 1970; Wood 1988).

The successional progression described by Hebb (1971) should be characteristic of clearcuts on the study area. The progression was: 1) the denuded site, 2) profusion of forbs and grasses, 3) dominance by relatively few species, and 4) shading out of understory by the developing overstory. We would expect plant species diversity and richness to increase initially.

Tallgrasses were prevalent in eastern Oklahoma and should be increased with overstory removal and fire. Fire should slow succession to seral stages dominated by trees on harvested areas and stem girdle small <15 cm hardwoods on unharvested sites (Kucera 1978, Niering 1978). Frequent winter prescribed burns (1- to 2-year intervals) should increase grass production 10 to 15 times and may control hardwood coppice to a degree (Ferguson 1961, Kucera 1978). We do not know if the frequent fire return intervals will entirely halt secondary succession on oak-pine sites. Winter prescribed burns of 3- to 4-year intervals should increase grass production and allow woody plants to invade such as blackberry and sumac (Rhus spp.) (Bragg and Hulbert 1976, Kucera 1978). Again we do not know how long these openings will persist under less frequent fire return intervals before forage production declines. Summer burns and/or periodic shortening of fire return intervals may give added flexibility to the management strategy of these openings and help maintain woody browse species. Woody browse species were important to deer but winter burns may lead to dominance by fire tolerant grasses that may not be utilized by deer (Stransky and Harlow 1981). Browse should increase in nutrient content and palatability on harvested and burned areas (Lay 1957, Halls and Epps 1969). Mast production on harvested areas will be severely impacted, but at this point we do not know if forage production and nutrient increases will offset the loss of mast.

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CHAPTER III

STUDY AREA

The study area was located on the Pushmataha Wildlife Management Area (PWMA), approximately 6 km southeast of Clayton, Pushmataha County Oklahoma (34° 32' N, 95° 21' W) (Fig. 1). The 29.1-ha study area was within the 45.3-ha Pushmataha Forest Habitat Research Area. The climate was semi-humid to humid with hot summers and mild winters. Summer temperatures frequently exceed 32 C with winds from the south averaging 17 km/hr. Winter mean daily maximum temperatures are approximately 13 C. The average frost free period was 190 days and occurred from late March to mid-October. Average annual precipitation was 109-127 cm (Bain and Watterson 1979). Rainfall on the study area between 1978 and 1990 ranged from an annual average of 106-188 cm based on an October to September water-year. Precipitation varied considerably in yearly and seasonal distribution, and August was the driest month (Tables 1 and 2) (Dep. For., Okla. State Univ., unpubl. data). Actual monthly and seasonal rainfall data from 1978 to 1990 are presented in Appendix A.

Fig. 1. Location of Pushmataha Wildlife Management Area and the Forest Habitat Research Area (study area).

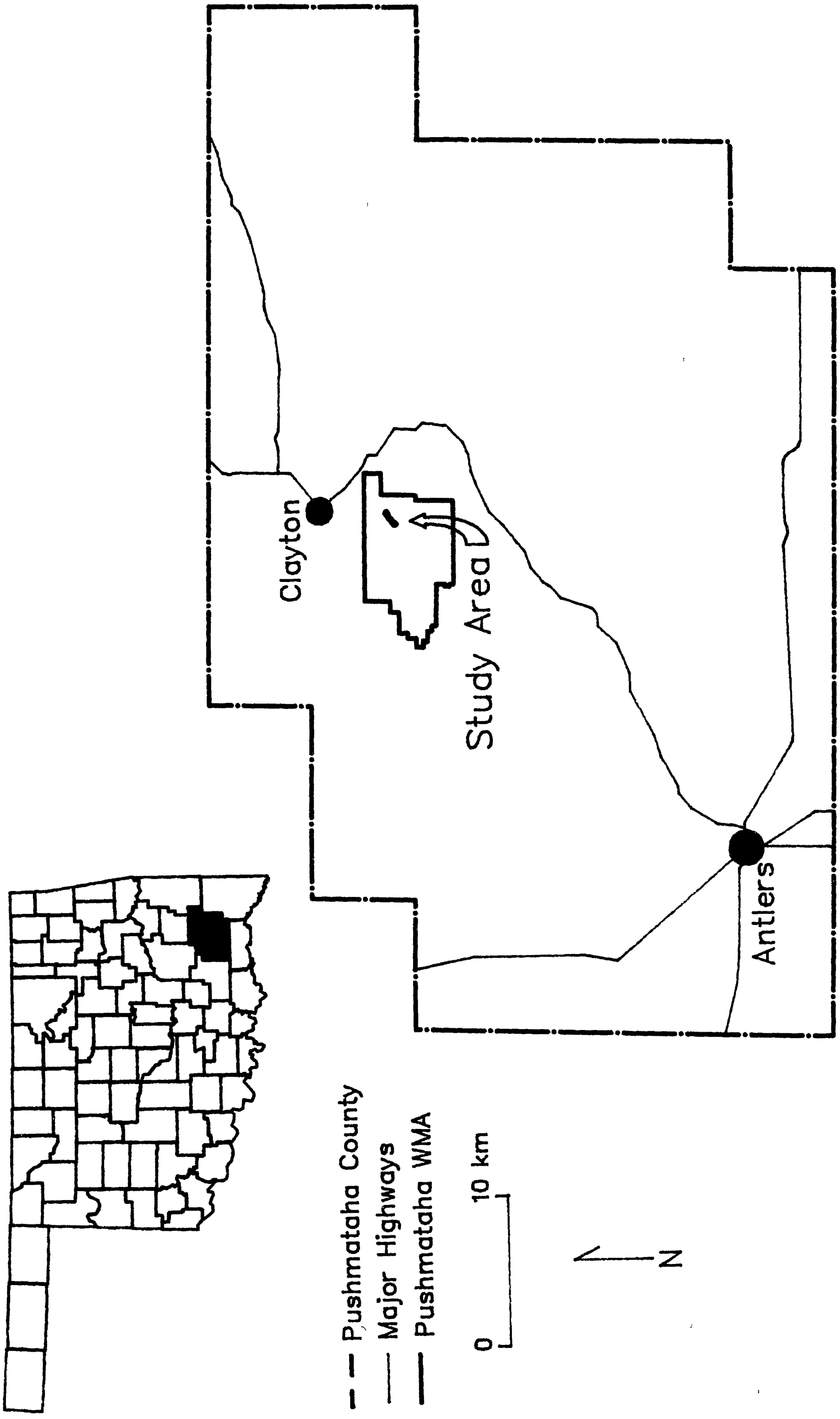

Clayton
Study Area
Antlers
Pushmataha County
Major Highways
Pushmataha WMA
0
10 km
N

Table 1. Mean monthly and annual rainfall (cm) on Pushmataha Forest Habitat Research Area from 1978 to 1990.[a]

Month	Mean	Range		Coefficient of Variation
		Minimum	Maximum	
October	13.7	2.5	48.0	89.6
November	10.4	0.5	29.6	79.1
December	8.2	0.4	20.3	86.0
January	8.0	0.5	21.7	73.9
February	11.1	5.2	23.6	44.8
March	11.6	4.3	20.3	47.4
April	12.1	1.8	34.8	76.0
May	20.0	3.1	34.8	46.0
June	12.2	4.3	25.0	53.6
July	9.2	1.4	18.2	59.8
August	6.1	0.4	11.5	66.0
September	11.1	0.7	21.4	67.3
Annual	134.6	105.7	187.9	19.8

[a] Monthly and annual precipitation was based on a October to September water-year (Dep. For., Okla. State Univ., unpubl. data).

Table 2. Mean seasonal and annual rainfall (cm) on Pushmataha Forest Habitat Research Area from 1978-1990.[a]

		Range		
Season	Mean	Minimum	Maximum	Coefficient of Variation
Oct-Dec	32.2	5.6	76.7	58.6
Jan-March	30.8	16.9	65.6	42.6
April-June	44.3	17.6	73.9	34.1
July-Sept	26.5	10.3	42.8	35.8
Annual	134.6	105.7	187.9	19.8

[a] Seasonal and annual precipitation was based on a October to September water-year (Dep. For., Okla. State Univ., unpubl. data).

The PWMA lies in the strongly dissected Kiamichi Mountains along the western edge of the Ouachita Highland Province. The Ouachita Mountain uplift was composed of folded and northward-thrusted Mississippian and Pennsylvanian rock. Cherty shales and resistant sandstones occurred along prominent ridges. The soils developed from sandstone and shales, and were thin and drought prone.

Study area soils belonged to the Carnasaw-Pirum-Clebit association with areas of rock outcrop. The surface layer was variable in depth to 30 cm, and texture was stony fine sandy loam (Bain and Watterson 1979). The Forest Habitat Research Area (FHRA) was approximately 335 m in elevation (near maximum), on a southeastern aspect south slope of 5-15% grade.

The PWMA was in the oak-pine (*Quercus* spp.-*Pinus* spp.) forest type and was unique in that 3 other vegetation types were in close proximity. Oak-hickory (*Carya* spp.) and Cross Timbers vegetation types were within 30 km of the study area. The nearest extant remnants of tallgrass prairie were approximately 45 km from the study area (Duck and Fletcher 1943).

The FHRA overstory plant community was dominated by post oak (*Q. stellata*), shortleaf pine (*P. echinata*), blackjack oak (*Q. marilandica*), and mockernut hickory (*C. tomentosa*). Common understory species include: huckleberry (*Vaccinium spp.*), poison ivy (*Toxicodendron radicans*), Virginia creeper (*Parthenocissus quinquefolia*), greenbriar (*Smilax spp.*), grape (*Vitis spp.*), little bluestem (*Schizachyrium scoparium*), panicums (*Panicum* spp., *Dicanthelium* spp.), and sedges (*Carex* spp.).

The PWMA was acquired in several tracts from 1946-54 (Okla. Dep. Wildl. Conserv. [ODWC] 1972). Prior to acquisition the PWMA was grazed, selectively harvested, and subject to frequent fire. Evidence of fire and logging persist in subsequently unburned areas. The PWMA was protected from fire, other than lightning fire and occasional wildfire, until 1975 when a prescribed burning program was instigated. The immediate study area was protected from logging and fire until 1984 when this study began (R. Robinson, ODWC, per. commun.).

The PWMA was initially established as a deer refuge. From 1946-68, 192 deer were stocked in Pushmataha County including PWMA (ODWC 1972). Management efforts at the time were limited to closure of deer hunting and the establishment of clearings from 0.1 to 2 ha in size. Deer hunts were first conducted in 1965 and have continued annually to present (except in 1969 and 1970 when elk [*Cervus elaphus*] were released on PWMA). Deer hunts were buck only until 1974 when the first either-sex hunt was held. Since that time, all hunts have been either-sex. From 1969-72, 71 elk were released on the PWMA (ODWC 1972). Eastern wild turkeys were released on the management area in

1973 and 1975-76 (ODWC 1983). Currently, there is a turkey population estimated at 1 bird per 16 ha. The elk population declined to a low of 6 in 1984 and has since increased to approximately 20 in winter 1991 (Fig. 2) (ODWC, unpubl. data). The initial decline was caused by emigration related to poor habitat conditions and to nutritional stress. Later declines were the result of impacts of the meningeal worm (Parelaphostrongylus tenuis) on the elk. I hypothesize that the elk population increase has been brought on by an increase in openings on the area and the use of prescribed fire, both of which may change microhabitat features necessary for the gastropod intermediate hosts. Openings maintained with fire may provide divergent enough habitats so niche overlap is minimized and elk and deer are spending less time occupying the same habitat at a time suitable for elk to pick up the meningeal worm (Raskevitz et al. 1991).

The deer population reached its highest point, before the ODWC implemented radical habitat alterations, during 1973 (Fig. 3). At that time the deer herd was estimated at 693 (± 102) (SE) (1 deer/10.7 ha), based on 12 1-mile Hahn lines run 2-4 times between late February and early April each year (Hahn 1949). The fawn/doe ratio was 0.21 and the buck/doe ratio was 0.10 as estimated by 20 mile spotlight routes run 10 times in September. During the 1974 hunts no yearling bucks were harvested under buck only harvest

Fig. 2. Elk population and hectares of openings (including cultivated foodplots) created by timber harvest and maintained in early successional stages with periodic prescribed fire from April 1969-91.

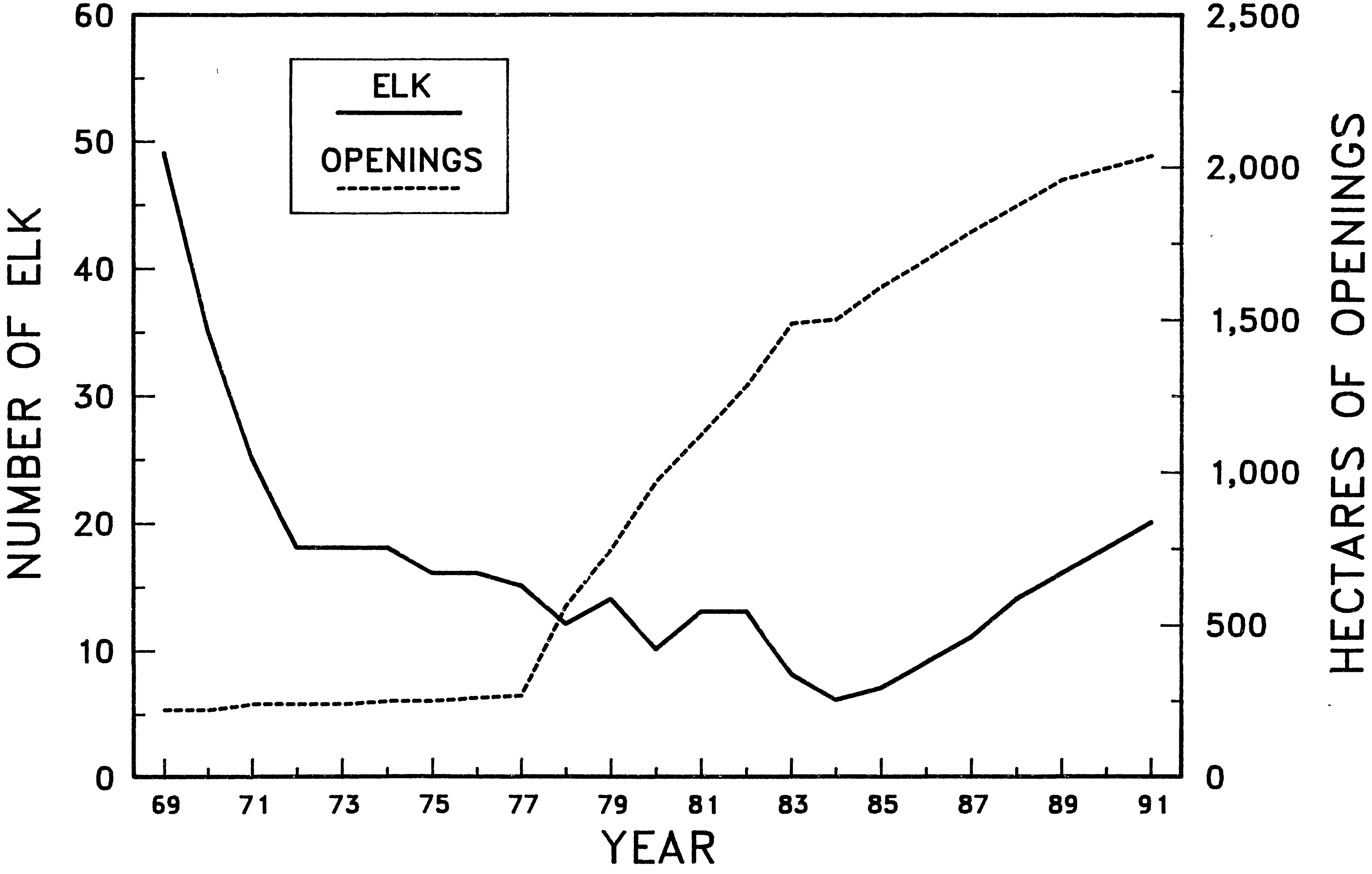
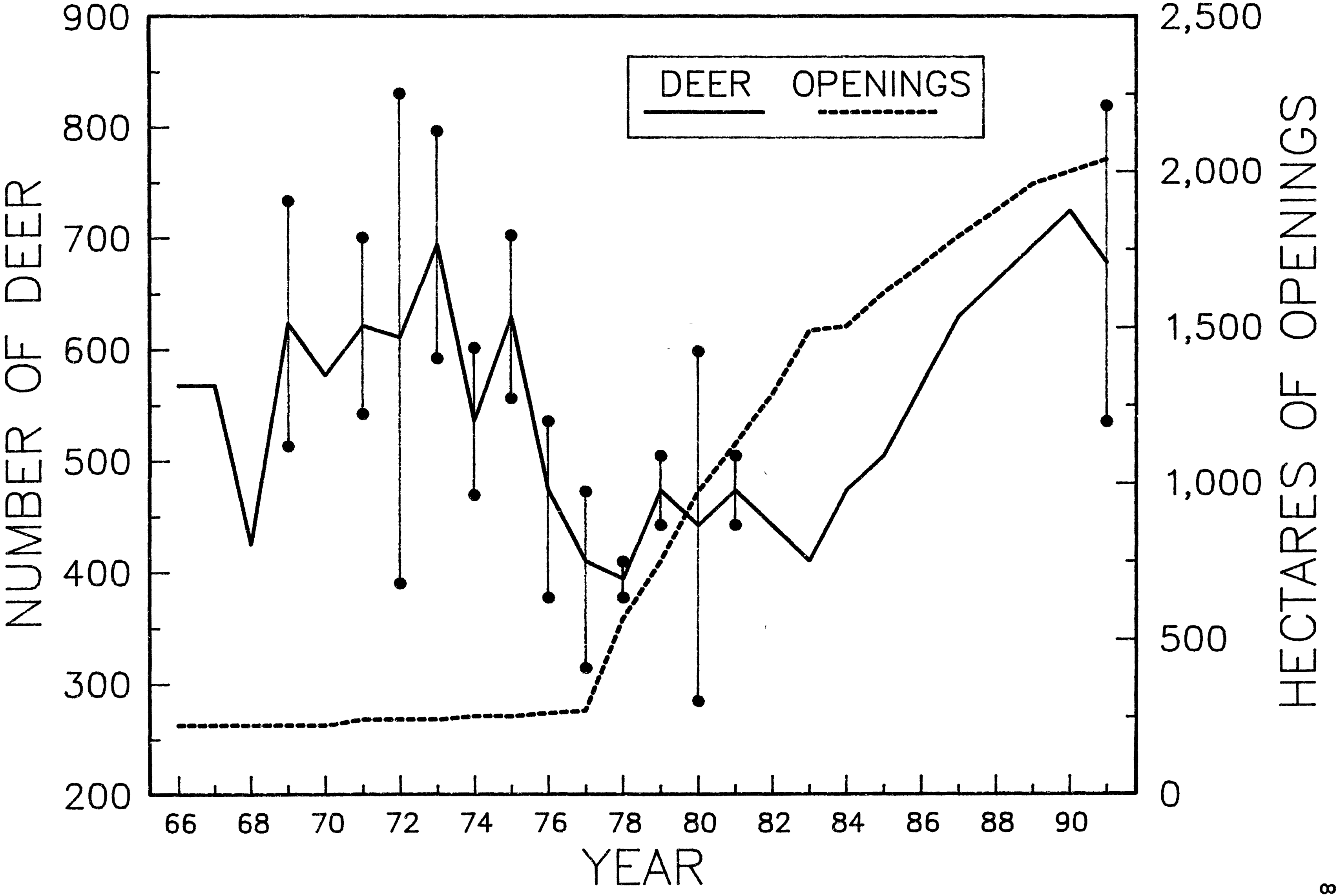

ELK
OPENINGS
NUMBER OF ELK
0
10
20
30
40
50
60
HECTARES OF OPENINGS
0
500
1,000
1,500
2,000
2,500
YEAR
69
71
73
75
77
79
81
83
85
87
89
91

Fig. 3. Deer population estimates (± SE) and hectares of openings (including cultivated foodplots) created by timber harvest and maintained in early successional stages with periodic prescribed fire from February 1966-91. Standard errors were not reported in years without standard error bars.


DEER
OPENINGS
NUMBER OF DEER
900
800
700
600
500
400
300
200
HECTARES OF OPENINGS
2,500
2,000
1,500
1,000
500
0
66
68
70
72
74
76
78
80
82
84
86
88
90
YEAR

regulations. The population declined to a estimated low of 394 (± 16) (SE) (1 deer/18.8 ha) in 1978 (ODWC unpubl. data).

Before habitat manipulation with timber harvest and prescribed fire began, a distinct browse line became apparent with heavy usage of eastern red cedar (Juniperus virginiana) in winter. An aggressive timber management and prescribed fire program was begun in 1977. A major part of this program was to maintain harvested sites in early succession by use of periodic prescribed fire. Prior to 1977 less than 4% of the PWMA was in cultivated openings. At present 24% of the area is maintained in clearcut openings at various successional stages through use of prescribed fire. Approximately 70 cultivated openings are maintained as well. Openings of all types comprise 28% of the total area. In March 1991, the deer population was an estimated 677 ± 142 (1/10.9 ha), similar to that before population decline. The September 1990 doe\fawn ratios were 0.39 and buck/doe ratios were 0.19.

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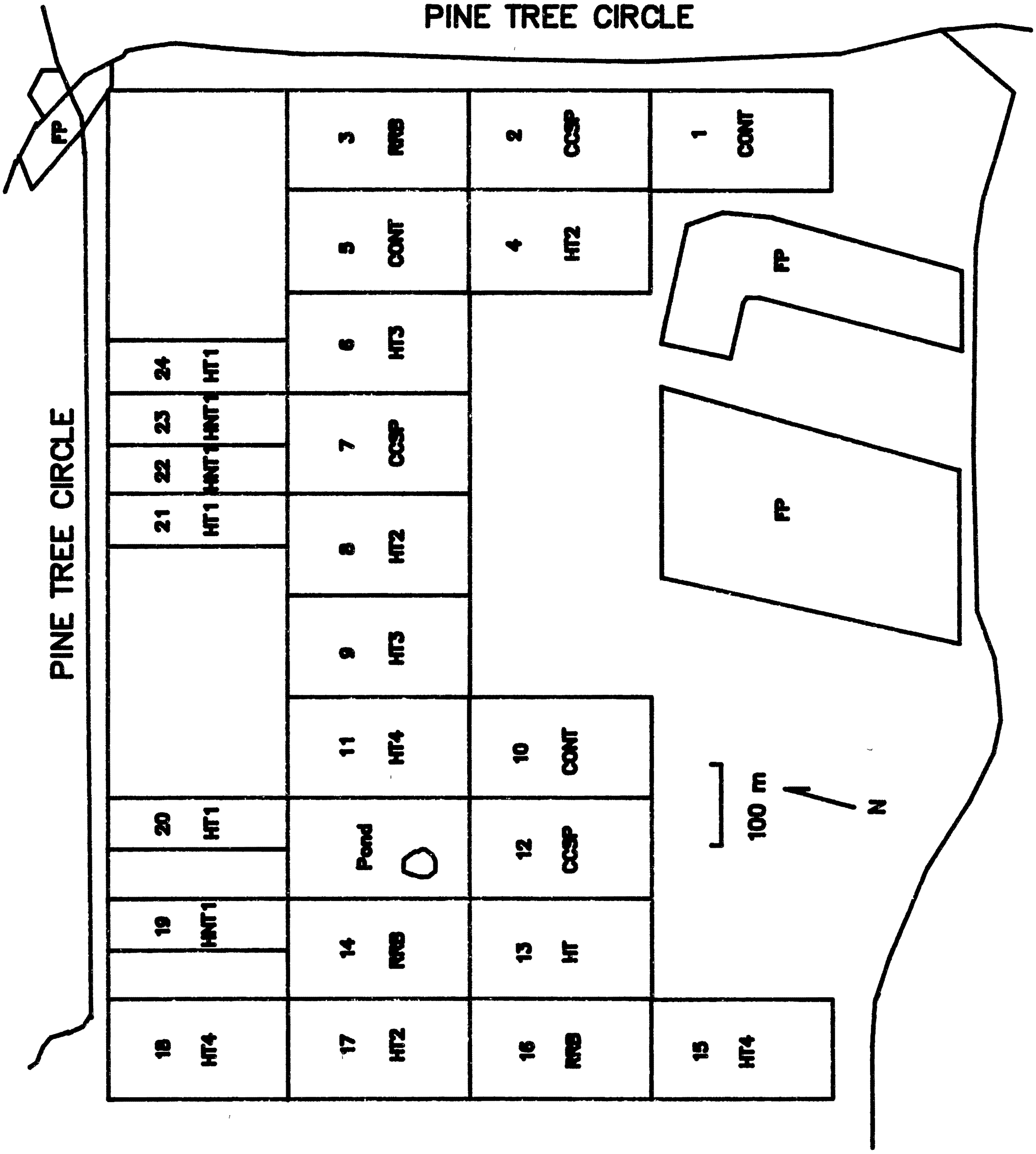
CHAPTER IV

METHODS

Experimental Design

The study area was laid out in a completely randomized experimental design in winter 1982 (Fig. 1). Fireguards were bull-dozed around 24 1.2-1.6 ha contiguous, rectangular units in 1983 (Chambers and Brown 1983). Beginning in summer 1984, 3 replications of 8 treatments were randomly applied to the 24 units. Two replicates of 1 treatment (HT) were inadvertently burned in winter 1985 because of fire control problems. Rather than eliminate these units from the study, data were collected and the units considered as replications of an additional treatment. This is a valid procedure for completely randomized designs (Steele and Torrie 1980:126, 139). The total number of treatments under consideration then became 9. In addition, unit 24 was not burned during the scheduled time in 1986 because of poor weather, and was dropped altogether.

Fig. 1. Pushmataha Forest Habitat Research Area (study area) treatment layout and experimental design.


PINE TREE CIRCLE
PINE TREE CIRCLE
FP
3 RRB
2 CCSP
1 CONT
5 CONT
4 HT2
FP
24 HT1
6 HT3
23 HNT1
7 CCSP
22 HNT1
21 HT1
8 HT2
FP
9 HT3
11 HT4
10 CONT
100 m
N
20 HT1
Pond
12 CCSP
19 HNT1
14 RRB
13 HT
18 HT4
17 HT2
16 RRB
15 HT4

Treatment Description

Treatments, burning sequence, treatment code, and number of replications (n) are summarized below:

(1) no treatment (control) (n = 3);

(2) rough reduction winter prescribed burn - 4-year interval, 1985, 1989 (RRB) (n = 3);

(3) harvest pine timber only, winter prescribed burn - 1-year interval, 1985-1990 (HNT1) (n = 3);

(4) harvest pine timber, thin hardwoods, no burn (HT) (n = 1);

(5) harvest pine timber, thin hardwoods, winter prescribed burn - 4-year interval, 1985, 1989 (HT4) (n = 3);

(6) harvest pine timber, thin hardwoods, winter prescribed burn - 3-year interval, 1985, 1988 (HT3) (n = 2);

(7) harvest pine timber, thin hardwoods, winter prescribed burn - 2-year interval, 1985, 1987, 1989 (HT2) (n = 3);

(8) harvest pine timber, thin hardwoods, winter prescribed burn - 1-year interval, 1985-1990 (HT1) (n = 2); and

(9) clearcut and summer site prep burn, 1985 (CCSP) (n = 3).

One additional treatment, cultivated food plot, was included in the part of this study that determined relative herbivore use of treatments (See Chapter VIII). Three food plots were established in the 1960's adjacent to the present FHRA location. They were included to compare herbivore use of a traditional management technique with those under development. According to Steele and Torrie (1980), inclusion of this additional treatment is valid in a completely randomized experimental design. The food plot treatment is summarized as follows:

(10) cultivated fertilized food plot, planted to fescue, rye, vetch, and Korean lespedeza; plots were mowed each fall and disced periodically (FP) ($\underline{n}$ = 3).

Application of Cultural Treatments

In summer 1984 merchantable pine timber was harvested and hardwoods selectively thinned by single stem injection using 2-4 D, to a basal area (BA) of 9 m^2/ha. Prescribed burns using strip-head fires were conducted in winter 1985 and in succeeding years at appropriate intervals. After 1985 burns, headfires were the primary type of fire used. The total fire configuration for experimental units was most often a ring fire. Fire behavior parameters were measured on 1988 prescribed burns. Methods and results from these burns are reported in Appendix B.

The clearcut site prep treatment was applied with standard practices used by industrial timber companies. The sites were prepared by shearing, raking and windrowing logging debris with a site prep burn conducted during summer 1985. The clearcut replicates (n = 3) were contour ripped to an average depth of 50 cm on 2.4 m centers the following March. Genetically improved loblolly pine from the Weyerhaeuser Co. (Fort Towson, Okla.), were planted on a 2.1 x 2.4 m spacing in early April 1986.

Vegetation Sampling

Density, Cover, and Use

In July 1983 a stratified random sampling scheme using 1 m x 1 m (1 m^2) and 4 m x 4 m (4 m^2) nested quadrats were set up to sample understory, midstory, and overstory vegetation (Oosting 1956:47-50, 62). Herbaceous plants were measured with 1-m^2 quadrats and woody plants measured with 4-m^2 quadrats. Two random points on a baseline were chosen with transect lines emanating perpendicular to the contour (Oosting 1956). Five permanent plots were established at 19.8-m intervals on each line within a treatment unit (n = 10). In order to avoid bias caused by influences from adjacent treatment units, I did not sample within 19.8 m of any edge to avoid bias from adjacent treatment units (Oosting 1956, Mueller-Dombois and Ellenberg 1974).

Vegetation sampling was conducted in September and October of each year to coincide with the late summer early fall stress period for deer (Fenwood et al. 1984). A baseline survey was conducted in 1983 prior to any treatment. Data collected included plant species density, percent ground cover, and browse utilization. Frequency of occurrence was calculated later from field data.

Browse use on each plant species was grouped into 4 categories based on the average proportion of current annual growth (CAG) browsed. The utilization categories were none, trace (<25% CAG browsed), moderate (25-50% CAG browsed), and heavy (>50% CAG browsed).

Vegetation data was recorded by strata occupied and crown position (midstory and overstory) relative to stand canopy structure. Strata designations were 0-1 m, 1-3 m, and >3 m. Strata >3 m were categorized by position relative to stand canopy structure and were suppressed (>3 m, but with crowns not extending into the canopy), intermediate (crowns extending only into mid-canopy), co-dominant (crowns in the upper canopy but not extending above average height), and dominant (crowns well established in upper canopy and extending above average canopy height) canopy position (Smith 1962). On harvested treatments, strata designations of residual trees was based on prior stand structure. No tree or shrub regrowth was >3 m.

Overstory vegetation was further quantified using the variable radius plot method (Avery 1964). Basal areas were taken using a 10-factor prism with plot center at the center of the 4-m^2 plot. Overstory canopy cover was measured at 9 cardinal locations with the center point being the location stake for the southwest corner of the 1-m^2 permanent plot. Measurements were made with a grided sighting tube with horizontal and vertical levels (Mueller-Dombois and Ellenberg 1974). The number of leaf-grid intersections were counted and percent canopy cover calculated.

Standing Crop

Standing crop was determined beginning in 1986 with 0.5 x 0.5 m (0.25-m^2) plots. Plot size and number of plots were determined using Cain and Castro's (1959) minimal area concept to derive species-category area curves. To separate out potential bias and to determine the effects of herbivory, 5 caged and 5 uncaged paired plots were located adjacent to the permanent plot markers. Vegetation was clipped to <2.5 cm height and hand separated into sedge, legume, panicum, grass, forb, and woody categories. Litter was collected to mineral soil and included dead grass, leaves, bark fragments, and twigs <2.5 cm diameter. Samples were dried to constant weight at 70 C in a forced air oven.

Permanent enclosures were constructed at 3 random locations on each treatment unit. The enclosures were 4 m^2 and 2 m in height. Five 0.25-m^2 plots, previously unclipped, were randomly located each year and clipped without replacement in succeeding years. Enclosures were not set up on the CCSP, HNT1, and HT1 treatments.

Forage Analysis

Treatment effects on nutrient content were determined on 5 preferred deer foods (ODWC, unpubl. data) which occurred in all treatments. The species selected were elmleaf goldenrod (*Solidago ulmifolia*), stiff-leaf sunflower (*Helianthus hirta*), greenbriar (*S. bona-nox*), winged sumac (*R. copallina*), and winged elm (*Ulmus alata*). Each treatment unit (replicate) was systematically searched by 2-4 observers, and approximately 100 grams of (green weight) current annual growth were collected for each species. A minimum of 10 plants were sampled if 100 grams were not available (Lay 1957). Plant samples were collected during a 2-week period in late September to early October from 1985 to 1989. Plants were sampled to mimic observed deer utilization of each species. The terminal 30-50% of goldenrod and stiff-leaved sunflower, random available terminal leaves of greenbriar, winged sumac, and winged elm were collected. Nutrient analyses were conducted by Servi-Tech, Inc. (Dodge City, Kan.) and included moisture content, dry matter content, ash, crude protein, ADF, TDN, calcium, phosphorous, magnesium, and potassium. Analysis were based on standard analytical methods for crude protein (AOAC 1982), minerals (Havlin and Soltanpour 1980), and acid detergent fiber (Sullivan 1959, Van Soest 1962). Digestibility was determined using the procedure of Tilley and Terry (1963) for 1986 samples.

Soil Samples

Soil samples were collected in late February 1989 using a 2.5-cm soil auger. I sampled the top 12 cm of soil at 19.8-m intervals on 2 randomly located transects for a total of 10 sample locations on each of 23 treatment units. Samples on each treatment unit were composited and bagged. Chemical analysis for pH, NO_3-N, P, K, Mg, and Ca were conducted by the Soil and Water Service Laboratory, Agronomy Department, Oklahoma State University based on standard analytical methods (Page 1982).

Pellet-group Counts

Pellet-groups have compared favorably with other techniques to determine white-tailed deer response to habitat manipulation techniques (Rollins et al. 1988). Habitat use patterns of mule deer (Odocoileus hemionus) (Loft and Kie 1988, Leopold et al. 1984) and elk (Edge and Marcum 1989) determined by radio telemetry have compared favorably with pellet-group counts. Eastern cottontail rabbit (Sylvilagus floridanus) pellet-group counts have not been tested as an index of habitat use or response to habitat change. However, with limited home range, high reproductive rates, and high rates of dispersal (Chapman et al. 1982) (compared to deer and elk), rabbits should exhibit some treatment preference given the randomization and availability of all treatment types.

Habitat/treatment use by white-tailed deer, elk and cottontail rabbit was determined using pellet-group counts on randomly located parallel transects in each experimental unit. Lines were 100 x 1 m (100 m^2) and located at least 19.8 m from any experimental unit edge. Transects were randomized each sampling period.

Temporary rather than permanent transects were used because rabbit pellet groups, in particular, may persist for long periods. Persistence is related to type of food utilized, temperature, and weather. No definitive method of aging rabbit pellet-groups has been reported (Cochran and Stains 1961). However, in warm climate with high rainfall and high dung beetle activity, persistence may not have such a confounding effect.

All deer, elk, and rabbit fecal pellet groups within a transect were counted and recorded. A pellet group was defined as >5 pellets in a pile or trail. Pellet groups that occurred on the plot boundary were counted if ≥ 5 pellets were within the transect boundary (Kinningham et al. 1980). Pellets that exhibited charring from burn treatments were excluded because charred pellets often persisted >1 year (pers. obser.).

Pellet-group counts (n = number of transects/experimental unit) were conducted in May (n = 1), September (n = 2) and December (n = 2) 1988, and in March (n = 4) and April (n = 3) 1989. In addition, transects were established on 3 food plots adjacent to FHRA for comparative purposes. Sampling dates were chosen to determine possible seasonal shifts in use (May, Sep, Dec, and Mar) and response to burning treatment application (May and Apr).

Experimental units were sampled within a 2 week period, but not all treatments were sampled in September 1988, March 1989, and April 1989. The FP treatment was not sampled September 1988 and the HI, HT3 and CCSP treatments were not sampled in March 1989 because rainfall >3 cm occurred on a single day during the sampling period and affected counts.

Rainfall

Rainfall data were obtained from the Department of Forestry, Oklahoma State University. A self-recording rain gauge was established approximately 100 m from the center of the study area in 1978. Precipitation amount, date, time of day, storm duration, and intensity were monitored as part of a large watershed study since 1978 (M. Kress, pers. commun.). Rainfall amounts were recorded to the nearest 0.01 inch and converted to centimeters. Data were compiled by week, month, season and year, based on an October to September water-year.

Statistical Analysis

Species diversity, evenness, richness, density, relative frequency and relative dominance were calculated from vegetation samples (Ludwig and Reynolds 1986). A total of 12 species diversity, evenness and richness indices were calculated using SPDIVERS.BAS (Ludwig and Reynolds 1986). A modification of Krueger's (1972) relative preference index (RPI_1) was used to determine plant species preference by cervids on each experimental unit:

$$RPI = \frac{\%\ \text{utilization (frequency of utilization)}}{\%\ \text{cover (frequency of occurrence)}} \times 100$$

Replicate means of response variables (e.g. sumac crude protein, grass standing crop, deer pellet groups) were tested for homogeneity of variance between treatments using Levene's test (Snedecor and Cochran 1980). Variable frequency distributions were compared with Poisson, log normal, and negative binomial distributions for indications of appropriate data transformations. One-way analysis of variance for unequal sample size was used when data were normally distributed and variances were homogeneous. Standing crop from caged, uncaged, and enclosed plots were compared using a 2-tailed paired t-test. The chosen level of significance was $\underline{P} < 0.05$ for the above analysis.

When nonparametric procedures were indicated as the appropriate analysis, unit means of the appropriate measure were ranked, then one-way analysis of variance was conducted on the ranks. This is equivalent to the Kruskal-Wallis nonparametric test (SAS Institute 1985). The chosen level of significance was ($\underline{P} < 0.05$), with ranks of means separated by the Waller-Duncan k-ratio T test or Duncan's multiple range test (SAS Institute 1985).

Main effects and interaction of timber harvest and burning in 1988 were determined using control, RRB, HT, and the HT4 treatment. The remaining treatments were dropped and these treatments were analyzed as factorial arrangement of treatments (2 levels of fire and 2 levels of timber harvest) using the method of fitting constants and method of unweighted means (Bancroft 1968, Steele and Torrie 1960).

Exploratory analysis was conducted using PROC RSQUARE in SAS to examine variable relationships (SAS Institute, 1985, 1987). Dependent variables for various analyses included deer, elk and rabbit pellet-group data, all soil macronutrient variables, all plant nutrient response variables, and all September standing crop (kg/ha) variables. Independent variables entered in the different regression analysis included; total basal area, hardwood basal area, pine basal area, ratio of hardwood basal area to pine basal area, ratio of pine basal area to hardwood basal area, percent canopy cover, time since burned, number of times burned, all September standing crop (kg/ha) variables, all soil macronutrient variables, all plant nutrient response variables, and where appropriate, yearly, seasonal, and monthly rainfall data. The best models describing a particular relationship were determined using plots of Mallows C_p statistic as an unbiased parameter estimator, where C_p is a measure of the total squared error (Mallows 1964).

Analysis was performed on the IBM 3081 Mainframe at OSU using procedures from Statistical Analysis Systems (SAS Institute, 1985) and on a microcomputer using PC-SAS (SAS Institute, 1985).

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CHAPTER V

EFFECTS OF TIMBER HARVEST AND PERIODIC FIRE ON SOIL CHEMICAL PROPERTIES IN THE OUACHITA MOUNTAINS

ABSTRACT

Soil chemical properties on mountainous terrain in oak-pine forests of southeastern Oklahoma, USA, changed following timber harvest and prescribed fire. Differences were related to residual stand characteristics, prescribed fire regimen and ensuing vegetation change following site perturbation. Available NO_3-N, Ca, and P significantly increased on retrogressed and burned sites, clearcut, windrowed, and summer burned sites compared to untreated sites. Increases to a lesser extent were found in pH, K and Mg. Nitrate levels were statistically unrelated to a 2,690 percent increase (7.5 to 212 kg/ha) in legume standing crop across site treatments. Effects of burning harvested sites on most soil chemical properties persisted less than 2 years. A timber harvest-fire interaction on levels of available K and Mg was evident 4 years post-treatment. Rough reduction burning caused some decline in all nutrient categories, except NO_3-N which was unaffected. Decreased

soil nutrients on this treatment were most likely a response to the mineralization pulse following fire and uptake by trees. Timber harvest, periodic prescribed fire and subsequent plant succession redirected nutrient cycling pathways and enhanced soil nutrient levels. Enhanced nutrient regimes are ecologically advantageous for stand reinitiation and recovery following site perturbation or possibly natural disturbance.

INTRODUCTION

Prescribed fire is widely used across the southeastern United States as a forest and wildlife management tool (Kodama and Van Lear 1980). Positive benefits such as increased nutrient uptake, increased tree growth (McKelvin and McKee 1986), and enhanced nutrient cycling (McKee 1982) are attributed to prescribed fire. The effects of forest management and fire on soil chemical properties and nutrient cycling have been determined in the southeastern US Coastal Plain and to a lesser extent the Piedmont (Kodama and Van Lear 1980, McKee 1982, Stransky et al. 1985).

The oak-shortleaf pine (Quercus spp.-Pinus echinata) forest is considered a fire subclimax (Oosting 1956), but concern has been expressed about timber harvest and the use of fire in mountainous terrain (Hobbs and Schimel 1984). Some authorities have recommended use of prescribed fire only on gentle slopes because of possible increased runoff and off-site loss of soluble minerals (Curtis et al. 1977).

Litter dynamics influence the effects fire and timber harvest have on nutrient cycling (Boerner 1982, Covington 1981, Vitousek 1982, Vitousek 1985). Forest floor litter acts as a nutrient sink and also hinders herbaceous plant establishment (Covington 1981, Sydes and Grime 1981ab). Once canopy cover is reduced (through harvest), litter decomposition is accelerated, and herbaceous plants that increase become a pool for elemental storage (Vitousek and Reiners 1975, Blank et al. 1980, Gholz 1980, Covington 1981, Tyler 1989). Fire increases nutrient flux by rapidly mobilizing nutrients from forest floor litter in a decomposition and mineralization pulse (Vitousek 1985, Sprugel 1985). Increased nutrient availability increases litterfall and that litterfall has higher nutrient concentrations (Vitousek 1982).

As disturbance increases in frequency or severity, the role of early successional species becomes more important for nutrient retention in the ecosystem (Marks 1974). Nutrient availability can remain high following disturbance depending on decomposition rates of pioneer species (Vitousek 1985). Species composition and richness of understory plants differ in relation to interacting influences of canopy cover and soil pH, and each species has different elemental requirements (Tyler 1989). Because grasses and forbs have different decomposition rates (Daubenmire 1968) and capacities for nutrient retention (Masters 1991a), they may differentially moderate nutrient availability following disturbance.

The objectives of this study were to determine responses of soil chemical properties and litter to a range of timber harvest and periodic prescribed fire regimes. I also sought to determine if nutrient cycling pathways on mountainous sites are redirected to conserve nutrient capital following disturbance. This objective was addressed by correlating soil nutrient levels with residual stand characteristics, understory plant response, site treatment, and litter dynamics.

STUDY AREA

The 29.1-ha study area was located within the Forest Habitat Research Area (FHRA) on the 7395-ha Pushmataha Wildlife Management Area (PWMA), approximately 6 km southeast of Clayton, Oklahoma, USA (34° 32' N, 95° 21' W). The PWMA lies in strongly disected terrain with considerable topographic relief along the western edge of the Ouachita Highland Province.

Study area soils were thin, drought prone, and developed from sandstone and shales. Soils belonged to the Carnasaw-Pirum-Clebit association with areas of rock outcrop. The surface layer was variable in depth to 30 cm and texture is stony fine sandy loam (Bain and Watterson 1979). The FHRA was situated near ridge top approximately 335 m in elevation, on a southeastern aspect south slope of 5-15% grade.

The climate was semi-humid to humid with hot summers and mild winters. Annual rainfall on the FHRA over a 12 year period averaged 135 cm and ranged from 105 to 188 cm based on an October to September water-year. Precipitation varies considerably in yearly and seasonal distribution, with August the driest month (unpubl. data, Dept. Forestry, Oklahoma State University) (Masters 1991a).

Before acquisition from 1946-54, PWMA was grazed, selectively harvested, and frequently burned. The Forest Habitat Research Area was protected from further logging, grazing, and fire until 1984. Presently it is managed for primarilly game species of wildlife. Primary habitat manipulation tools are timber management and prescribed fire.

Post oak (_Quercus_ _stellata_), shortleaf pine (_Pinus_ _echinata_), and to a lesser extent blackjack oak (_Q._ _marilandica_) and mockernut hickory (_Carya_ _tomentosa_) dominated the undisturbed overstory. Common understory species included: tree sparkleberry (_Vaccinium_ _arboreum_), greenbriar (_Smilax_ spp.), grape (_Vitis_ spp.), little bluestem (_Schizachyrium_ _scoparium_), panicums (_Panicum_ spp., Dicanthelium spp.), and sedges (Carex spp.).

Post-treatment forest openings on the study area were dominated by little bluestem, big bluestem (Andropogon gerardi), and to a lesser extent, Indiangrass (Sorghastrum nutans). The overstory was dominated by sparse post oak, blackjack oak, and to a lesser extent mockernut hickory (Masters 1991ab).

METHODS

Cultural Treatments

Beginning in summer 1984, 9 treatments were applied to 23, 1.2- to 1.6-ha units in a completely randomized experimental design. Cultural treatments and number of replications (n) are summarized as follows:

(1) no treatment (Control) (n=3);

(2) rough reduction winter prescribed burn - 1985 (RRB) (n=3);

(3) harvest pine timber only, winter prescribed burn, annually (HNT1) (n=3);

(4) clearcut and summer site prep burn - 1985 (CCSP) (n=3);

(5) harvest pine timber, thin hardwoods, no burn (HT) (n=1);

(6) harvest pine timber, thin hardwoods, winter

prescribed burn - 1985 (HT4) (n=3);

(7) harvest pine timber, thin hardwoods, winter prescribed burn - 1985 and 1988 - (3-year interval) (HT3) (n=2);

(8) harvest pine timber, thin hardwoods, winter prescribed burn - 1985 and 1987 (2-year interval) (HT2) (n=3);

(9) harvest pine timber, thin hardwoods, winter prescribed burn annually (HT1) (n=2).

Merchantable pine timber was harvested, in appropriate treatments and hardwoods selectively thinned by single stem injection using 2-4 D, to approximately 9 m^2/ha, during summer 1984. Prescribed burns using strip-head fires were conducted in winter 1985 and in succeeding years at appropriate intervals. Fireline intensity of March 1988 burns ranged from 630 to 900 kW/m (Masters and Engle 1991). The clearcut site prep treatment included shearing, raking, and windrowing of logging debris with a site prep burn conducted during summer 1985. After contour ripping, genetically improved loblolly pine were planted on a 2.1 by 2.4 m spacing in early April, 1986.

Soil and Other Measurements

Samples of the top 12 cm of soil were collected in late February 1989 using a 2.5 cm diameter soil auger. Samples were taken at 20-m intervals on 2 randomly located transects (>20 m from any edge) for a total of 10 sample locations on each of 23 experimental units. Samples on each experimental unit were composited and bagged. Soil pH, NO_3-N, and elemental P, K, Mg, and Ca were determined by the Soil, Water, and Forage Testing Laboratory, Oklahoma State University, using standard analytical methods (Page 1982).

Vegetation samples were taken yearly in August and September from 1986 to 1990 within 0.5 m of 1989 soil sample locations. Standing crop of grasses, panicums (*Panicum* spp., *Dicanthelium* spp., primarily cool season and C_3 photosynthetic pathway), sedges (*Carex* spp.), forbs, legumes, current annual growth of woody species, and total litter was collected. Percent canopy cover, basal area, vertical strata and relative crown position of overstory and midstory trees was recorded. Vegetation sampling protocol and data were reported by Masters (1991a).

Analysis

Treatment means of soil response variables were tested for homogeneity of variance using Levene's test (Snedecor and Cochran 1980). Nonparametric procedures were indicated as the appropriate analysis, except for Ca and P which met assumptions for parametric one-way analysis of variance. Differences ($P < 0.05$) in soil nutrient response to treatments were determined by the Kruskal-Wallis nonparametric test (SAS Institute 1985). Mean ranks were separated by the Waller-Duncan k-ratio T test (SAS Institute 1985). The summed ranks of nutrient variables by experimental units (n=23) were subjected to analysis of variance to determine which treatment most enhanced the overall soil nutrient pool.

The control, RRB, HT, and HT4 treatments were compared to determine main effects and interaction of timber harvest and burning. Data were analyzed as a factorial arrangement of treatments (2 levels of fire and 2 levels of timber harvest) by the method of fitting constants and method of unweighted means (Bancroft 1968, Steele and Torrie 1960). Exploratory analysis was conducted using PROC RSQUARE in SAS to determine relationships between residual stand characteristics, fire regimen, and vegetation with soil chemical properties (dependent variables) (SAS Institute, 1985, 1987). Soil pH and Mg were negative binomial transformed and K values were sin transformed for regression analysis. Independent variables entered in regression analysis were; total basal area (TOTBA), hardwood basal area (HDWDBA), pine basal area (PINEBA), ratio of hardwood basal area to pine basal area (HPRATIO), percent canopy cover (CANPYCOV), time since burned (YRSNBURN), number of times burned (BURNREP), individual September standing crop (kg/ha) plant groups, and litter weight in September

(LITTER) (Masters 1991a). The best model was determined using plots of Mallows C_p statistic as an unbiased parameter estimator, where C_p is a measure of the total squared error (Mallows 1964).

RESULTS

Soil Properties

Soil chemical properties were enhanced by timber harvest and periodic prescribed fire (Table 1). Nitrate, P, and Ca levels in soil were significantly higher after treatments (P=0.02, P=0.05, and P=0.007, respectively). Available K was somewhat different (P=0.07) when compared among all treatments. Soil pH or Mg did not significantly differ among treatments (P=0.11 and P=0.24) but was higher on harvested and burned treatments.

Factorial analysis indicated that 4.5 years after harvest of overstory trees, available K was increased by 25.5 kg/ha, available Ca increased by 419 kg/ha, and available Mg increased by 40.5 kg/ha (Tables 2-4). Although burning showed no effect after 4 years on K, Ca and Mg, it did significantly interact with timber harvest to substantially increase K and Ca. Factorial analysis revealed no significant main effects or interaction of timber harvest and burning on pH, NO_3-N or P.

Regression analysis revealed that soil chemical response was related, for the most part, to overstory characteristics and to a lesser extent understory vegetation standing crop (Table 5). The only fire related variables that explained a significant amount of variation was BURNREP for Mg and K and YRSNBURN for K. Although mean legume standing crop in September ranged from 7.5 to 212 kg/ha across treatments it had no effect on February NO_3-N levels (r^2=0.038, $\underline{P}$=0.36).

When ranks of chemical responses were summed across treatments and analyzed, significant differences between treatments were found in overall nutrient enhancement ($\underline{P}$=0.006). Harvested and burned treatments had higher soil nutrient levels compared to unharvested (control and RRB) and HT treatments. The HT3 and CCSP ranked highest in overall nutrient levels. The control, HT, and RRB treatments ranked lowest respectively in overall enhanced soil fertility.

Litter

Litter weight was highest on the control and lowest on the HT1 treatment in all years (Table 6). Litter levels on the RRB had recovered from the winter 1985 prescribed burns by September 1987 (2.5 years and 3 growing seasons). Litter weights on retrogressed sites followed the predictable sequence of a sharp drop after burning then a steady increase until the next burn, except the HT3 treatment. Litter levels on the annually burned treatments (HNT1 and HT1) tended to decline after repeated burning.

DISCUSSION

Soil Chemical Properties

Soil pH increases with burning on Coastal Plain sites (McKee 1982, McKee and Lewis 1983) but is little changed by timber harvest and site preparation (Stransky et al. 1985). In contrast, I found a tendency for pH to increase on harvested and burned treatments, although not significantly on these mountainous sites.

Soil nitrate in this study was low, possibly because of season of sampling (Vitousek 1983, Stoin et al. 1985) or leaching (Stoin et al. 1985). Nitrate concentrations can exhibit considerable seasonal fluctuations (Vitousek 1983, Stoin et al. 1985). The low levels observed may be an indication of nitrogen limitation on these sites (Vitousek 1983). Soil nitrate was slightly elevated by burning retrogressed sites but increases persisted only about a year. Nitrate varied little and as a result slight differences were statistically but not biologically significant.

Wells (1971) hypothesized that increased N on some burned sites may be the result of a dramatic increase in legumes. Results from this study do not substantiate this hypothesis as differences in NO_3-N were unrelated to legume standing crop. Legume standing crop was 2,690 percent higher on HT1 treatments compared to the control, with a range of intermediate weights across treatments (Masters 1991a).

Available P, K, Ca, and Mg generally increase with prescribed burning on forested Coastal Plain sites (McKee 1982, Wells 1971). I found these minerals to increase in the nutrient pool only in the advent of timber harvest and prescribed fire. Moehring et al. (1966) reported slight declines in these minerals after 9 years of biennial burns, except for P which was unchanged on forested sites in Arkansas. The RRB treatment, similarly lowered P, Ca, K, and Mg levels but to a greater extent.

Several major differences may account for lower soil mineral levels on the RRB treatment. My study area had been protected from burning for the previous 30 years and many Coastal Plain studies (e.g., Wells 1971, KcKee 1982, McKee and Lewis 1983) documented the effects of frequent long-term burning regimes in predominantly pine forests. My study site was forested with mixed oak-pine species. Reduced soil fertility could be the result of shifting nutrients from litter to soil, following mineralization by fire, then loss through leaching or by rapid immobilization in plant or microbial mass.

Clearcutting, mechanical site preparation, and summer site prep burns enhanced soil nutrient levels, in contrast to reported declines in nutrient availability on Coastal Plain soils (Stransky et al. 1985). The differences are probably a result of parent material and soil structural differences. Others have reported that similar site treatments (i.e., clearcutting and site preparation) initially increase pH, NO_3-N, and P (Stoin et al. 1985, Vitousek 1985). The CCSP treatment ranked second only to the HT3 treatment in overall nutrient enhancement.

Nutrient Cycling

Timber harvest and fire interacted to increase K, Ca, and Mg. Timber harvest and fire liberated nutrient capital from the forest floor in a pulse. The interaction of timber harvest and fire is an indication of the complexity of cycling processes. Timber harvest, forest floor leaf litter reduction (by burning), and subsequent plant community development most likely redirected nutrient cycling on this site (Table 5). The nutrient cycling process is enhanced by burning (McKee 1982). Site perturbation in the present study most likely initiated a nutrient pulse from litter decomposition and mineralization (Sprugel 1985). Pioneer species that contribute to the litter layer on retrogressed sites may tend to decompose more rapidly and increase nutrient availability (Vitousek 1985). But they also accumulate lower concentrations of nutrients than forest floor leaf litter (Nye 1959) thus accounting for increased soil storage in this study.

Elemental concentrations of winged elm (*Ulmus alata*), winged sumac (*Rhus copallina*), greenbriar (*S. bona-nox*), elmleaf goldenrod (*Solidago ulmifolia*), and stiff sunflower (*Helianthus hirsutus*) tracked on this study area over a 5 year period immediately following site perturbation give indications that a decomposition-mineralization pulse occurred (Masters 1991a). Phosphorous concentrations in these species increased dramatically for 2 years following treatment application then declined to levels slightly above the control in the latter three years. Calcium concentrations, on the other hand, tended to be highest in ground level plants sampled from the control treatments in most years and lowest on disturbed sites, demonstrating that calcium uptake by plants was related to overstory cover. Calcium tended to pool in the soil as plant uptake decreased (Masters 1991a).

Forest disturbance such as understory fires may change nutrient cycling and storage sites in several ways. First by causing mortality of small stemmed hardwoods thereby removing potential future stand dominants or competitors.

Next removal of forest floor litter creates a suitable seed bed for pine seedling establishment. As pines gradually achieve stand dominance storage sites of nutrients are changed. Storage sites of nutrient capital are gradually shifted from the forest floor leaf litter to above ground.

When midstory and small- to medium- sized hardwoods are killed by fire, the hardwood proportion in leaf litter will decline. Subsequently nutrient inputs will be reduced because hardwood litter is more nutrient rich than pine litter (Broadfoot and Pierre 1939, Chandler 1941, 1944). Nutrient transfer by leaf fall is substantially higher than other means of nutrient input into soil, such as precipitation throughfall and stemflow (Kodama and Van Lear 1980). The total nutrient capital in the litter layer after burning is proportional to the reduction in weight of the litter layer (Hough 1981). With repeated burning this nutrient sink is reduced and pines (and residual hardwoods) move the nutrient capital above ground (Boerner 1982). The reduction of soil nutrients following rough reduction burns in this study gives some indication that a change in storage sites does occur.

Long-term prescribed burning has been shown to increase nutrient uptake and growth of pines (McKelvin and McKee 1986). Rapid nutrient uptake following increased nutrient availability by fire is a nutrient conservation mechanism of species adapted to nutrient scarcity (Boerner 1982). Pines are well adapted to nutrient scarcity because they tolerate lower nutrient levels than other plants (Jorgensen and Wells 1986). After pine dominance is achieved and a different system equilibrium is reached, fire may begin to increase nutrient availability. Conifer litter is notably slow in decomposition compared to hardwoods and fire would speed nutrient release.

CONCLUSIONS

These results are significant in that they document enhanced soil mineral status on mountainous terrain following site perturbation by timber harvest and periodic prescribed fire. Increased soil nutrient storage most likely results from changes in mineral cycling through a decomposition/mineralization pulse following disturbance. Enhanced soil nutrient regimes following site perturbation or natural disturbance are ecologically advantageous. Stand reinitiation and recovery would have greater chances of success with increased mineral availability following major forest disturbance such as hurricanes or catastrophic fire (Sprugel 1985) or timber harvest and periodic prescribed fire as in this study.

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Table 1. Mean soil pH and nutrient response 4.5 years after timber harvest and after periodic prescribed fire on oak-pine sites in the Ouachita Mountains.[1]

				Available (kg/ha)									
Treatment code[2]	Years since burned[3]	PH		NO_3-N		P		K		Ca		Mg	
		X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
CONTROL	30+	5.1	0.1	1.1b	0.0	25ab	2	183	5	950cd	76	173	15
RRB	4	4.8	0.0	1.1b	0.0	22b	1	154	9	636d	67	147	7
CCSP	3.5	5.4	0.1	1.9ab	0.4	39a	7	193	23	1749ab	227	191	17
HT	30+	4.8	.	1.1b	.	24b	.	170	.	995cd	.	180	.
HT4	4	5.3	0.2	1.1b	0.0	29ab	3	218	2	1429abc	218	221	17
HT3	1	5.4	0.5	2.2a	0.0	36ab	3	224	8	1920a	31	214	27
HT2	2	5.0	0.2	1.1b	0.0	24b	3	220	15	1072bcd	232	190	10
HT1	1	5.3	0.2	1.1b	0.0	30ab	4	221	9	1421abc	53	189	15
HNT1	1	5.5	0.2	1.5b	0.4	30ab	4	227	45	1279abcd	271	189	49

[1] Column means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[2] Control = no treatment; RRB = rough reduction burn; CCSP=clearcut, summer site prep burn; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle; HT1 = harvest pine timber, thin hardwoods, winter burn 1 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn 1 year cycle.

[3] Years since burning at time of soil sampling, 30+=unburned treatment.

Table 2. Table of available K (kg/ha) means illustrating main effects and interaction of timber harvest and fire four years after harvest and burning.

FACTOR	Timber Harvest				
	Level	None	Harvest	Mean	Diff.
Winter Burn	None	183	170	176.9	-13
	Burn	154	218	185.9	64
	Mean	168.7	194.1	181.4	25.5
	Diff.	-29	48	9.5	

Factor Effects	Effects on Available K	Prob > F
Burning	increased by 9.5 kg/ha	ns
Harvest	increased by 25.5 kg/ha	<0.025
B X H	increased by 38.5 kg/ha	<0.005

Table 3. Table of available Ca (kg/ha) means illustrating main effects and interaction of timber harvest and fire four years after harvest and burning.

FACTOR	Timber Harvest				
	Level	None	Harvest	Mean	Diff.
Winter Burn	None	950	995	972.5	45
	Burn	636	1429	1032.5	793
	Mean	792.8	1212.2	1002.5	419
	Diff.	-314	434	60	

Factor Effects	Effects on Available Ca	Prob > F
Burning	increased by 60 kg/ha	ns
Harvest	increased by 419 kg/ha	0.05
B X H	increased by 374 kg/ha	0.08

Table 4. Table of available Mg (kg/ha) means illustrating main effects and interaction of timber harvest and fire four years after harvest and burning.

FACTOR	Timber Harvest				
	Level	None	Harvest	Mean	Diff.
Winter Burn	None	173	180	176.7	7
	Burn	147	221	184.2	74
	Mean	160.1	200.8	180.4	40.5
	Diff.	-26	41	7.5	

Factor Effects	Effects on Available Mg	Prob > F
Burning	increased by 7.5 kg/ha	ns
Harvest	increased by 40.5 kg/ha	0.048
B X H	increased by 33.5 kg/ha	0.09

Table 5. Regression equations for illustrating relationships between site treatment, vegetation characteristics and soil nutrient levels.

Dependant Variable		Intercept	Independant Variables[1]				R^2	P>F
pH	=	4.97494	- 0.038340(PINEBA) + 0.00084362(WOODY)	+ 0.087747(TOTBA) -0.0009346(FORBS)	- 0.018987(CANPYCOV) + 0.00073944(PANICUM)	+ 0.017135(HPRATIO)	0.830	0.0001
P	=	22.05690	+ 0.34057(HPRATIO)	- 0.074930(LEGUME)	- 0.017384(GRASS)	+ 0.015560(TOTAL)	0.782	0.0001
K	=	206.87800	- 3.28210(HDWDBA)	+ 1.48412(HPRATIO)			0.472	0.0017
Ca	=	1407.18000	+ 101.18(TOTBA)	- 38.5042(CANPYCOV)	- 2.55828(LEGUME)	+ 0.29620(GRASS)	0.808	0.0001
Mg	=	223.18700	- 4.64618(HDWDBA)	+ 2.10370(HPRATIO))	- 16.7303(BURNREP)		0.426	0.0128

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[1] TOTBA = Total basal area (m^2/ha), CANPYCOV = percent canopy cover, HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), WOODY = standing crop of woody current annual growth, FORBS = standing crop of forbs, SITEDIST = relative rank of site disturbance regime, LEGUME = standing crop of legumes, and HDWDBA = basal area of hardwoods > 5 cm diameter breast height (m^2/ha).

Table 6. September litter (kg/ha) in response to timber harvest and periodic prescribed fire from 1987 to 1990.[1]

Treatment Code[2]	Year							
	1987		1988		1989		1990	
	X	SE	X	SE	X	SE	X	SE
CONTROL	6037ab	1135	7939a	674	7736a	149	8177a	1279
RRB	7375a	1131	8516a	2170	2725cd	844	4057bc	402
HNT1	1253cd	430	1258c	583	468e	192	869de	167
HT	7572a	.	6236ab	.	4655b	.	5480b	.
HT4	4881ab	583	5983ab	219	245e	75	2489cd	386
HT3	3870bc	78	1750c	358	1521de	255	3448bc	56
HT2	1569cd	378	4064bc	477	753e	295	2372cd	218
HT1	593d	165	964c	200	314e	199	140e	4
CCSP	1758cd	659	2823bc	600	3200c	320	4028bc	420

[1] Column means followed by the same letter were not significantly different at the 0.05 level.

[2] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP = clearcut, summer site prep burn (1985); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually.

CHAPTER VI

NUTRIENT RESPONSE OF SELECTED DEER BROWSE TO TIMBER HARVEST AND FIRE IN OKLAHOMA OUACHITA MOUNTAINS

Abstract: I compared early fall nutritional quality of 5 browse species of white-tailed deer (_Odocoileus virginianus_) subjected to a range of timber harvest and periodic prescribed fire regimes in Oklahoma Ouachita Mountains over 5 years. Nutritional quality was related to seasonal rainfall distribution, overstory characteristics, and to a lesser extent, presence or absence of fire. In years with either low or periodic rainfall, forage quality was little changed by even the most radical habitat alteration schemes. Browse quality on retrogressed treatments was similar regardless of burning regime (0-, 1-, 2-, 3-, or 4-year burn intervals). Clearcuts consistently produced browse of higher quality than unharvested controls. Rough reduction and later hazard reduction burns had little effect on browse quality. Crude protein and P values increased with overstory removal and burning. Conversely, Ca was higher on unharvested sites. Seasonal rainfall distribution often had a greater effect on fiber content and total digestible nutrients than treatments. There was no consistent pattern of difference in Mg and K content or digestibility between treatments. Management strategies should be directed to increase production of a diversity of plants. Retention of late successional habitats in a mosaic of clearcut and retrogressed sites will provide optimum year-round foraging conditions for white-tailed deer.

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Key words: browse, clearcut, habitat manipulation, nutritional quality, Oklahoma, Ouachita Mountains, prescribed fire, white-tailed deer.

Understory deer forage on oak-pine sites in the Ouachita Highlands of eastern Oklahoma and western Arkansas is low in both quality and quantity (Segelquist and Pennington 1968, Fenwood et al. 1984). Forage quality in late summer and early fall may be of critical importance in the advent of mast shortfall. Manipulation of timber stand conditions have been recommended as a solution to this problem (Halls 1970, Fenwood et al. 1984).

Forage quality reportedly changes in response to changes in overstory cover (i.e., light intensity in the understory) (Hall and Epps 1969, Blair et al. 1983), prescribed fire (Lay 1957, Lewis et al. 1982), fire intensity, possibly seasonal rainfall distribution (Dewitt and Derby 1955), and changes associated with stage of plant maturity (Daubenmire 1968, Wolters 1973, Fuller 1976).

Evidence is far from conclusive that either reducing overstory or prescribed burning of stands will enhance nutrient response of forages. For example, nutrient response was unrelated to overstory characteristics (either canopy cover, basal area, or shade intensity) in some studies (Fuller 1976, Conroy et al. 1982, Fenwood et al. 1984) and strongly related in others (Valentine and Young 1959, Hall and Epps 1969, Wolters 1973, Blair et al. 1983). Prescribed fire caused short-term (2 years) increases in nutrient concentrations in some studies (Dewitt and Derby 1955, Lay 1957) and little or no changes in others (Dills 1970, Lewis et al. 1982, Wood 1988). Wood (1988) argued that purported benefits from prescribed fire were often overstated.

The Oklahoma Department of Wildlife Conservation (ODWC) began using timber harvest and prescribed fire in 1975 to improve habitat conditions for white-tailed deer on selected management areas. Forest openings were created by commercial timber harvest and maintained in early stages of secondary succession (induced retrogression) with periodic prescribed fire. Induced retrogression to increase forage production was untested as a wildlife management technique in this region. Experimental testing and development of this technique offered the opportunity to extend our understanding of overstory and fire relationships on nutritional quality of selected deer browse.

This study was designed to compare induced retrogression with regeneration clearcutting and understory rough reduction (and later hazard reduction) burns. I compared changes in early fall nutrient contents of preferred deer forages over a 5-year period to evaluate the influence of overstory, periodic prescribed fire, and seasonal rainfall.

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STUDY AREA

The 29.1-ha study area was located within the Forest Habitat Research Area (FHRA) on Pushmataha Wildlife Management Area (PWMA), Pushmataha County, Oklahoma (34° 32' N, 95° 21' W). The PWMA lies in strongly disected topography along the western edge of the Ouachita Highland Province. The climate was semi-humid to humid with hot summers and mild winters. Summer temperatures frequently exceeded 32 C with winds from the south averaging 17 km/hr. Rainfall was monitored with a self-recording rain gauge located approximately 100 m from the study area center. Annual rainfall between 1978 and 1989 ranged from 106-173 cm based on an October to September water-year, and monthly averages varied considerably from year to year. Late summers were drought prone with rainfall in July and August averaging 15 cm (Dep. For., Okla. State Univ., unpubl. data) (Masters 1991).

Study area soils belong to the Carnasaw-Pirum-Clebit association with areas of rock outcrop. Soils developed from sandstone and shales and were thin and drought prone. The surface layer was variable in depth to 30 cm and texture was stony fine sandy loam (Bain and Watterson 1979). The FHRA was situated near a ridge top approximately 335 m in elevation on a southeastern aspect and with a slope of 5-15%.

The FHRA overstory plant community was dominated by post oak (*Quercus stellata*), shortleaf pine (*Pinus echinata*), blackjack oak (*Q. marilandica*), and mockernut hickory (*Carya tomentosa*). Common woody understory species included: tree sparkleberry (*Vaccinium arboreum*), poison ivy (*Toxicodendron radicans*), greenbriar (*Smilax spp.*), grape (*Vitis spp.*), little bluestem (*Schizachyrium scoparium*), panicums (*Panicum* spp., *Dicanthelium* spp.), and sedges (*Carex* spp.) (Masters 1991).

The PWMA was grazed by cattle, selectively harvested, and subject to frequent fire (1- to 3-year intervals) prior to completed acquisition in 1954. Approximately 24% of the PWMA was maintained in retrogressed forest openings through use of prescribed fire and 4% in cultivated openings. The FHRA was protected from logging and fire until 1984 after this study began (Masters 1991). The PWMA supported an average population of 590 ± 35 (SE) deer and approximately 11 ± 2 elk (*Cervus elaphus*) (1985-89) (Masters 1991).

METHODS

Cultural Treatments

Beginning in summer 1984, 9 treatments were applied in a completely randomized experimental design to 23 1.2- to 1.6-ha units. Treatments, burning sequence, treatment code, and number of replications (*n*) are summarized below:

(1) no treatment (control) (*n* = 3);

(2) rough reduction winter prescribed burn - 4-year interval, 1985, 1989 (RRB) (*n* = 3);

(3) harvest pine timber only, winter prescribed burn - 1-year interval, 1985-1989 (HNT1) (*n* = 3);

(4) harvest pine timber, thin hardwoods, no burn (HT) (*n* = 1);

(5) harvest pine timber, thin hardwoods, winter prescribed burn - 4-year interval, 1985, 1989 (HT4) (*n* = 3);

(6) harvest pine timber, thin hardwoods, winter prescribed burn - 3-year interval, 1985, 1988

(HT3) (n = 2);

(7) harvest pine timber, thin hardwoods, winter prescribed burn - 2-year interval, 1985, 1987, 1989 (HT2) (n = 3);

(8) harvest pine timber, thin hardwoods, winter prescribed burn - 1-year interval, 1985-1989 (HT1) (n = 2); and

(9) clearcut and summer site preparation burn, 1985 (CCSP) (n = 3).

Merchantable pine timber was harvested and hardwoods selectively thinned by single stem injection using 2-4 D to approximately 9 m^2/ha basal area (stems >5 cm at 1.4 m height), in summer 1984. Prescribed burns using strip-head fires were conducted in winter 1985 and in succeeding years at appropriate intervals. Mean fireline intensity of March 1988 burns ranged from 630 to 900 kW/m (Masters and Engle 1991).

The clearcut site preparation treatment included shearing, raking, and windrowing logging debris with a site preparation burn conducted during summer 1985. Clearcut replicates (n = 3) were contour ripped to an average depth of 50 cm on 2.4 m centers the following March. Genetically improved loblolly pine (*P. taeda*) (Weyerhaeuser Co., Fort Towson, Okla.) were planted on a 2.1 x 2.4 m spacing in early April 1986.

Forage Analysis

Elmleaf goldenrod (Solidago ulmifolia), stiff sunflower (Helianthus hirsutus), greenbriar (S. bona-nox), winged sumac (Rhus copallina), and winged elm (Ulmus alata) were selected from a group of preferred browse and forb species known to occur on the range of site treatments. Importance was determined from previous browse surveys conducted in southeastern Oklahoma (Lindzey 1951; ODWC, unpubl. data; T. Silker, unpubl. data) and later confirmed by food habitats studies (Fenwood et al. 1985, Jenks et al. 1990) and preference indices derived from relative use versus availability of these species (Masters 1991).

Elmleaf goldenrod, stiff sunflower, greenbriar, winged sumac, and winged elm samples were collected during a 2-week period in late September to early October from 1985 to 1989. Each experimental unit was systematically searched by 2-4 observers and approximately 100 g (green wt) of plant material were collected for each species. A minimum of 10 plants was sampled if 100 g were not available (Lay 1957). Unbrowsed plants were sampled to mimic observed deer use of each species. The terminal 30-50% of goldenrod and stiff sunflower was collected. Leaves of residual greenbriar and terminal leaves of residual winged sumac and winged elm were collected randomly $\leq$19.8 m from any edge to avoid bias from adjacent treatment units (Oosting 1956, Mueller-Dombois and Ellenberg 1974).

Plant materials were air dried and ground through a 2-mm screen. Each sample was divided and randomly selected blind duplicates (25-40% of the total number submitted) were included to verify lab accuracy. Nutrient analysis were conducted by Servi-Tech, Inc. (Dodge City, Kan.) and included moisture content, dry matter content, ash, crude protein, ADF, TDN, calcium, phosphorous, magnesium, and potassium. In vitro dry matter digestibility (IVDMD) was determined for 1986 samples using inoculum from a fistulated heifer fed a prairie grass standard (Tilley and Terry 1963).

Overstory Characterization

Basal areas were quantified using the variable radius plot method (Avery 1964). Basal areas were taken with a 10-factor prism at 10 points per experimental unit. Overstory foliage density was measured at 90 locations per experimental unit using a grided sighting tube with horizontal and vertical levels (Mueller-Dombois and Ellenberg 1974). All readings were taken at fixed intervals along randomly selected parallel transects $\leq$19.8 m from any edge (Oosting 1956, Mueller-Dombois and Ellenberg 1974). Overstory data were reported by Masters (1991).

Analysis

Treatment means were tested for homogeneity of variance using Levene's test (Snedecor and Cochran 1980). Variances were heterogeneous for most parameters within a given year but were homogeneous when all years were considered together except P. Differences ($\underline{P} < 0.05$) in nutrient response to treatments for each year were determined by the Kruskal-Wallis nonparametric test (SAS Institute 1985). Mean ranks were separated by Duncan's multiple range test (SAS Institute 1985). Analysis of covariance with rainfall as a covariate was conducted only on control, HNT1, and HT1 treatments. The periodic application of burns on other treatments introduced a source of variation that could only be removed through replication in time.

The control, RRB, HT, and HT4 treatments were used to determine main effects and possible interaction of timber harvest and burning each year. These treatments were analyzed as a factorial arrangement of treatments (2 levels of fire and 2 levels of timber harvest) using the method of fitting constants and method of unweighted means (Bancroft 1968, Steele and Torrie 1960).

Exploratory analysis was conducted using PROC RSQUARE to examine relationships between residual stand characteristics, fire regime, and rainfall with plant nutrient properties (dependent variables) (SAS Institute, 1985, 1987). Independent variables entered in regression analysis were: total basal area (TOTBA), hardwood basal area (HDWDBA), pine basal area (PINEBA), ratio of hardwood basal area to pine basal area (HPRATIO), percent canopy cover (CANPYCOV), months since burned (MOSNBURN), number of times burned (BURNREP), and subsets of monthly, seasonal and yearly rainfall data (Masters 1991). The best model was determined using plots of Mallows C_p statistic as an unbiased parameter estimator, where C_p was a measure of the total squared error (Mallows 1964).

RESULTS

Nutrient response of plants was related to overstory characteristics, seasonal rainfall patterns, and in some instances, burning regime (Tables 1-6) (see Masters 1991 for tabular data, correlation and factorial analysis).

Analysis of IVDMD for elmleaf goldenrod and stiff sunflower indicated differences ($\underline{P} < 0.05$) between treatments (Table 7). The control treatments had higher IVDMD values for these 2 species than did the CCSP treatments. There were no consistent relationships between overstory characteristics or burning regimes in any browse species, and therefore, IVDMD was not determined in subsequent years (Masters 1991).

Crude Protein

Crude protein was higher ($\underline{P} < 0.05$) in all browse from CCSP treatments than on control sites in most years. In the 2 years (1987 and 1989) when crude protein was similar among treatments, total April rainfall was 1.8 and 6.1 cm. Mean April rainfall was 12.1 cm (Masters 1991). Harvested and thinned treatments tended to be intermediate in response regardless of burning regime (0-, 1-, 2-, 3-, or 4-year burn interval) and were not different from each other ($\underline{P} > 0.05$) (Figs. 1a - 5a). Within year variation was correlated with overstory characteristics ($r \leq 0.884$, $P < 0.01$) and between year variation with summer rainfall patterns ($r \leq 0.652$, $P < 0.001$) (Masters 1991). Higher crude protein was found after overstory removal when adequate rainfall occurred. Greenbriar and winged elm differences were substantial only in the first year after harvest and burning (Figs. 3a and 5a). Factorial analysis revealed significant main effects from burning in the second year for goldenrod and first year for greenbriar. The interaction of burning and overstory removal was significant in greenbriar in 2 years and winged elm in 1 year. The percent change in fall crude protein values from burning as a main effect was generally <10% (Masters 1991).

ADF and TDN

Acid detergent fiber and TDN were variable among treatment and years (Figs. 1bd - 5bd). Data suggested that under higher summer rainfall ADF would decline and TDN would increase. This effect was moderated by overstory characteristics (Tables 1-6). Goldenrod ADF was lower ($P < 0.05$) on harvested treatments and higher on unharvested treatments in later years (Fig. 1b). Conversely lower ADF in greenbriar was found on unharvested treatments and higher values on harvested treatments except in 1 year (Fig. 3b). The opposite was true for TDN in both instances (Figs. 1d and 3d). Stiff sunflower TDN on HT1, HT2, and HNT1 was significantly higher than control or RRB treatments the last year (Fig. 2d). Acid detergent fiber or TDN was not different for winged elm or winged sumac. When analyzed as factorial arrangement of treatments, burning significantly ($\underline{P} < 0.05$) lowered ADF and increased TDN only in greenbriar and winged elm. Effects were persistent and moderated by summer rainfall patterns. The percent change in fall ADF from burning alone was generally <10% for all browse species except sumac. The percent change in fall TDN from burning alone was <10% for all browse species and most often <5% (Masters 1991).

Ash

Percent ash differed among species of plants and with summer rainfall patterns (Figs. 1c - 5c) (Tables 1-6). Ash content of winged elm, winged sumac, and stiff sunflower varied year-to-year but was not affected by treatments. Goldenrod ash content was lower ($\underline{P} = 0.002$) on harvested and burned treatments in the 3rd year except for HT2. Greenbriar ash was higher ($\underline{P} < 0.05$) on control treatments and lower on harvested treatments regardless of burn regime in the last 3 years. Factorial analysis of these last 3 years revealed a significant main effect due to harvest and none from burning (Masters 1991). Total mineral content was unaffected by burning in other browse. The percent change in fall ash content from burning as a main effect was most often <10% for all browse species (Masters 1991).

Calcium

Calcium content of browse was related to overstory characteristics and moderated by summer rainfall patterns (Table 1-6). Goldenrod and winged elm Ca contents were depressed by overstory removal and higher ($\underline{P} < 0.05$) on control and RRB treatments than CCSP in 3 of 5 years (Figs. 6a and 10a). The same was true in greenbriar but significant in only 1 year (Fig. 8a). Factorial analysis revealed a main effect decrease in Ca from both burning and harvest only in greenbriar after a second 4-year burn (HT4 and RRB). Other than a first year burn by harvest interaction, burning had no effect on Ca content of stiff sunflower.

Phosphorus

Timber harvest and burning elevated P content of all browse in most years, except winged elm which approached significance ($\underline{P} < 0.09$) in 3 years. The magnitude of difference diminished noticeably over time in all browse species (Figs. 6b - 10b). Phosphorus levels in goldenrod and winged sumac showed significant main effect increases from burning for 3 years after burning and some burn by harvest interaction was noted for both species. The percent change in fall P content from burning as a main effect was most often >10% for all browse species and as much as 58% greater in sumac during 1 year (Figs. 6b - 10b). Phosphorus content of plants was influenced by spring and summer rainfall patterns, fire, and overstory characteristics (Tables 1-6).

Magnesium and Potassium

Significant differences ($\underline{P} < 0.05$) among treatments were noted in Mg and K content in some years and in most browse species. However consistent relationships with either overstory characteristics, rainfall patterns, or burning were not evident (Figs. 6cd - 10cd) (Tables 1-6).

DISCUSSION

Timber harvest and fire influenced early fall crude protein, ADF, ash, TDN, Ca, and P content of 5 common browse species in the Ouachita Mountains. Nutritional quality was related to seasonal rainfall distribution, overstory characteristics, and to a lesser extent, presence or absence of fire. During years of adequate rainfall (amount and distribution), treatment differences were significant ($\underline{P} < 0.05$). Browse quality on retrogressed treatments were similar regardless of burning regime (0-, 1-, 2-, 3-, or 4-year burn intervals). Clearcuts consistently produced browse of higher quality than unharvested controls. Rough reduction and later hazard reduction burns had little effect on browse quality.

My results corroborate other studies that found higher crude protein and P, and lower Ca with no overstory (Halls and Epps 1969) and increased P with burning (Lay 1967). Lay (1957) found that effects on forage nutrient contents due to fire persisted about 2 years on unharvested sites. Others have reported that effects from winter burns on forage quality were largely gone by the end of the following summer (Thill et al. 1987, Wood 1988). I found that effects from burning on most fall nutrient parameters were low (<10% change) but persistent with adequate rainfall (Masters 1991). However, I found that changes in P and in Ca/P ratios from burning were generally >10%.

Timber harvest and fire affected nutrient absorption and retention of selected browse by changing nutrient cycling pathways on these sites (Masters 1991). Hardwood and pine leaf litter act as a nutrient sink and overstory removal or fire will mobilize nutrients (Covington 1981, Sprugel 1985, Vitousek 1985). Nutrient storage sites are moved below ground to root biomass of tallgrass regrowth after overstory removal and leaf litter reduction. Subsequent grass litter buildup does not retain the level of nutrient capital as hardwood leaves and pine needles. Therefore, frequent repeated burns on retrogressed sites tend to mobilize fewer nutrients and have less of an effect on browse quality (Table 6) (Masters 1991).

Available soil P, Ca, and K were higher 4.5 years after treatment as a result of a mineralization decomposition pulse following timber harvest and fire (Masters 1991). Plant uptake increases linearly with increased availability (Chapin and Van Cleave 1981). However, plants grown on infertile sites (as in this study) exhibit lower absorption rates in response to increased nutrient availability compared to more fertile sites (Chapin 1980:239). Chapin and Van Cleve (1981) suggested that P absorption is dependent upon the relative growth rate of the plant but may be limited by diffusion rates in the soil. Growth of the plant is also contingent on adequate soil moisture.

Although soil Ca was increased by 11-50% on harvested and burned sites (depending on time since burning), concentrations in browse were generally lower on harvested and burned areas, which indicated a negative relationship between overstory cover and Ca uptake (Masters 1991). Increased P availability and lower Ca uptake decreased Ca:P ratios in browse. The effects were again rainfall-dependent. The Ca:P ratios of all browse species were extremely high and ranged from 4.3:1 in sumac to 56.3:1 in stiff sunflower. Optimal Ca:P ratios have not been determined for white-tailed deer although anecdotal references are often made to an optimum 2:1 ratio. Very few naturally occurring forages in this region approach this ratio (Fenwood et al. 1984, Reeb and Silker 1979, Fuller 1976). Nutritional requirements for Ca are high in the summer and evidence suggests some selectivity for Ca (Vanguilder et al. 1982). Excess Ca has less of an effect on P absorption than excess P does on Ca absorption (Robbins 1983:37). Calcium exceeded requirements of weaned white-tailed deer fawns (Ullrey et al. 1973) in all cases and P was low except after overstory removal, recent burns and, higher summer rainfall.

Deer will select diets higher in P and with lower Ca:P ratios on clearcut areas than in forested areas (Thill et al. 1990). Deer utilization increases on burned areas with higher P levels over similar unburned areas (Lay 1967). Changes in P and Ca:P ratio described in this study may be substantial enough to cause differences in foraging behavior relative to the range of treatments. We are in need of research to establish the P requirements of deer and effects of browse P content and Ca:P ratios on forage selection.

Protein requirements of white-tailed deer fawns have been estimated to be 14-22% (Ullrey et al. 1967) and for yearling deer 11% (Holter et al. 1977). However, as little as 7% protein intake has been found to be sufficient for normal reproduction (Murphy and Coats 1966). In years of low spring and/or summer rainfall, crude protein levels were marginal in plants selected for this study. Masters (1991) suggested that these sites may be N limited which may account for low crude protein.

This study and others suggest that diet quality may vary considerably from 1 year to another (DeLiberto et al. 1989). Carrying capacity assessments are often based on physiological indices. Evaluation of deer herd health based on physiological indices should take yearly variation in dietary quality into account and sample over at least a 3-year period.

In situations where an adequate forage base and evergreen winter browse are lacking, overstory removal and prescribed fire will significantly improve nutritional quality. However, effects may be different on sites having a long history of periodic burning (Lay 1967, Wood 1988). The primary benefit from controlled burning and overstory removal were improved crude protein and P levels, lower Ca/P ratios and maintenance of retrogressed sites for continued forage production.

MANAGEMENT IMPLICATIONS

In years with either low or poorly distributed rainfall, fall forage quality other than P content or the Ca:P ratio was little changed (i.e., <10%) by even the most radical habitat alteration strategies. Management options are contingent on providing quantity and diversity because of the selective foraging tendencies of deer (Vangilder et al. 1982, Thill et al. 1990). Deer will select diets of higher quality from a more diverse forage base (Thill et al. 1990). Among the treatments compared, HT, HT4, HT3, and CCSP maximized nutritional quality, production, and diversity of plants selected by deer in late summer (Masters 1991). Benefits from both HT and CCSP treatments will decline with increased canopy closure at about 6 years post-treatment (Masters 1991). Retrogressed sites burned in winter green-up earlier and provide forage high in digestibility and in critical nutrients during a period of nutritional stress (Short 1971, Lewis et al. 1982). Forage quality will not be improved as much with 1-year burn intervals as with longer burn intervals. Frequent burning does not allow litter buildup and therefore frequent burns will not mobilize nutrients to the extent of longer intervals. Periodic burning (3- or 4-year intervals) will retard secondary succession while 1- and 2-year burn intervals will decrease species richness of woody plants (Masters 1991). I recommend an overall management strategy that retains a mosaic of late successional habitats with a substantial oak component because of the importance of hard mast as a winter food (Harlow et al. 1975). This is important because forage quality in late summer and early fall is marginal in years with inadequate or poorly distributed rainfall.

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Table 1. Regression equations illustrating the relationship between elmleaf goldenrod nutrient content, seasonal or monthly rainfall, overstory characteristics and prescribed fire regime on oak-pine sites 1985-1989.

Dependent Variable	Intercept	Independent Variables[a]	R^2	P>F
Crude Protein	= 6.78906	+ 0.18573(MAR) - 0.28419(JUL) + 0.17597(APR) - 0.040480(TOTBA) - 0.014636(HPRATIO)	0.604	0.0001
ADF	= 37.11230	- 0.45369(MAY) + 0.058322(CANPYCOV) - 0.34211(BURNREP)	0.458	0.0001
Ash	= 5.25809	+ 0.099251(PINEBA) - 0.17763(TOTBA) + 0.053609(CANPYCOV) + 0.16758(BURNREP) + 0.20561(FEB)	0.438	0.0001
TDN	= 62.16760	+ 0.35618(MAY) - 0.05297(CANPYCOV) - 0.09837(HPRATIO) + 0.88113(BURNREP)	0.419	0.0001
Ca	= 0.37010	+ 0.044277(JULTOSEP) + 0.0032338(CANPYCOV)	0.487	0.0001
P	= 0.15547	+ 0.0027413(APR) + 0.0017248(MAY) - 0.008095(MAR) - 0.0010609(PINEBA) - 0.000071531(MOSNBURN)	0.588	0.0001
Mg	= 0.26811	- 0.0043917(SEP) - 0.0064108(JUL) - 0.0078(BURNREP)	0.226	0.0001
K	= 1.53886	+ 0.012717(MAR+SEP) - 0.019749(AUG) + 0.0022495(CANPYCOV) + 0.034142(BURNREP)	0.303	0.0001

[a] MAR = March rainfall each year, etc., TOTBA = Total basal area (m^2/ha), HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), HDWDBA = basal area of hardwoods (m^2/ha) > 5 cm diameter breast height (m^2/ha), CANPYCOV = percent canopy cover, BURNREP = number of times burned, and MOSNBURN = number of months since burned.

Table 2. Regression equations illustrating the relationship between stiff sunflower nutrient content, seasonal or monthly rainfall, overstory characteristics and prescribed fire regime on oak-pine sites 1985-1989.

Dependent Variable		Intercept	Independent Variables[a]				R^2	P>F
Crude Protein	=	8.84319	+ 0.18593(APR)	- 0.17215(JUL)	- 0.14235(HDWDBA)	- 0.35733(BURNREP)	0.499	0.0001
ADF	=	45.09600	- 0.88871(MAY)	+ 0.17137(JUN)	- 0.0053595(MOSNBURN)	- 1.44043(BURNREP)	0.300	0.0001
Ash	=	16.92810	- 0.64783(APR)	+ 0.40884(MAY)	+ 0.64391(JUN)	- 0.91120(SEP)		
			+ 0.24424(PINEBA)	- 0.02143(CANPYCOV)	+ 0.64051(BURNREP)		0.559	0.0001
TDN	=	51.23000	+ 1.01377(MAY)	+ 0.80985(JUL)	+ 0.079133(HPRATIO)		0.318	0.0001
Ca	=	1.57360	+ 0.21286(MAY+JUL)	- 0.21286(MAR+APR)	+ 0.13181(TOTBA)	- 0.037276(CANPYCOV)		
			+ 0.19852(BURNREP)				0.500	0.0001
P	=	0.13162	- 0.0056931(JUL)	+ 0.0027403(APR)	+ 0.0037748(PINEBA)	- 0.0056359(TOTBA)		
			+ 0.0008036(CANPYCOV)				0.532	0.0001
Mg	=	0.44333	+ 0.26751(AUG)	+ 0.013944(PINEBA)	- 0.0056549(TOTBA)		0.187	0.0001
K	=	2.70973	- 0.059317(MAR+AUG)	- 0.015494(PINEBA)	-0.010562(HPRATIO)	+ 0.051994(BURNREP)	0.211	0.0001

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[a] APRIL = April rainfall each year, etc., TOTBA = Total basal area (m^2/ha), HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), HDWDBA = basal area of hardwoods (m^2/ha) > 5 cm diameter breast height (m^2/ha), CANPYCOV = percent canopy cover, BURNREP = number of times burned, and MOSNBURN = number of months since burned.

Table 3. Regression equations illustrating the relationship between greenbriar nutrient content, seasonal or monthly rainfall, overstory characteristics and prescribed fire regime on oak-pine sites 1985-1989.

Dependent Variable	Intercept	Independent Variables[a]				R^2	P>F
Crude Protein =	8.20130	+ 0.081969(MARTOAUG)	+ 0.21723(PINEBA)	- 0.30537(TOTBA)	+ 0.046284(CANPYCOV)	0.242	0.0001
ADF =	66.56730	- 2.96995(JULTOSEP)	+ 0.16023(TOTBA)	- 0.069224(HPRATIO)		0.620	0.0001
Ash =	3.10634	+ 0.20368(JULTOSEP)	+ 0.015386(CANPYCOV)	+ 0.011520(CANPYCOV)		0.536	0.0001
TDN =	35.17990	+ 2.71124(JULTOSEP)	- 0.14660(TOTBA)	+ 0.062997(HPRATIO)		0.620	0.0001
Ca =	1.02475	+ 0.043687(JULTOSEP)	- 0.0249541(MAR+APR)	- 0.015698(HDWDBA)	- 0.0347581(FEB)	0.491	0.0001
P =	0.11119	+ 0.0011764(APR+MAY)	- 0.0021847(JUL)	- 0.00022432(CANPYCOV)		0.419	0.0001
Mg =	0.15312	+ 0.0073978(AUG)	+ 0.0028974(PINEBA)	- 0.00059918(HPRATIO)		0.265	0.0001
K =	1.16238	- 0.026091(TOTBA)	- 0.0033551(CANPYCOV)	+ 0.049516(BURNREP)		0.426	0.0001

[a] MARTOAUG = March to August rainfall each year, etc., TOTBA = Total basal area (m^2/ha), HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), HDWDBA = basal area of hardwoods (m^2/ha) > 5 cm diameter breast height (m^2/ha), CANPYCOV = percent canopy cover, BURNREP = number of times burned, and MOSNBURN = number of months since burned.

Table 4. Regression equations illustrating the relationship between winged sumac nutrient content, seasonal or monthly rainfall, overstory characteristics and prescribed fire regime on oak-pine sites 1985-1989.

Dependent Variable	Intercept	Independent Variables[a]				R^2	P>F
Crude Protein =	8.67692	+ 0.30800(APR)	- 0.17384(TOTBA)	+ 0.34950(CANPYCOV)	- 0.043503(HPRATIO)	0.451	0.0001
ADF =	28.87640	+ 0.61236(APR)	- 1.03082(JUN)	- 1.57498(AUG)	+ 0.54352(TOTBA)		
		- 0.16319(CANPYCOV)	- 0.0037341(MOSNBURN)			0.498	0.0001
Ash =	4.89973	- 0.073991(AUG)	+ 0.085415(TOTBA)	- 0.024783(CANPYCOV)		0.131	0.004
TDN =	67.89920	+ 1.12611(MAY+JUL)	- 0.18328(MAR+APR)	- 0.53969(TOTBA)	+ 0.16258(CANPYCOV)		
		+ 0.16258(CANPYCOV)	+ 0.0036487(MOSNBURN)			0.491	0.0001
Ca =	0.99910	+ 0.024423(JUL)	+ 0.037464(TOTBA)	- 0.009713(CANPYCOV)	+ 0.0031476(HPRATIO)	0.343	0.0001
P =	0.01864	+ 0.0038989(APR)	+ 0.0043431(MAY)	- 0.0017346(TOTBA)	- 0.00024179(MOSNBURN)	0.496	0.0001
Mg =	0.28639	- 0.010812(JULTOSEP)	+ 0.0024210(PINEBA)	- 0.00040602(CANPYCOV)		0.396	0.0001
K =	1.19439	- 0.019134(AUG+SEP)	- 0.001267(CANPYCOV)	- 0.0024571(HPRATIO)	+ 0.00027253(MOSNBURN)	0.184	0.0007

[a] APRIL = April rainfall each year, etc., TOTBA = Total basal area (m^2/ha), HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), HDWDBA = basal area of hardwoods (m^2/ha) > 5 cm diameter breast height (m^2/ha), CANPYCOV = percent canopy cover, BURNREP = number of times burned, and MOSNBURN = number of months since burned.

Table 5. Regression equations illustrating the relationship between winged elm nutrient content, seasonal or monthly rainfall, overstory characteristics and prescribed fire regime on oak-pine sites 1985-1989.

Dependent Variable		Intercept	Independent Variables[a]				R^2	P>F
Crude Protein	=	3.42630	+ 0.34393(MAY)	+ 0.740554(AUG)	+ 0.72076(MAR)	- 0.10199(HDWDBA)		
			- 0.001158(MOSNBURN)	- 0.44169(BURNREP)			0.446	0.0001
ADF	=	51.85350	+ 1.38002(APR)	- 1.92604(JUN)	- 3.73504(AUG)	- 1.21727(BURNREP)	0.629	0.0001
Ash	=	-1.32842	+ 0.70695(JUL)	+ 0.92176(AUG)	- 0.27497(HDWDBA)	+ 0.055611(CANPYCOV)		
			+ 0.024540(HPRATIO)	+ 0.28045 (BURNREP)	+ 1.06686(FEB)		0.674	0.0001
TDN	=	48.65320	- 1.25873(APR)	+ 1.75326(JUN)	+ 3.40722(AUG)	+ 1.10865(BURNREP)	0.629	0.0001
Ca	=	1.52621	- 0.033239(APR)	+ 0.030765(MAY)	- 0.030333(SEP)	- 0.029944(HDWDBA)		
			+ 0.0079906(CANPYCOV)	+ 0.0041837(HPRATIO)			0.498	0.0001
P	=	0.19415	- 0.011825(MAR)	- 0.0001966(CANPYCOV)	- 0.00005039(MOSNBURN)	- 0.0037114(BURNREP)	0.415	0.0001
Mg	=	0.29877	- 0.0014489(TOTLRAIN)	+ 0.0023009(PINEBA)	- 0.000026702(MOSNBURN)		0.249	0.0001
K	=	0.39647	+ 0.039427(JULTOSEP)	+ 0.14169(BURNREP)			0.347	0.0001

[a] MAY = MAY rainfall each year, etc., TOTBA = Total basal area (m^2/ha), HPRATIO = ratio of hardwood basal area (m^2/ha) to pine basal area (m^2/ha), HDWDBA = basal area of hardwoods (m^2/ha) > 5 cm diameter breast height (m^2/ha), CANPYCOV = percent canopy cover, BURNREP = number of times burned, and MOSNBURN = number of months since burned.

Table 6. Nutrient response (% dry matter) of 5 browse species to timber harvest and annual burning 1985-1989, adjusted across years for seasonal rainfall distribution (analysis of covariance).[a]

	Treatment[b]					
Nutrient,	Control		HNT1		HT1	
species	x	SE	x	SE	x	SE
Crude Protein						
Goldenrod	6.2	0.2	6.5	0.2	6.4	0.2
Sunflower	7.3a	0.3	6.4b	0.3	7.2ab	0.4
Greenbriar	9.4	0.3	9.2	0.3	9.7	0.4
Sumac	8.4	0.3	7.9	0.3	8.6	0.3
Elm	9.2	0.4	8.6	0.4	9.6	0.5
ADF						
Goldenrod	39.7a	0.7	35.3b	0.8	35.4b	1.0
Sunflower	38.7	1.3	35.6	1.4	37.2	1.7
Greenbriar	35.9a	1.0	28.4b	1.2	28.3b	1.4
Sumac	21.0a	0.5	18.5b	0.4	18.3b	0.6
Elm	35.6a	1.7	28.0b	1.9	30.2ab	2.5
Ash						
Goldenrod	7.2a	0.1	6.8b	0.1	6.4c	0.1
Sunflower	17.5	0.7	18.0	0.8	17.2	0.9
Greenbriar	7.0a	0.2	6.5ab	0.2	6.1b	0.3
Sumac	4.8	0.2	4.8	0.1	4.8	0.2
Elm	9.8	0.3	10.1	0.4	10.4	0.5
TDN						
Goldenrod	59.6b	0.8	62.7a	0.9	62.5a	0.1
Sunflower	60.6	1.2	63.7	1.3	62.0	1.6
Greenbriar	63.1b	0.9	70.0a	1.1	70.1a	1.3
Sumac	76.7b	0.5	79.0a	0.4	79.2a	0.5
Elm	63.4b	1.6	70.4a	1.8	68.3ab	2.3
Ca						
Goldenrod	1.21a	0.03	1.05b	0.03	0.94c	0.04
Sunflower	3.63	0.20	4.07	0.22	3.77	0.27
Greenbriar	1.46	0.06	1.32	0.06	1.30	0.08
Sumac	1.16a	0.07	1.07ab	0.06	0.93b	0.07
Elm	1.68	0.05	1.61	0.05	1.53	0.07
P						
Goldenrod	0.10b	0.00	0.13a	0.00	0.14a	0.00
Sunflower	0.09b	0.00	0.09b	0.00	0.11a	0.00
Greenbriar	0.09b	0.00	0.11a	0.00	0.11a	0.00
Sumac	0.09b	0.01	0.13a	0.01	0.15a	0.01
Elm	0.11b	0.00	0.12a	0.00	0.13a	0.01

Table 6. Continued.

	Treatment[b]					
Nutrient,	Control		HNT1		HT1	
species	x	SE	x	SE	x	SE
Mg						
Goldenrod	0.23a	0.01	0.18b	0.01	0.22a	0.01
Sunflower	0.58a	0.03	0.49b	0.03	0.51ab	0.04
Greenbriar	0.21	0.01	0.20	0.01	0.19	0.01
Sumac	0.16	0.01	0.15	0.01	0.14	0.01
Elm	0.26	0.01	0.21	0.01	0.24	0.01
K						
Goldenrod	1.78	0.03	1.77	0.03	1.70	0.04
Sunflower	2.05ab	0.05	2.00b	0.06	2.22a	0.07
Greenbriar	1.59a	0.05	1.45b	0.05	1.34b	0.07
Sumac	0.79b	0.04	0.90ab	0.04	1.00a	0.04
Elm	0.87	0.03	0.92	0.04	0.94	0.05

[a] The yearly effects due to rainfall were accounted for by analysis of covariance. Row means followed by the same letter were not significantly different at the 0.05 level (LSD).

[b] Control = no harvest, no burn; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT1 = harvest pine timber, thin hardwoods, winter burn annually.

Table 7. In vitro dry-matter digestibility response in fall 1986 of selected deer browse after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains.[a]

	Treatment[b]															
	CONTROL		RRB		HNT1		HT		HT4		HT2		HT1		CCSP	
Species	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
Goldenrod	54.8a	1.7	48.6abc	2.8	46.3bc	1.8	47.7abc	.	42.7c	1.2	43.9bc	0.4	49.5ab	1.8	45.9bc	0.2
Sunflower	57.1ab	3.2	56.1ab	4.7	63.6a	3.6	59.6a	.	50.6bc	1.2	52.8abc	1.9	56.9ab	0.7	48.8c	0.7
Greenbriar	46.3	3.1	53.4	3.3	54.7	2.7	48.5	.	44.1	1.5	48.3	1.8	50.5	5.3	52.5	1.7
Winged sumac	49.0	0.3	41.5	5.1	50.3	0.7	46.5	.	38.5	1.5	46.1	2.6	50.8	2.2	48.1	2.5
Winged elm	46.7	6.5	44.5	3.9	46.3	1.3	42.0	.	43.7	5.7	38.8	2.5	46.3	.	42.4	2.8

[a] Row means followed by the same letter within species are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = winter rough reduction burn 1985; CCSP=clearcut, summer site prep burn 1985; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 1985; HT2 = harvest pine timber, thin hardwoods, winter burn 1985; HT1 = harvest pine timber, thin hardwoods, winter burn annually (1985, 1986); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually (1985, 1986). Note that the HT4 and HT2 are essentially the same treatment at this point in time.

Figure 1. Nutrient response of elmleaf goldenrod after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Crude protein, (B.) Acid detergent fiber (ADF), (C.) Ash, and (D.) Total digestible nutrients (TDN). Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

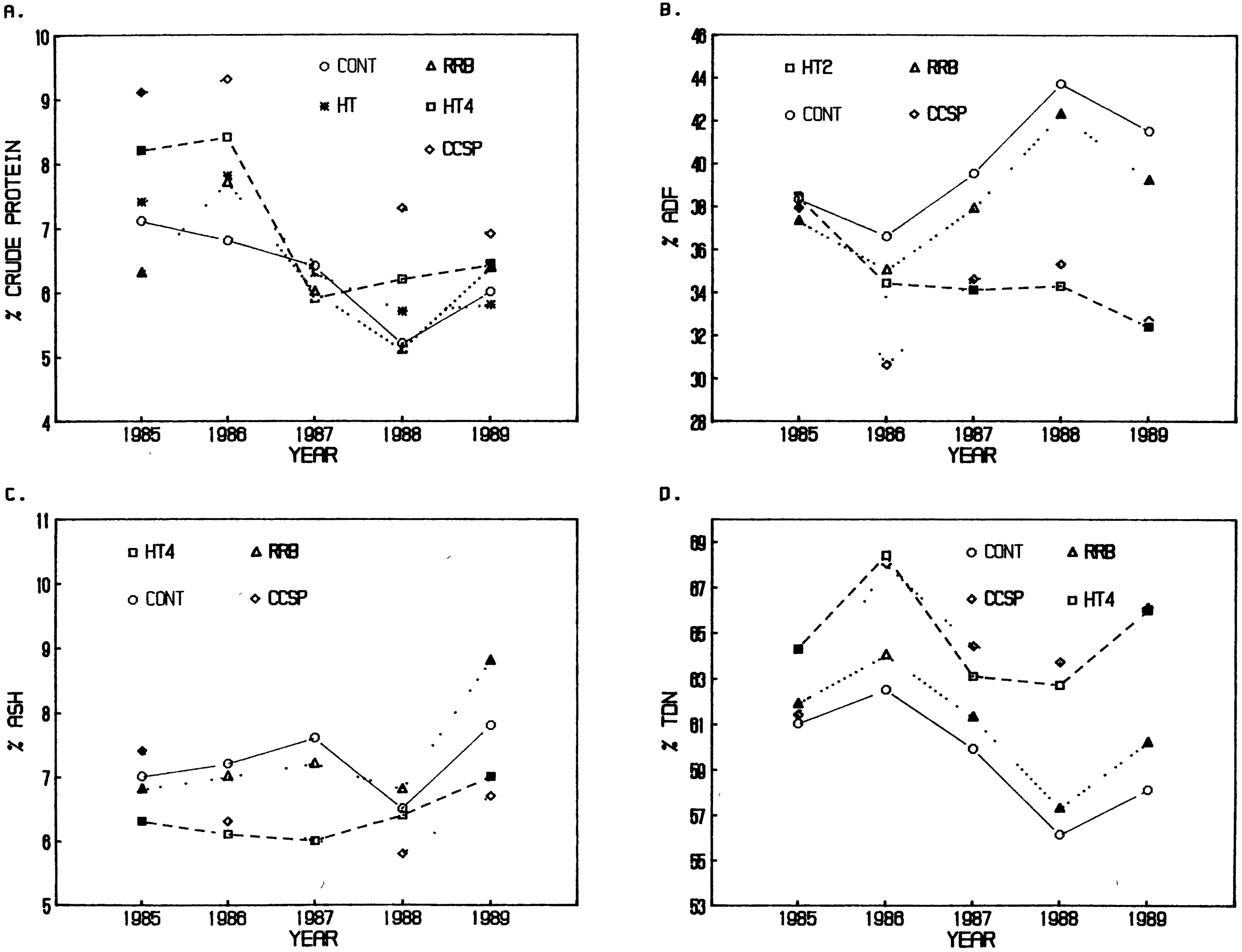

A.
% CRUDE PROTEIN
4
5
6
7
8
9
10
○ CONT
△ RRB
✱ HT
□ HT4
◇ CCSP
1985
1986
1987
1988
1989
YEAR
B.
% ADF
28
30
32
34
36
38
40
42
44
46
□ HT2
△ RRB
○ CONT
◇ CCSP
1985
1986
1987
1988
1989
YEAR
C.
% ASH
5
6
7
8
9
10
11
□ HT4
△ RRB
○ CONT
◇ CCSP
1985
1986
1987
1988
1989
YEAR
D.
% TDN
53
55
57
59
61
63
65
67
69
○ CONT
△ RRB
◇ CCSP
□ HT4
1985
1986
1987
1988
1989
YEAR

Figure 2. Nutrient response of stiff sunflower after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Crude protein, (B.) Acid detergent fiber (ADF), (C.) Ash, and (D.) Total digestible nutrients (TDN). Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

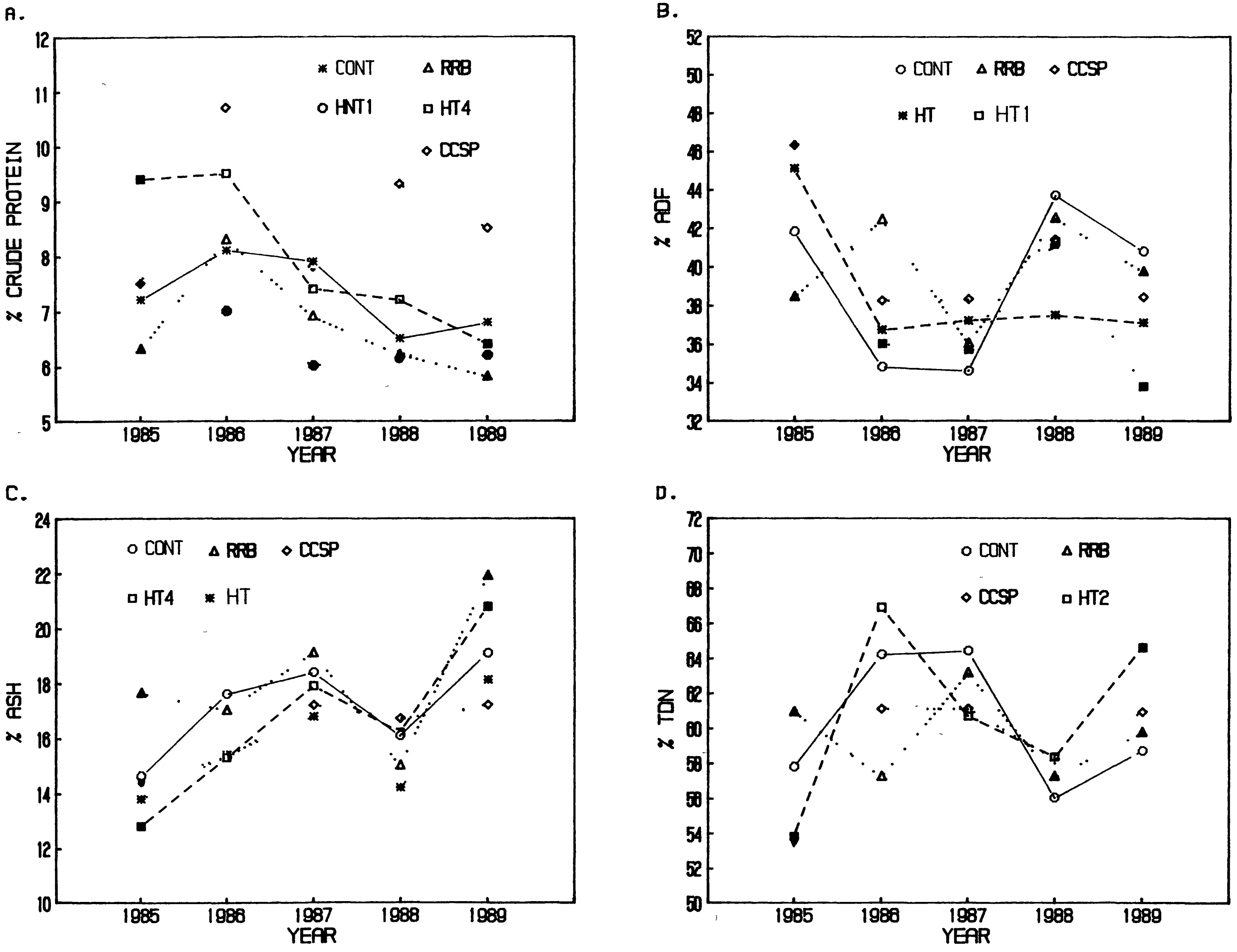

A.
% CRUDE PROTEIN
12
11
10
9
8
7
6
5
* CONT
△ RRB
○ HNT1
□ HT4
◇ CCSP
1985
1986
1987
1988
1989
YEAR
B.
% ADF
52
50
48
46
44
42
40
38
36
34
32
○ CONT
△ RRB
◇ CCSP
* HT
□ HT1
1985
1986
1987
1988
1989
YEAR
C.
% ASH
24
22
20
18
16
14
12
10
○ CONT
△ RRB
◇ CCSP
□ HT4
* HT
1985
1986
1987
1988
1989
YEAR
D.
% TDN
72
70
68
66
64
62
60
58
56
54
52
50
○ CONT
△ RRB
◇ CCSP
□ HT2
1985
1986
1987
1988
1989
YEAR

Figure 3. Nutrient response of greenbriar after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Crude protein, (B.) Acid detergent fiber (ADF), (C.) Ash, and (D.) Total digestible nutrients (TDN). Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

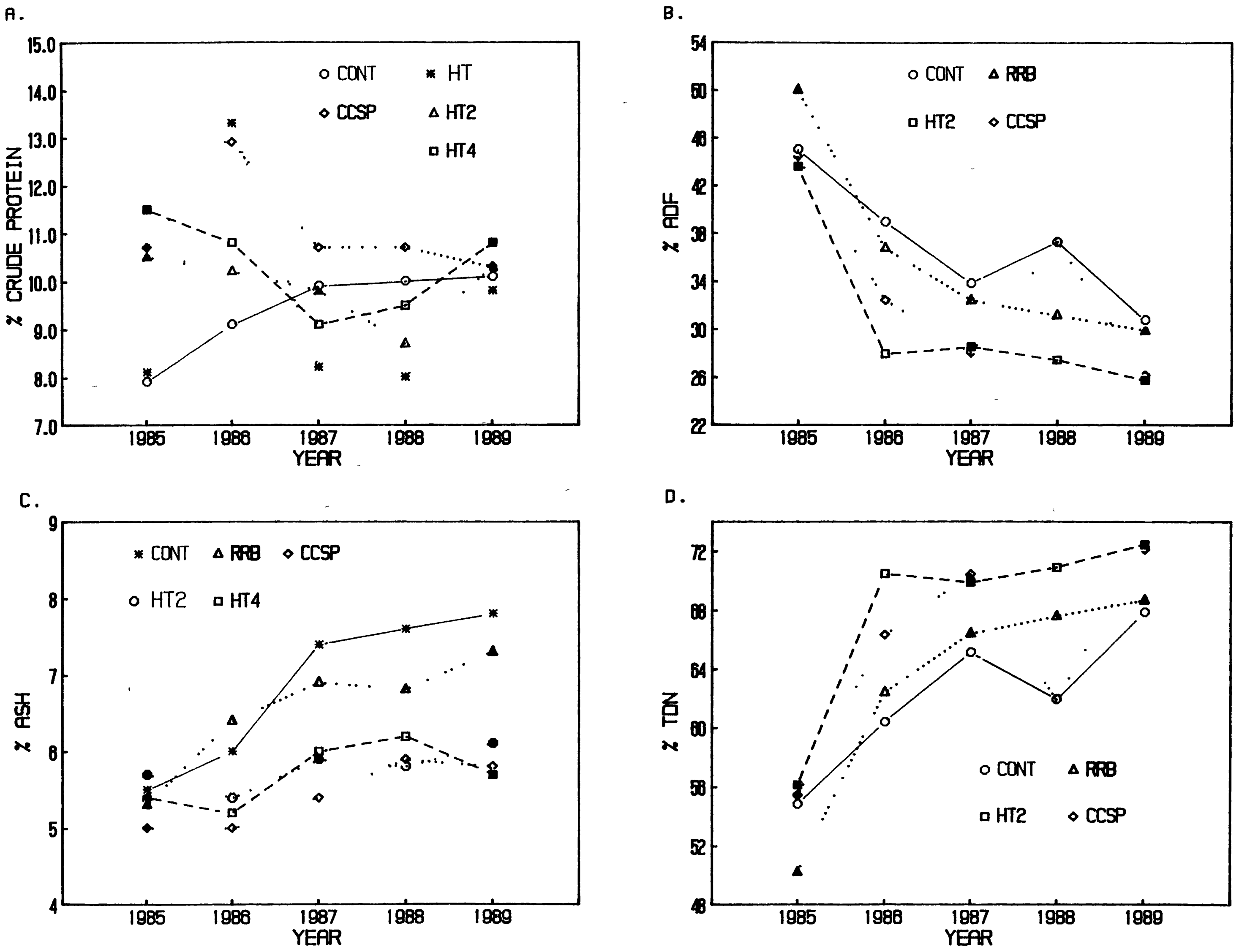

A.
% CRUDE PROTEIN
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
CONT
HT
CCSP
HT2
HT4
1985
1986
1987
1988
1989
YEAR
B.
% ADF
54
50
46
42
38
34
30
26
22
CONT
RRB
HT2
CCSP
1985
1986
1987
1988
1989
YEAR
C.
% ASH
9
8
7
6
5
4
CONT
RRB
CCSP
HT2
HT4
1985
1986
1987
1988
1989
YEAR
D.
% TDN
72
68
64
60
56
52
48
CONT
RRB
HT2
CCSP
1985
1986
1987
1988
1989
YEAR

Figure 4. Nutrient response of winged sumac after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Crude protein, (B.) Acid detergent fiber (ADF), (C.) Ash, and (D.) Total digestible nutrients (TDN). Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

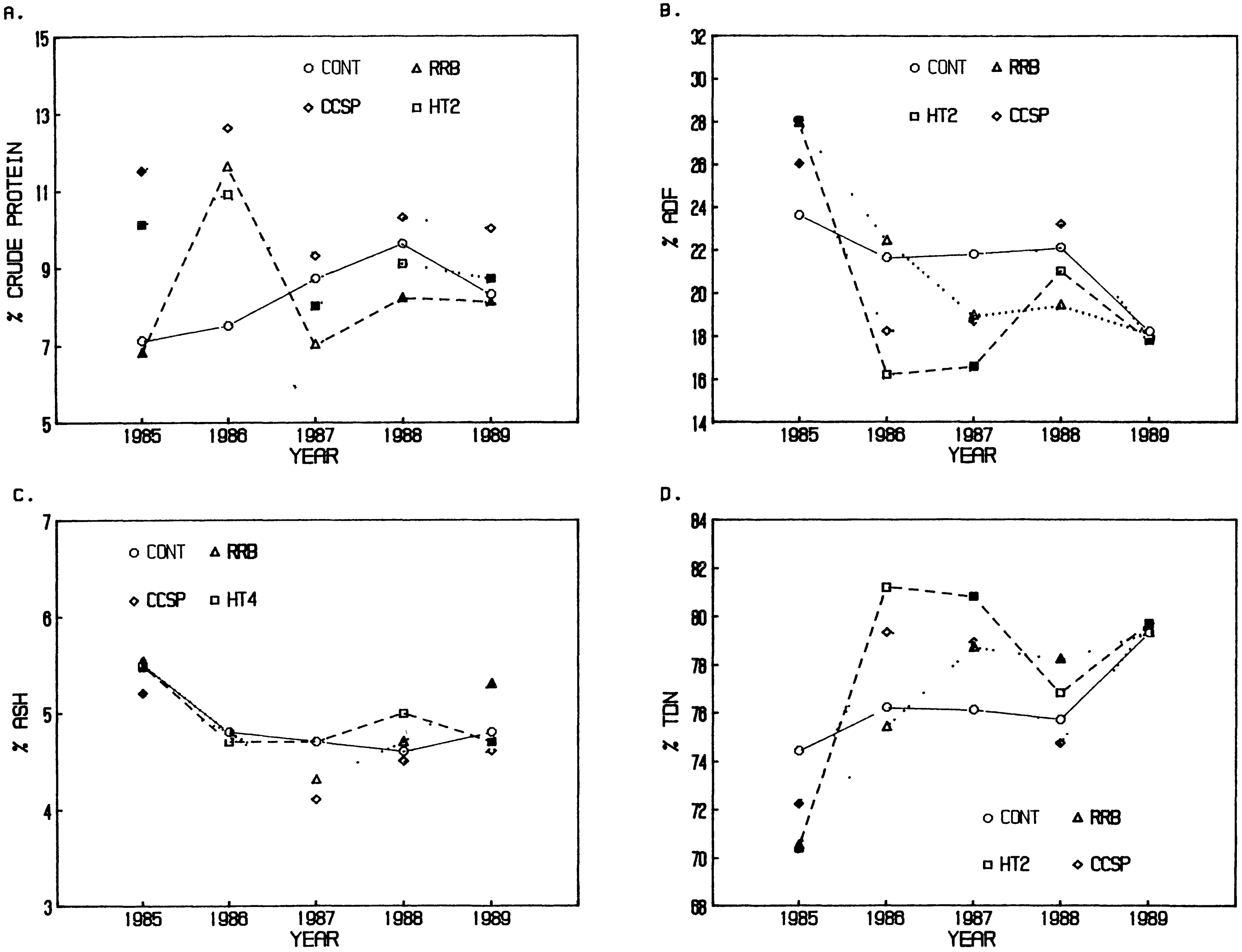

A.
% CRUDE PROTEIN
15
13
11
9
7
5
1985
1986
1987
1988
1989
YEAR
○ CONT
△ RRB
◇ CCSP
□ HT2
B.
% ADF
32
30
28
26
24
22
20
18
16
14
1985
1986
1987
1988
1989
YEAR
○ CONT
△ RRB
□ HT2
◇ CCSP
C.
% ASH
7
6
5
4
3
1985
1986
1987
1988
1989
YEAR
○ CONT
△ RRB
◇ CCSP
□ HT4
D.
% TDN
84
82
80
78
76
74
72
70
68
1985
1986
1987
1988
1989
YEAR
○ CONT
△ RRB
□ HT2
◇ CCSP

Figure 5. Nutrient response of winged elm after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Crude protein, (B.) Acid detergent fiber (ADF), (C.) Ash, and (D.) Total digestible nutrients (TDN). Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

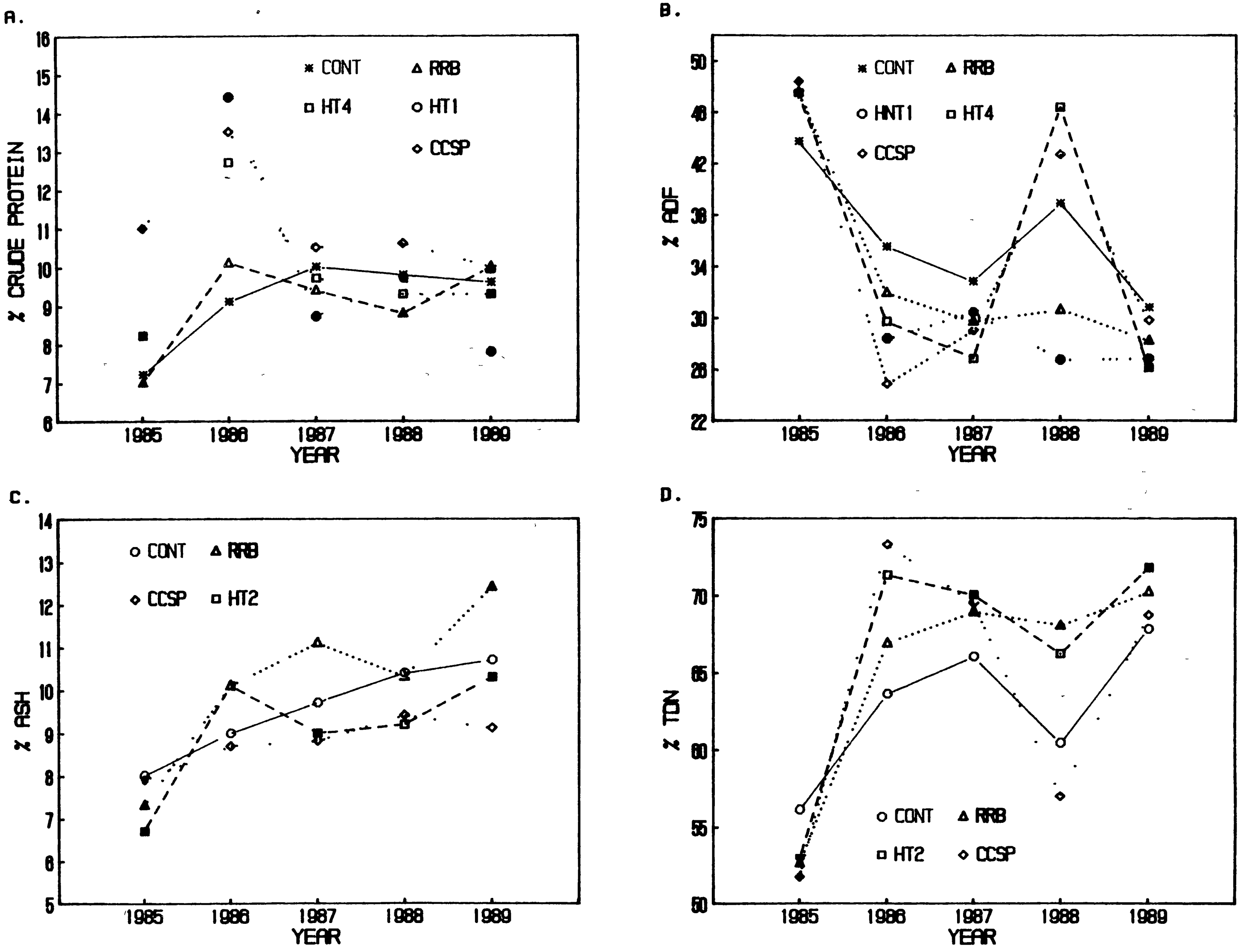

A.
% CRUDE PROTEIN
16
15
14
13
12
11
10
9
8
7
6
1985
1986
1987
1988
1989
YEAR
CONT
RRB
HT4
HT1
CCSP
B.
% ADF
50
46
42
38
34
30
26
22
1985
1986
1987
1988
1989
YEAR
CONT
RRB
HNT1
HT4
CCSP
C.
% ASH
14
13
12
11
10
9
8
7
6
5
1985
1986
1987
1988
1989
YEAR
CONT
RRB
CCSP
HT2
D.
% TDN
75
70
65
60
55
50
1985
1986
1987
1988
1989
YEAR
CONT
RRB
HT2
CCSP

Figure 6. Nutrient response of elmleaf goldenrod after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Calcium, (B.) Phosphorus, (C.) Potassium, and (D.) Magnesium. Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

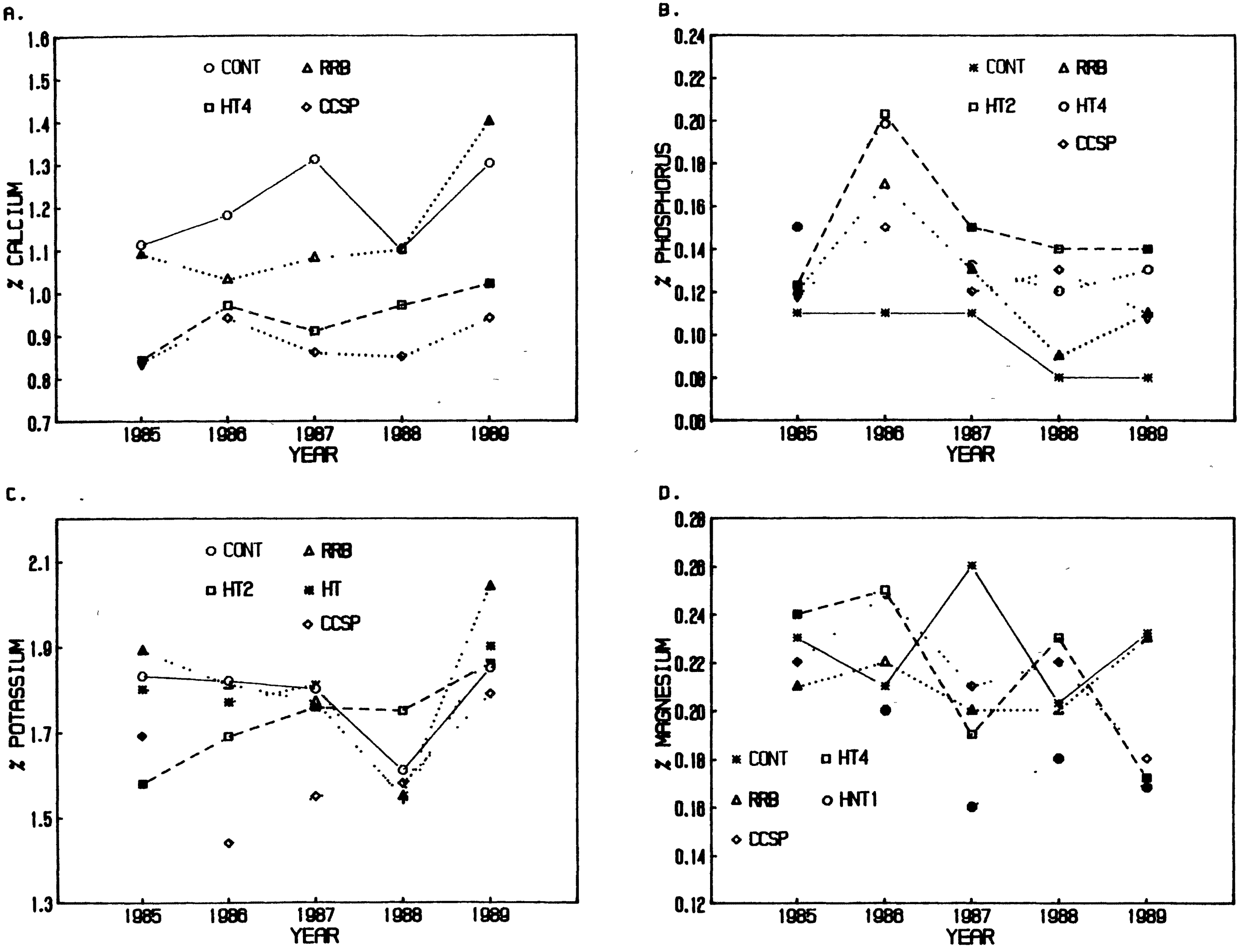

A.
% CALCIUM
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
○ CONT
▲ RRB
□ HT4
◇ CCSP
1985
1986
1987
1988
1989
YEAR
B.
% PHOSPHORUS
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
✱ CONT
▲ RRB
□ HT2
○ HT4
◇ CCSP
1985
1986
1987
1988
1989
YEAR
C.
% POTASSIUM
2.1
1.9
1.7
1.5
1.3
○ CONT
▲ RRB
□ HT2
✱ HT
◇ CCSP
1985
1986
1987
1988
1989
YEAR
D.
% MAGNESIUM
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
✱ CONT
□ HT4
▲ RRB
○ HNT1
◇ CCSP
1985
1986
1987
1988
1989
YEAR

Figure 7. Nutrient response of stiff sunflower after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Calcium, (B.) Phosphorus, (C.) Potassium, and (D.) Magnesium. Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

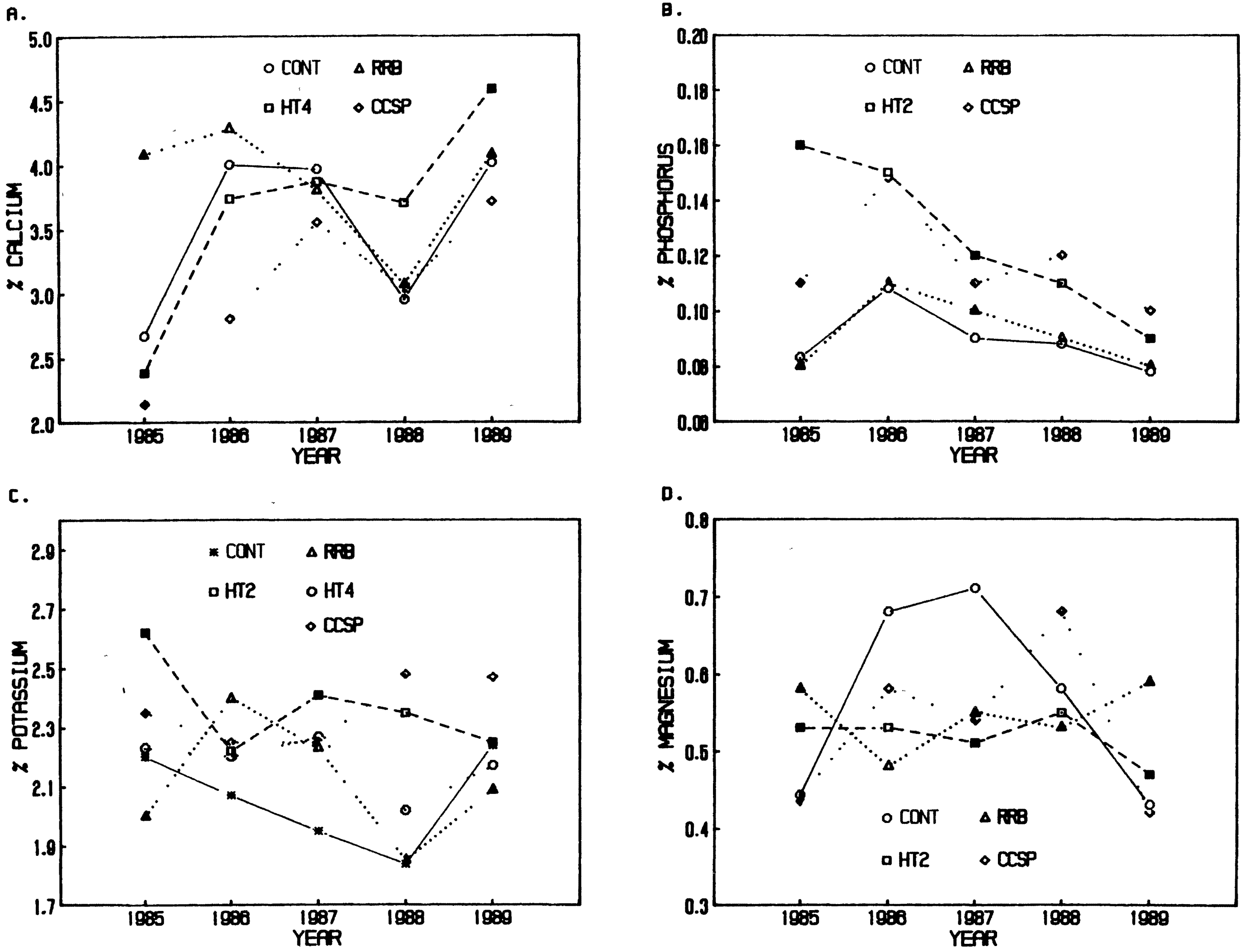

A.
% CALCIUM
5.0
4.5
4.0
3.5
3.0
2.5
2.0
CONT
RRB
HT4
CCSP
1985
1986
1987
1988
1989
YEAR
B.
% PHOSPHORUS
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
CONT
RRB
HT2
CCSP
1985
1986
1987
1988
1989
YEAR
C.
% POTASSIUM
2.9
2.7
2.5
2.3
2.1
1.9
1.7
CONT
RRB
HT2
HT4
CCSP
1985
1986
1987
1988
1989
YEAR
D.
% MAGNESIUM
0.8
0.7
0.6
0.5
0.4
0.3
CONT
RRB
HT2
CCSP
1985
1986
1987
1988
1989
YEAR

Figure 8. Nutrient response of greenbriar after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Calcium, (B.) Phosphorus, (C.) Potassium, and (D.) Magnesium. Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

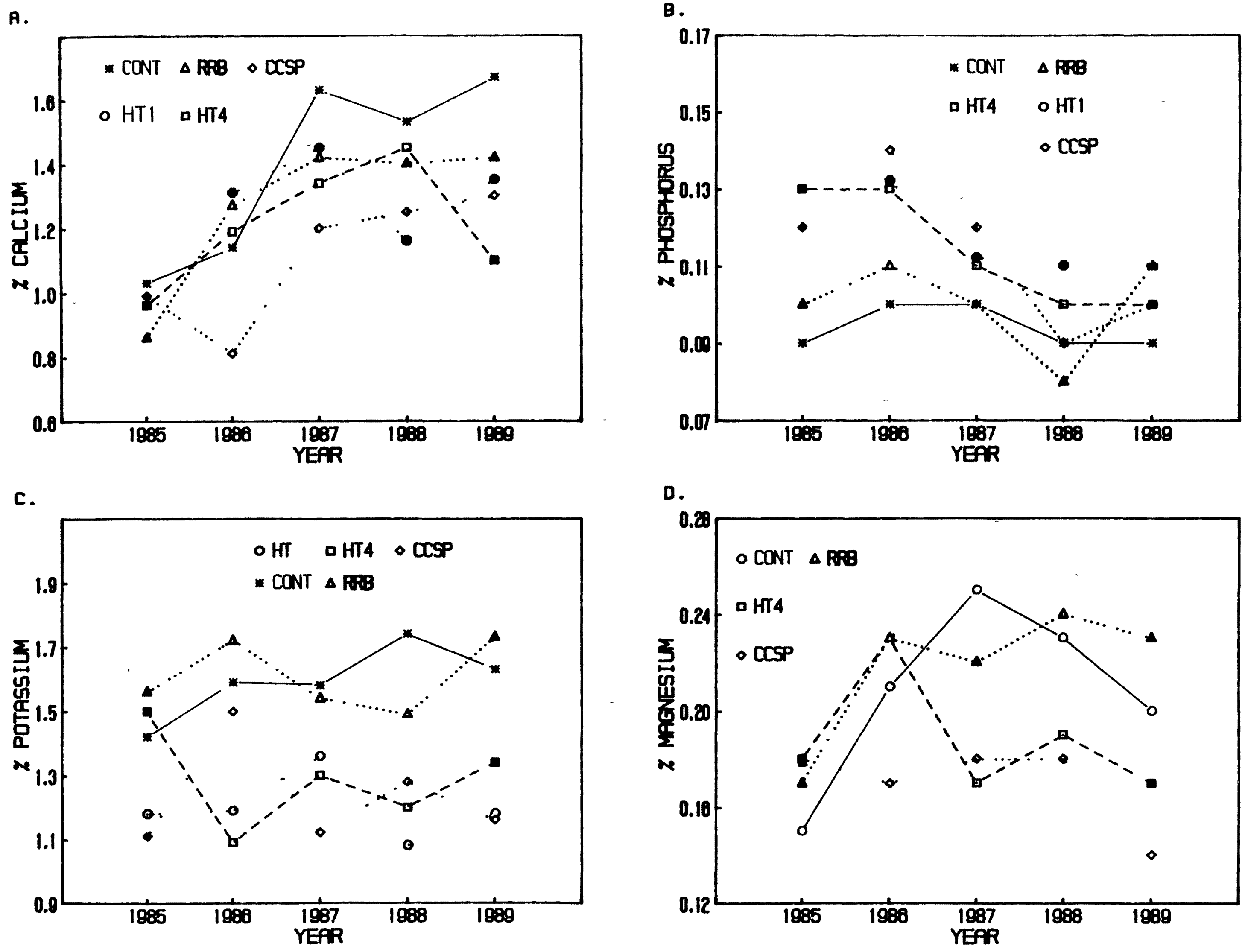

A.
* CONT
△ RRB
◇ CCSP
○ HT1
□ HT4
% CALCIUM
1.6
1.4
1.2
1.0
0.8
0.6
1985
1986
1987
1988
1989
YEAR
B.
* CONT
△ RRB
□ HT4
○ HT1
◇ CCSP
% PHOSPHORUS
0.17
0.15
0.13
0.11
0.09
0.07
1985
1986
1987
1988
1989
YEAR
C.
○ HT
□ HT4
◇ CCSP
* CONT
△ RRB
% POTASSIUM
1.9
1.7
1.5
1.3
1.1
0.9
1985
1986
1987
1988
1989
YEAR
D.
○ CONT
△ RRB
□ HT4
◇ CCSP
% MAGNESIUM
0.28
0.24
0.20
0.16
0.12
1985
1986
1987
1988
1989
YEAR

Figure 9. Nutrient response of winged sumac after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Calcium, (B.) Phosphorus, (C.) Potassium, and (D.) Magnesium. Filled symbols indicate that this treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.

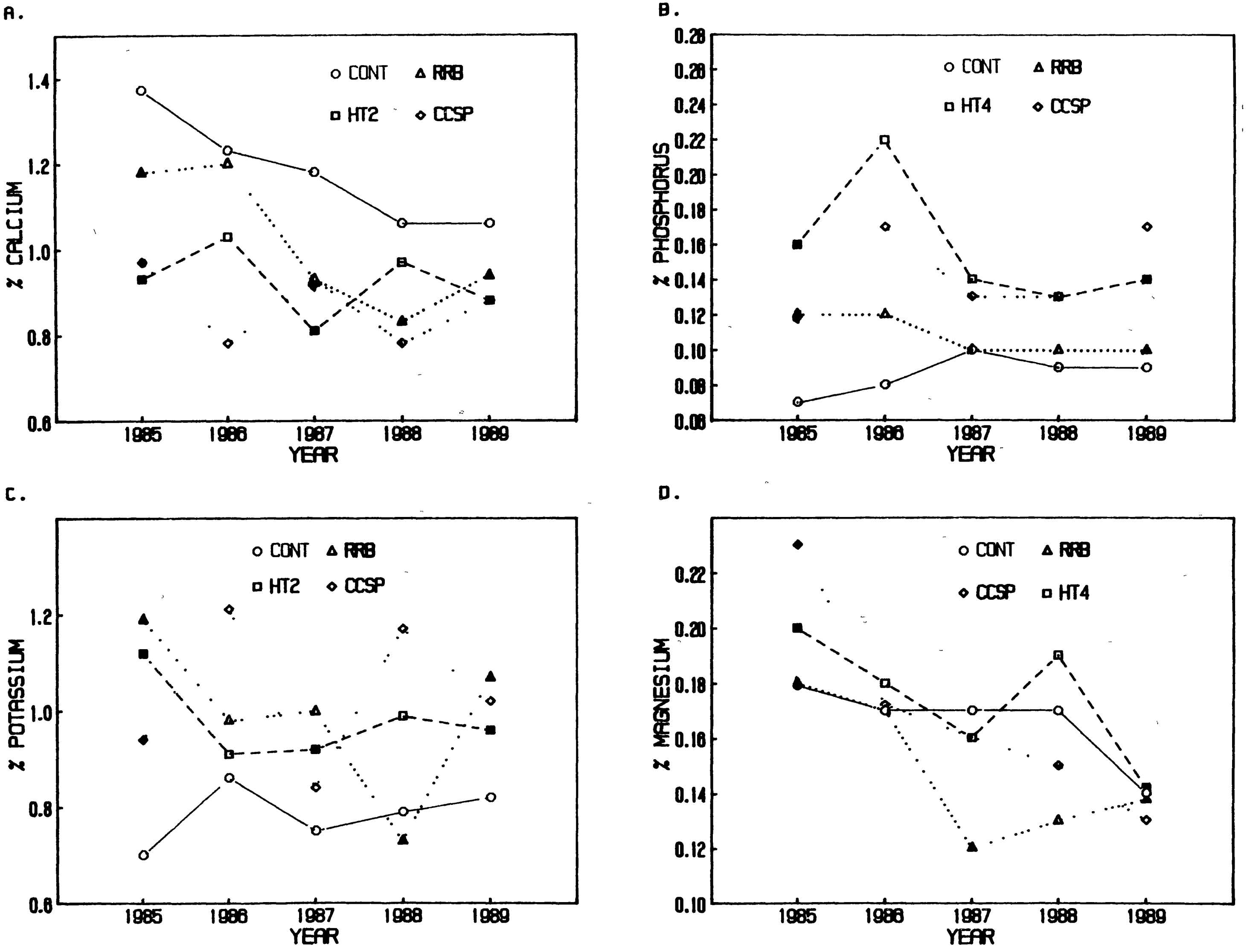
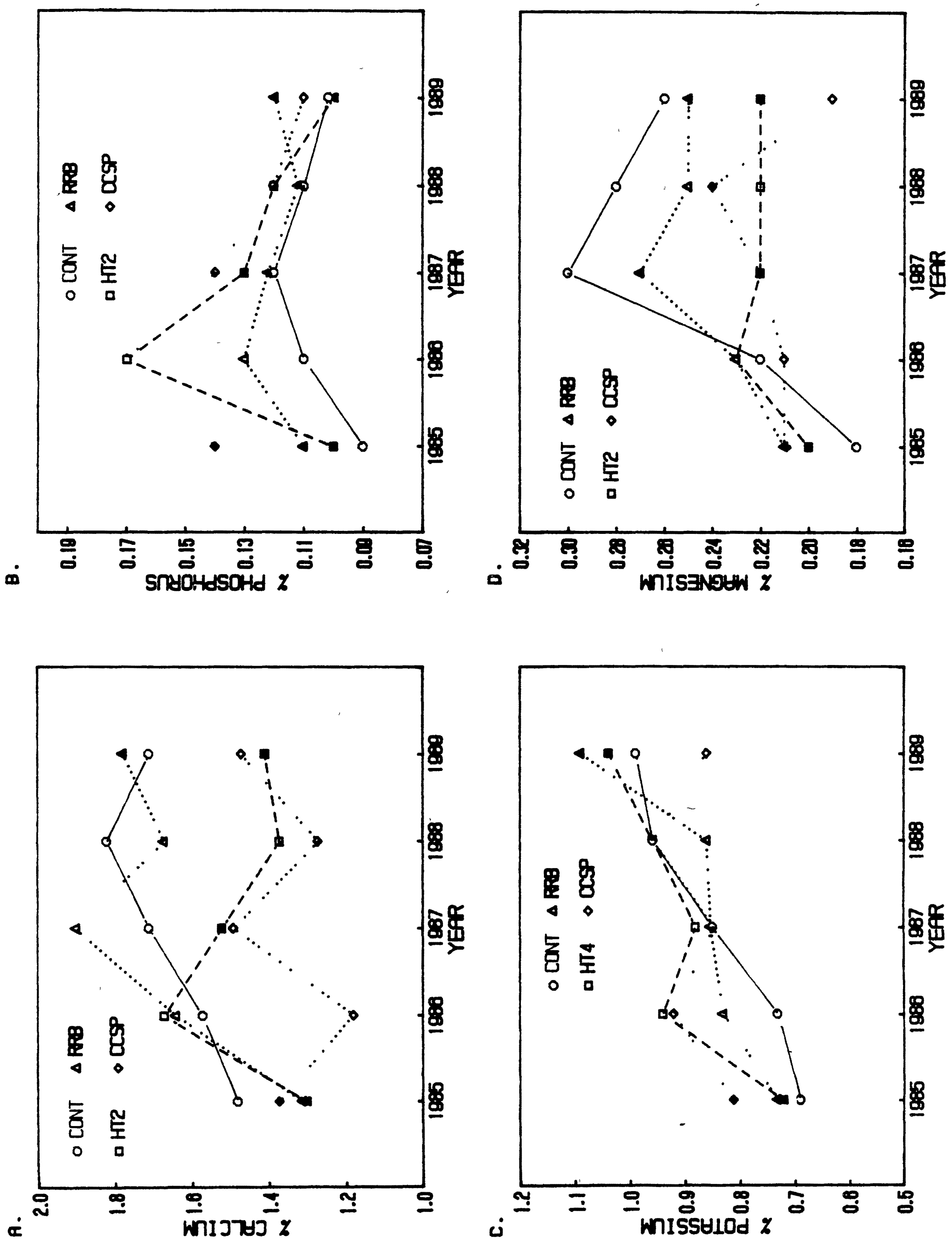

A.
○ CONT
▲ RRB
□ HT2
◇ CCSP
% CALCIUM
1.4
1.2
1.0
0.8
0.6
1985
1986
1987
1988
1989
YEAR
B.
○ CONT
▲ RRB
□ HT4
◇ CCSP
% PHOSPHORUS
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
1985
1986
1987
1988
1989
YEAR
C.
○ CONT
▲ RRB
□ HT2
◇ CCSP
% POTASSIUM
1.2
1.0
0.8
0.6
1985
1986
1987
1988
1989
YEAR
D.
○ CONT
▲ RRB
◇ CCSP
□ HT4
% MAGNESIUM
0.22
0.20
0.18
0.16
0.14
0.12
0.10
1985
1986
1987
1988
1989
YEAR

Figure 10. Nutrient response of winged elm after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. (A.) Calcium, (B.) Phosphorus, (C.) Potassium, and (D.) Magnesium. Filled symbols indicate that treatment was burned that year. The CCSP treatment was summer burned and all others were winter burned. Some treatments were not depicted for clarity of presentation and were intermediate in response.


A.
% CALCIUM
2.0
1.8
1.6
1.4
1.2
1.0
○ CONT
△ RRB
□ HT2
◇ CCSP
1985
1986
1987
1988
1989
YEAR
B.
% PHOSPHORUS
0.19
0.17
0.15
0.13
0.11
0.09
0.07
○ CONT
△ RRB
□ HT2
◇ CCSP
1985
1986
1987
1988
1989
YEAR
C.
% POTASSIUM
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
○ CONT
△ RRB
□ HT4
◇ CCSP
1985
1986
1987
1988
1989
YEAR
D.
% MAGNESIUM
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
○ CONT
△ RRB
□ HT2
◇ CCSP
1985
1986
1987
1988
1989
YEAR

CHAPTER VII

EFFECTS OF TIMBER HARVEST AND FIRE ON VEGETATION IN OKLAHOMA OUACHITA MOUNTAINS

Abstract: I compared vegetation response following an array of timber harvest and fire regimes on oak-pine (Quercus spp.-Pinus spp.) sites in the Ouachita Highlands of eastern Oklahoma over a 8-year period. Nine treatments were replicated 1-3 times in a completely randomized design on 23 (1.2-1.6 ha) units. The treatments were: no treatment control; winter rough reduction burn; clearcut, site preparation and summer burn; harvest pine (P. echinata) only and annual burn; and 5 harvest pine and thin hardwood treatments (to 9 m^2/ha basal area) with no burn, 4-, 3-, 2-, and 1-year winter-burn intervals. Little bluestem (Schizachyrium scoparium) and big bluestem (Andropogon gerardi) dominated harvested and winter burned (retrogressed) treatments. Plant frequency, percent ground cover, and standing crop of these 2 species increased on harvested sites burned more frequently. Plant species richness was significantly ($P < 0.05$) increased by timber harvest and fire. Among harvested sites, frequency of burning had no significant effect on plant species diversity or plant species evenness. September total standing crop was up to 25x greater on harvested and burned than control treatments (4,500 vs. 190 kg/ha). Response was related to overstory canopy cover, litter accumulation, and burn interval. One or 2-year winter-burn intervals increased grass and legume production and decreased woody browse species richness. Harvested sites that were unburned or burned at 3- or 4-year intervals allowed woody browse species used by white-tailed deer (*Odocoileus virginianus*) and possibly elk (*Cervus elaphus*) to increase. Clearcut and summer burned sites were initially dominated by forbs and panicums (*Dicanthelium* spp. and *Panicum* spp.). Then as forbs declined, little bluestem increased in frequency and percent ground cover. Forage production declined 6 years post-harvest on clearcuts and harvested and unburned sites because of increased canopy cover from pine regeneration. Rough reduction and later hazard reduction burns increased forage production by only 1.5x (390 vs 160 kg/ha). I recommend retaining mature oak-pine stands for acorn production within a mosaic of harvested sites burned every 3 to 4 years, and clearcuts regenerated to mixed oak-pine stands. Site treatments should be applied in different years to provide optimal forage for deer seasonally and between years.

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Key words: clearcut, habitat manipulation, forage, Oklahoma, Ouachita Mountains, prescribed fire, white-tailed deer, vegetation.

Winter and late summer forage production in the mountainous regions of eastern Oklahoma and western Arkansas is low in standing biomass (Segelquist and Pennington 1968, Fenwood et al. 1984). Winter mortality of white-tailed deer has been related to mast failure and may be compounded by the lack of an evergreen winter browse (Segelquist and Pennington 1968; Segelquist et al. 1969, 1972). Deer use of supplemental forage openings (food plots) increase during years of mast shortfall, and mortality has been reduced in enclosures with openings (Segelquist 1974, Segelquist and Rogers 1974). Decreased productivity and summer fawn mortality has also been related to mast failures the previous fall (Logan 1972). Forage production in late summer and early fall may be of critical importance in the advent of mast shortfall (Fenwood et al. 1984).

The Oklahoma Department of Wildlife Conservation (ODWC) began using timber harvest and prescribed fire on Pushmataha Wildlife Management Area (WMA) in 1977 to improve habitat conditions for deer. Forest openings were created through commercial pine timber harvest and maintained in early successional stages with prescribed fire (site retrogression) to supplement forage in years of mast shortfall. Site retrogression to increase forage production was untested as a wildlife management technique. Forage response to regeneration clearcutting and hazard reduction burns have been studied in depth across the Southeast (e.g., Hebb 1971, Stransky and Halls 1978, Wood 1988, Locascio et al. 1990).

My objective was to compare site retrogression through timber harvest and periodic prescribed fire, with regeneration clearcutting and understory rough reduction burns. Changes in plant species richness, diversity, evenness, composition, percent ground cover (1983 to 1988), and standing crop (1987 to 1990) were used as measures of treatment effects.

Previous work on Pushmataha WMA in the early 1970's suggested that deer densities exceeding $8/km^2$ may affect measures of forage production in unenclosed areas (T. Silker, deceased, Okla. State Univ., unpubl. data). Deer density estimates from 1985-1990 equal or exceed those in previous years (Masters 1991). A secondary objective was to determine if cervid herbivory had a measurable effect on forage production.

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STUDY AREA

The 29.1-ha study area was located within the Forest Habitat Research Area (FHRA) on the 7,395-ha Pushmataha WMA, Pushmataha County, Oklahoma (34° 32' N, 95° 21' W). The Pushmataha WMA lies in mountainous terrain along the western edge of the Ouachita Highland Province. The climate was semi-humid to humid with hot summers and mild winters. Summer temperatures frequently exceeded 32 C with southerly winds averaging 17 km/hr. Rainfall on the study area between 1978 and 1990 ranged from 106 to 188 cm annually based on an October to September water-year. Late summers were drought prone with rainfall in July and August averaging 15 cm (Dep. For., Okla. State Univ., unpubl. data).

Study area soils belonged to the Carnasaw-Pirum-Clebit association with areas of rock outcrop. Soils developed from sandstone and shales and were thin and drought prone. The surface layer was variable in depth to 30 cm, and texture was stony fine sandy loam (Bain and Watterson 1979). The FHRA was situated near ridge top approximately 335 m in elevation on a southeastern aspect and with a slope of 5-15%.

The FHRA overstory plant community was dominated by post oak (Q. stellata), shortleaf pine (P. echinata), blackjack oak (Q. marilandica), and mockernut hickory (Carya tomentosa). Common woody understory species included tree sparkleberry (Vaccinium arboreum), poison ivy (Toxicodendron radicans), and greenbriar (Smilax spp.). Predominant herbaceous plants were little bluestem (Schizachyrium scoparium), panicums (Panicum spp., Dicanthelium spp.), and sedges (Carex spp.).

Before acquisition (1946-1954), the Pushmataha WMA was grazed by cattle, selectively harvested, and subject to frequent fire. The Pushmataha WMA was initially established as a deer refuge. From 1969-1972, 71 elk (Cervus elaphus) were released on the Pushmataha WMA (ODWC 1972). Deer populations reached an estimated 693 ± 102 (SE) by 1973. Browse lines became apparent and by 1978 deer numbers declined to a low of 394 ± 16 (Masters 1991). Elk numbers decreased to an estimated 6 in 1988, but estimates from the winter 1991 census were 20 (R. Robinson, ODWC, unpubl. data). Between 1986-1990 the estimated deer population has averaged 645 ± 25.

Prior to 1971, <4% of the area was in cultivated openings (>96% closed forest). By 1990, 24% of the area was in dispersed forest openings created with timber harvest and maintained in various successional stages through use of prescribed fire. Openings of all types comprised 28% of the total area in 1990. The FHRA was protected from livestock grazing, logging, and fire since acquisition until this study began.

METHODS

Cultural Treatments

Beginning in summer 1984, 9 treatments were applied to 23 1.2- to 1.6-ha units in a completely randomized experimental design. Treatments, burning sequence, treatment code, and number of replications (n) are summarized below:

(1) no treatment (control) (n = 3);

(2) rough reduction winter prescribed burn - 4-year interval, 1985, 1989 (RRB) (n = 3);

(3) harvest pine timber only, winter prescribed burn - 1-year interval, 1985-1990 (HNT1) (n = 3);

(4) harvest pine timber, thin hardwoods, no burn (HT) (n = 1);

(5) harvest pine timber, thin hardwoods, winter prescribed burn - 4-year interval, 1985, 1989 (HT4) (n = 3);

(6) harvest pine timber, thin hardwoods, winter prescribed burn - 3-year interval, 1985, 1988 (HT3) (n = 2);

(7) harvest pine timber, thin hardwoods, winter prescribed burn - 2-year interval, 1985, 1987, 1989 (HT2) (n = 3);

(8) harvest pine timber, thin hardwoods, winter

prescribed burn - 1-year interval, 1985-1990 (HT1) (_n_ = 2); and

(9) clearcut and summer site prep burn, 1985 (CCSP) (_n_ = 3).

During summer 1984, merchantable pine timber was harvested in assigned treatments, and hardwoods were selectively thinned by single stem injection using 2-4 D to an approximate basal area (BA) of 9 m^2/ha. Prescribed burns using strip-head fires were conducted in winter 1985 and in succeeding years at appropriate intervals. Fireline intensity of March 1988 burns ranged from 630 to 900 kW/m (Masters and Engle 1991). The clearcut site prep treatment included shearing, raking, and windrowing of logging debris with a site prep burn conducted during summer 1985. After contour ripping, genetically improved loblolly pine (_P. taeda_) were planted on a 2.1- x 2.4-m spacing in early April, 1986.

Vegetation Sampling

Species Composition, Density, and Cover

Understory, midstory and overstory vegetation was sampled using nested quadrats (1- x 1-m and 4- x 4-m) (Oosting 1956:47-50, 62). Vegetation sampling was conducted in September and October of each year because this was a critical period of the year for deer (Fenwood et al. 1984). On each treatment unit, 10 permanent plots were established at 19.8-m intervals on 2 randomly located lines perpendicular to the contour. In order to avoid bias caused by influences from adjacent treatment units, I did not sample within 19.8 m of any edge (Oosting 1956, Mueller-Dombois and Ellenberg 1974). Data collected included plant species density, frequency, and percent ground cover.

Overstory and midstory were categorized by vertical strata and crown position relative to stand canopy structure. Strata designations were 0-1 m, 1-3 m, and >3 m. Strata greater than 3 m were categorized by position relative to stand canopy structure and were suppressed, intermediate, codominant, and dominant canopy position (Smith 1962). On harvested treatments strata designation of residual trees was based on prior stand structure. No tree or shrub regrowth was greater than 3 m. Baseline sampling prior to cultural treatment application was conducted in 1983.

Basal Area and Canopy Cover

Overstory vegetation was further quantified using the variable radius plot method (Avery 1964). Basal areas (BA) of stems $\geq$5 cm diameter breast height (DBH) were taken using a 10-factor wedge prism with plot center at the center of each 4 m^2 plot.

Overstory canopy cover was determined using a 5-point grid in a sighting tube with vertical and horizontal levels at 90 points (Mueller-Dombois and Ellenberg 1974). Readings were taken at 9 cardinal points around each 4 m^2 plot.

Complete canopy cover and basal area were reported by Masters (1991).

Standing Crop

Herbaceous and woody standing crop determinations were measured by the harvest method in the first 2 weeks of September 1986-1990 within 0.5- x 0.5-m (0.25 m^2) quadrats. Quadrat size and number were determined using Cain and Castro's (1959) minimal area concept to derive species-group area curves. Sample number ranged from 5-15.

To determine effects of cervid herbivory, I harvested paired plots in and out of movable cages along randomly located transects in 1987-1989. Cages were moved to new locations each March. Permanent enclosures (4-m^2 and 1.8-m tall) also were constructed at 3 random locations on each treatment unit. Because of personnel and time constraints enclosures were not set up on the CCSP, HNT1, and HT1 treatments. Five previously unclipped 0.25-m^2 quadrats were randomly located and clipped each year in enclosures. Current years growth of vegetation was clipped to <2.5 cm height and hand separted into sedge, legume, panicum (primarily those that form winter rosettes), grass, forb, and woody categories. Litter was collected to mineral soil and included dead grass, leaves, bark fragments, and twigs <2.5 cm diameter. Samples were dried to constant weight at 70 C in a forced air oven.

Data Analysis

Species diversity, evenness, richness, density, and frequency were calculated from vegetation samples using PC-SAS (SAS Institute 1985, 1987) and SPDIVERS.BAS (Ludwig and Reynolds 1988). Treatment means were tested for homogeneity of variance using Levene's test (Snedecor and Cochran 1980). Analysis of variance (ANOVA) was used to test for treatment differences when data were normally distributed and variances were homogeneous. The Kruskal-Wallis nonparametric test was used for variables with heterogeniety of variance. Standing crop differences among years within treatments were tested by the Kruskal-Wallis proceedure when the year x treatment interaction was not significant. Means and mean ranks were separated by the Duncan's multiple range test when significant effects were detected ($\underline{P} < 0.05$) (Steele and Torrie 1980).

Effects of herbivory on standing crop were determined using a 2-tailed paired t-test to compare caged and uncaged standing crop and a unpaired t-test to compare uncaged and enclosed standing crop (SAS Institute 1985, 1987). When differences between uncaged and caged or enclosed plots were not significant ($\underline{P} < 0.05$), plots were combined for ANOVA.

RESULTS

Basal Area and Canopy Cover

Basal area was reduced by 61-80% on all harvested thinned and burned treatments ($P \leq 0.01$) (Table 1). After the initial treatment in 1984 and 1985, BA changed little and canopy cover changed only on CCSP treatments. Canopy cover increased significantly ($P = 0.002$) on CCSP as planted loblolly pine seedlings entered the sapling stage by 1990.

Species Composition, Density, and Cover

Pretreatment vegetation sampling in 1983 indicated higher ($P < 0.05$) percent cover of midstory trees in control and RRB replicates than on other treatment units (Table 2). Other descriptors of vegetation did not differ among units prior to application of treatments. The only significant differences found between control and RRB treatments in succeeding years were in percent cover of suppressed trees. Rough reduction burning reduced ($P < 0.05$) percent cover in that stratum by 1986-88 (Table 2).

Understory response varied after initial timber harvest and thinning of residual hardwoods. In 1984, species diversity increased, and evenness declined ($P < 0.05$) on all harvested and thinned treatments compared to the control and RRB treatments. The species evenness indices were responsive for shrubs only in 1984. Species richness of herbs and shrubs immediately after timber harvest was unchanged (Figs. 1 and 2).

In 1985 and 1986 after all burning and timber harvest treatments had been applied, species richness of herbaceous and shrub vegetation on treated areas were significantly ($P < 0.05$) higher than on untreated controls (Figs. 1 and 2).

Grass cover on treated areas was dominated by little bluestem, big bluestem, and panicums. The predominant forbs were horseweed (Conyza canadensis), white snakeroot (Eupatorium rugosum), and fireweed (Erechtities hieracifolia). Shrub response on harvested and burned treatments was composed of primarily winged sumac (Rhus copallina), dewberry (Rubus spp.), and post oak sprouts. Only legume and vine categories showed no difference in cover among treatments (Table 2).

In 1986, values of most vegetational characteristics of CCSP areas did not differ significantly from corrresponding values for areas that were harvested and burned (Table 2). However species composition and shrub species richness differed by treatment ($P < 0.05$) (Fig. 2). Panicums and little bluestem were respective grass dominants on CCSP and all the harvested, thinned and burned treatments. Crabgrass (Digitaria violescens) was a significant component of the grass response of the CCSP treatment and occurred infrequently on other treatments. Broomsedge bluestem (Andropogon virginianus) also occurred more frequently on CCSP treatments than on other treatments. Forb response was greatest during 1986 on the CCSP treated areas and was significantly higher for this treatment than for others ($P < 0.05$) (Table 2).

By 1988, percent cover of all plant groups, except vines, differed among treatments (Table 2). For herbaceous plants, species richness and evenness differed significantly among treatments. Species richness and diversity differed significantly among treatments for shrubs (Fig. 2). Timber harvest and prescribed fire decreased herbaceous species evenness but increased shrub and herb richness and shrub diversity (Figs. 1 and 2). Bluestems and panicums were dominant grasses on harvested and burned treatments. In the CCSP treatment areas, grasses were mainly comprised of panicums and to a lesser extent little bluestem. Broomsedge bluestem occurred more frequently on this treatment than others.

Dominant shrub species on harvested and burned sites included winged sumac, dewberry, post oak sprouts, tree sparkleberry, and winged elm (Ulmus alata). On the H-T treatment, sumac was not prevalent, but the above species and shortleaf pine seedlings and saplings were prominent. Dewberry, post oak, coralberry (Symphoricarpos orbiculatus), and loblolly pine were primary shrub constituents on CCSP treatments.

Standing Crop

Of 189 paired comparisons (9 treatments x 7 species groups x 3 years) of caged vs. uncaged plots only 2 were significantly different ($P < 0.05$). Eight other caged vs uncaged comparisons approached significance ($P < 0.10$), but in 4 of these, caged plots had lower standing crop of the respective category than uncaged pairs.

In 8 of 168 uncaged vs. enclosed comparisons (unpaired) (6 treatments x 7 species groups x 4 years), differences were detected ($\underline{P} < 0.05$), but 2 of these showed negative utilization. Ten other uncaged vs. enclosed comparisons approached significance ($\underline{P} < 0.10$), but in 6 of these, caged plots had lower standing crop of the respective category than enclosed plots.

Standing crop in caged or enclosed vs uncaged plots were similar in only 1 case. Differences (significant or near-significant) occurred more frequently on control (36%), HT2 (21%), HT (16%), and RRB (14%) treatments. The HT1 and HT3 were the only treatments that showed no differences in any species group in any year among paired or unpaired comparisons.

Grass standing crop averaged 35x greater ($\underline{P} < 0.05$) on HT1 than on control treatments (3200 vs 90 kg/ha) (Table 3). Little bluestem, big bluestem, and Indiangrass were dominant on all treatments, except the CCSP where broomsedge bluestem (A. virginianus) and crabgrass (Digitaria violescens) contributed to grass standing crop. Crabgrass diminished on CCSP as tallgrasses became prevalent by 1989. Grass standing crop on harvested and burned treatments increased in the year after a winter burn and then gradually declined as litter accumulated.

Panicum standing crop averaged across years was higher ($\underline{P} < 0.001$) on CCSP than other treatments except HT, HT4, and HT2 (Table 3). Differences among treatments were dependent on burn synchrony among treatments. In 1989 when HNT1, HT1, HT2, HT4, and RRB were burned panicum standing crop was not different ($\underline{P} > 0.05$) among treatments. Panicum standing crop on the CCSP was highest 3 years post harvest and then declined as tallgrasses and later canopy cover of planted pines increased. On harvested and burned treatments, standing crop of panicums declined the first growing season after a burn but increased in the second growing season.

Average sedge standing crop was increased with harvest and burning ($\underline{P} = 0.0001$) compared to unharvested treatments (Table 3). Harvested and burned treatments had similar sedge standing crop reguardless of burning regime. On the CCSP treatment sedge standing crop was greatest the fourth year after timber harvest.

Legumes were consistently higher ($\underline{P} < 0.05$) the first growing season after a burn on harvested treatments than controls (Table 3). More frequent burning intervals (annual or biennial) favored legume production. Forbs were variable in response by year. Clearcutting and summer site prep burns initially increased forb production and reduced tallgrasses. Tallgrasses and planted pines increased in percent cover; forb and legume production declined.

Standing crop of current annual growth of woody plants was not different ($\underline{P} < 0.05$) until 1989, the fifth growing season after timber harvest. Less frequent burning intervals favored woody plant production. On harvested and burned treatments the primary woody species were winged sumac (Rhus copallina), dewberry (Rubus spp.), and post oak sprouts. Winged sumac was never a major component on unburned treatments.

Total standing crop was consistantly higher ($P < 0.05$) on HT1, HT2, HT3, and HT4 than control and RRB treatments (Table 3). September total standing crop was up to 25x greater on harvested and burned (retrogressed) vs control treatments (4,500 vs 190 kg/ha). Rough reduction and later hazard reduction burns increased forage production by only a factor of 1.5 (390 vs 160 kg/ha for all years). Total standing crop was related to canopy cover ($r = -0.559$, $P = 0.0001$, n = 840), litter accumulation ($r = -0.355$, $P = 0.0001$, n = 1,100), and months since burned ($r = -0.359$, $P = 0.0001$, n = 1,140). In the year following a burn, production increased but declined in subsequent years. Grasses were the primary component in harvested and burned treatments except for the HT4 treatment where current annual woody growth was important in latter years.

DISCUSSION

Some plant species increased on retrogressed sites and others decreased from pretreatment levels. Species evenness was highest on the control and pretreatment, indicating that herbaceous species were equally abundant. Site perturbation, caused some plant species, particularly tallgrasses, to become more abundant relative to other species.

Community progression on harvested and burned sites was similar to that reported by Hebb (1971) for clearcutting. Successional stages after harvest were: (1) disturbed site with pretreatment understory ground cover; (2) profusion of grasses and annual forbs; (3) increase in perennial forbs, shrubs and grasses, and decrease in annuals; and (4) increases in shrubs and grasses and declines in forbs in the absence of periodic prescribed fire.

Chronosequences of vegetation on retrogressed sites subjected to fire at varying frequencies was similar to response of burned mesic tallgrass prairie (Anderson and Brown 1986). Longer fire intervals allowed woody species to increase (Bragg and Hulbert 1976, Petranka and McPherson 1979). Summer site-prep burns and ripping associated with the CCSP treatment caused a lag in plant community progression. Species composition was different under this treatment regime with forbs dominating the year following the summer site prep burn. As grasses increased, panicums were the primary dominant followed by little bluestem. The broomsedge bluestem component was higher on the CCSP treatment than others. The summer site prep burn apparently set back bluestems and allowed cool season grasses (panicums) and sedges to increase. Shrub species richness and percent cover were slower to increase on CCSP than retrogressed and winter burned sites (Table 2 and Fig. 2).

Rough-reduction burns caused smaller increases in herbaceous cover and species richness than they have in other cases (Oosting 1944, Lewis and Harshbarger 1976). Herbaceous species will increase as repeated fire eliminates smaller diameter midstory and overstory hardwoods and as pines assume dominance (Lewis and Harshbarger 1976).

Timber harvest and fire increased forage production on oak-pine sites in the Ouachita Mountains. Either sampling intensity was not sufficient to measure herbivory or the effects from herbivory were negligible. Previous work on the Pushmataha WMA before initiation of a timber management program suggested that similar deer densities caused a browse line, so deer densities appeared high for these sites.

The relationship between forage production and overstory is curvilinear with forage production negatively related to presence of overstory (e.g., Jameson 1967, Wolters 1973, Blair and Enghart 1976, Fenwood et al. 1984). Also fire serves to reduce standing dead herbaceous vegetation and herbaceous litter accumulation that suppress herbaceous vegetation growth (Hulbert 1988). On harvested and burned sites, growth initiation is earlier and production increases as a result of increased nitrogen availability, warmer soil temperatures, and increased surface light intensity (Peet et al. 1975, Knapp 1984, Hulbert 1988, Svejcar and Browning 1988).

My results cooroborate other studies that found increased production with reduction of overstory (Stransky and Halls 1978, Fenwood et al. 1984). The CCSP treatment had a similar response and followed the successional progression described by Hebb (1971). Total standing crop averaged across years on HNT1, HT2, HT3, and HT4 was not significantly different from CCSP during the course of this study. These treatments had higher total standing crop than HT and lower total standing crop than HT1. However, production was declining on the CCSP and should continue to decline with canopy closure. Although their value for forage production may diminish as canopy cover increases, the HT and CCSP are important because they provide escape and screening cover for deer (Masters 1991). The RRB treatment demonstrated a nonsignificant increase in production of approximately the same magnitude described by Lay (1967).

Grass production increased by a magnitude relative to other species groups on harvested and burned treatments and for a short period on the CCSP treatment. Grasses and panicums are important during late winter and early spring months because they provide forage high in digestibility and in critical nutrients during a period of nutritional stress (Short 1971, Lewis et al. 1982). However, woody browse is the major constituent of deer diets, under heavy cattle stocking, in southeastern Oklahoma in all months except May (Jenks et. al 1990). Forbs are important in May and constitute up to 48% of deer diets in this month (Jenks et al. 1990). When hard mast is available in fall and winter, it comprises the major portion of deer diets in the Ouachita Mountains (Fenwood et al. 1985).

MANAGEMENT IMPLICATIONS

Poor habitat quality has been implicated as a major limiting factor for deer on oak-pine sites (Fenwood et al. 1984, Segelquist and Pennington 1968). Management of habitats by conventional timber harvest, selective thinning of hardwoods, and use of prescribed fire to maintain retrogressed sites improves forage production and plant diversity without the costs associated with traditional supplemental forage openings (food plots). Less frequent burning or no burning allowed woody browse species preferred by deer to increase on retrogressed sites (Landers 1987). A prescribed burning rotation at 2- to 4-year intervals on retrogressed sites will allow growth of important deer foods. Winter prescribed fire at 1- or 2-year intervals favored legumes.

Deer forage selectively and have diverse diets (Vangilder et al. 1982, Jenks et al. 1990, Masters 1991). The HT4, HT3, HT, and CCSP treatments maximized production and richness of those plant groups important to deer.

Benefits from CCSP and HT treatments begin to decline in the sixth growing season following timber harvest as canopy closure occurs. Stem density and percent cover of woody species, particularly post oaks and winged sumac, have increased over time on HT3 and HT4 treatments. As winged sumac increases in prevalence, fuel loads will decline because of the phytotoxic effects on growth and germination of other plants (Petranka and McPherson 1979, Smith 1990). When herbaceous plants are reduced, fuel loads will decline and periodic burns will be less successful in killing small diameter hardwoods. This indicates that 3- or 4-year burn intervals will not be adequate to halt secondary succession or maintain higher levels of forage production.

One management option is to increase winter burn frequency for a period of years after hardwood or pine stem density and canopy cover begins to cause decreases in forage production (Kucera and Koelling 1964). Summer burns should be explored as a possible means of maintaining the open nature of these sites because growing season burns are more successful in controlling small diameter hardwoods (Ferguson 1961, Brender and Copper 1968, Grano 1970). The long-term effects of prescribed fire on vegetation response and site quality in mountainous terrain should also be evaluated. I recommend retaining mature oak-pine stands for acorn production and habitat for other species within a mosaic of HT4, HT3, HT and CCSP treated sites. Clearcuts should be regenerated as mixed oak-pine stands rather than pure pine stands to retain hardwoods for mast production. Site treatments should be scheduled in different years to provide optimal forage for deer seasonally and between years.

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Table 1. Total basal area (m^2/ha) of stems >5 cm dbh and % canopy cover after summer 1984 timber harvest and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1983 to 1990.[a]

	Treatment[bc]																	
	CONTROL		RRB		HNT1		HT		HT4		HT3		HT2		HT1		CCSP	
Parameter, year	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Total Basal Area																		
1983	27	2	26	1	.	.	25	.	23	1	26	2	26	1	.	.	24	1
1984	26a	2	25a	1	.	.	9b	.	9b	2	5b	0	8b	2	.	.	9b	1
1985	27a	2	25a	1	.	.	7ab	.	4bc	2	3bc	1	5bc	1	.	.	1c	1
1986	27a	2	25ab	1	9bc	2	8bc	.	3d	1	3de	1	5cd	1	3de	0	0e	0
1987	27a	2	24ab	1	9bc	2	8bc	.	3cd	1	3d	1	4cd	1	2de	0	0e	0
1988	27a	2	24ab	1	8bc	2	8bc	.	3cd	1	3de	1	4cd	1	2de	0	0e	0
1989	27a	2	24a	1	8ab	2	9ab	.	3bc	1	3c	1	4bc	1	2c	0	2c	1
1990	27a	2	24a	1	8ab	2	9ab	.	3bc	1	3c	1	4bc	1	2c	0	4bc	1
Percent Canopy Cover																		
1985	77a	2	67ab	4	.	.	23abc	.	7cd	4	6cd	4	14bcd	6	.	.	4d	4
1986	82a	1	73ab	6	30bcd	8	32abc	.	9def	5	7def	4	15cde	7	6ef	6	0f	0
1987	86a	3	79ab	4	31bc	8	33abc	.	12cd	6	11cd	7	19cd	9	5de	4	0e	0
1988	85a	3	84a	4	35ab	7	29bc	.	11cde	6	7de	4	19bcd	8	8de	6	0e	0
1989	85a	1	80a	5	31ab	6	39ab	.	11cd	5	9cd	5	17bc	5	8cd	5	2d	1
1990	87a	2	78ab	4	31bcd	6	45abc	.	12de	6	10de	7	19cde	7	8e	5	14de	0

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[a] Row means followed by the same letter within category were not significantly different at the 0.01 level, based on the Kruskal-Wallis nonparametric test. Ranks of treatment means were separated using Duncans multiple range test. Means without letters were not different.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; CCSP=clearcut, summer site prep burn (1985).

[c] Columns with . represent missing data points or in the case of SE only 1 replication was included for that treatment.

Table 2. Average percent cover for major species groups, 1983-88.

VEGETATIVE GROUP	TREATMENT^b								
	CONT	RRB	HNT1	HT	HT4	HT3	HT2	HT1	CCSP
Grasses									
1983	3	6	.	7	12	8	4	.	7
1984	9	10	.	14	14	8	5	.	7
1985	7b	6b	.	23a	22a	20a	14ab	.	5b
1986	7b	8b	30a	20ab	29a	27a	20ab	28a	17ab
1987	4c	7c	34a	19b	25ab	21b	21b	35a	25ab
1988	3d	6d	31ab	11cd	25ab	32ab	20cb	37a	28ab
Forbs									
1983	2	2	.	1	1	tr	2	.	3
1984	5	6	.	7	1	1	2	.	2
1985	2	2	.	25a	17b	11b	14b	.	3
1986	3c	5bc	13bc	16bc	18b	17b	19b	18b	37a
1987	1	2	11abc	10bc	9bc	7c	17ab	13abc	20a
1988	1b	2b	7ab	4b	5b	7ab	8ab	6ab	13a
Legumes									
1983	1	1	.	1	1	1	2	.	1
1984	2	2	.	<1	1	1	2	.	2
1985	1	1	.	2	4	3	6	.	1
1986	2	2	4	4	5	6	7	9	3
1987	1b	1b	6ab	8a	4ab	3ab	9a	5ab	4ab
1988	1c	1c	5abc	2bc	3abc	5abc	9a	8ab	5abc
Vines									
1983	1	<1	.	<1	<1	1	<1	.	<1
1984	1	1	.	<1	<1	1	1	.	<1
1985	1	<1	.	0	<1	1	1	.	<1
1986	2	<1	<1	<1	1	1	1	1	<1
1987	1	<1	<1	<1	1	3a	1	1	<1
1988	1	<1	<1	<1	1	1	<1	1	<1

Table 2. Continued.[a]

VEGETATIVE GROUP	TREATMENT[b]								
	CONT	RRB	HNT1	HT	HT4	HT3	HT2	HT1	CCSP
Shrub 0-1 m									
1983	6	13	.	6	10	11	7	.	6
1984	10	24	.	16	11	8	9	.	7
1985	7	9	.	20	13	17	19	.	4
1986	9	19	10	27	20	14	19	14	9
1987	6c	14abc	10bc	29a	21abc	24ab	22abc	8bc	13abc
1988	7c	15abc	10bc	29a	26ab	28a	23ab	10bc	17abc
Shrub 1-3 m									
1983	1	3	.	0	1	1	<1	.	2
1984	3	5	.	1	2	<1	4	.	1
1985	5a	3ab	.	1b	<1b	0b	0b	.	<1b
1986	6a	1bc	1bc	3bc	2bc	2bc	4ab	<1bc	0c
1987	4	2	2	12	6	5	3	2	3
1988	4b	2b	2b	24a	11b	2b	9b	1b	12b
Tree Mid[c]									
1983	14a	10a	.	4b	2b	1b	4b	.	4b
1984	23a	24a	.	9ab	1b	7b	3b	.	9ab
1985	24a	17a	.	1b	2b	0b	2b	.	<1b
1986	22a	10b	3bc	4bc	2c	0c	1c	0c	0c
1987	22a	10b	4c	2c	<1c	2c	1c	0c	0c
1988	16a	9bc	2c	12ab	1c	0c	<1c	0c	0c

Table 2. Continued.[a]

[a] Row means with the same letter are not significantly different ($\underline{P} < 0.05$).

[b] CONT = control, no treatment; RRB = rough reduction burn in winter, at 4 year intervals; HNT1 = harvest pine timber, no thinning of hardwoods, winter prescribed burn at 1 year intervals; HT = harvest pine timber, thin hardwoods; HT4 = harvest pine timber, thin hardwoods, winter prescribed burn at 4 year intervals; HT3 = harvest pine timber, thin hardwoods, winter prescribed burn at 3 year intervals; HT2 = harvest pine timber, thin hardwoods, winter prescribed burn at 2 year intervals; HT1 = harvest pine timber, thin hardwoods, winter prescribed burn at 1 year intervals; CCSP = clearcut, windrow logging slash, summer site prep burn, rip.

[c] TREE MID = Suppressed trees > 3 m height in the midstory, but not extending into the upper canopy layer.

Table 3. Early September standing crop (kg/ha) in response to 1984 timber harvest and periodic prescribed fire from 1986 to 1990.[a]

Plant group, treatment[bc]	Year											
	1986		1987		1988		1989		1990		All Years	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Grass												
CONT	.	.	105d	80	61e	18	108b	64	104d	21	92d	23
RRB	.	.	132d	47	188de	92	326b	162	248d	201	246cd	72
HNT1	.	.	2396ab	875	1499abc	598	1985ab	765	923cd	170	1701b	326
HT	.	.	732cd	.	609cde	.	1238ab	.	550cd	.	538c	113
HT4	.	.	1452bcd	423	1132bcd	384	2970a	1192	1972b	454	2036b	394
HT3	.	.	1817bc	367	1946ab	578	3037a	891	883cd	541	1780b	458
HT2	.	.	1202bcd	203	1258abc	200	2915a	459	1444bc	262	1593b	221
HT1	.	.	3572a	500	2458a	242	3257a	253	3660a	284	3237a	220
CCSP	457	86	1007bcd	57	1609ab	184	2977a	217	868cd	296	1554b	266
Panicum												
CONT	.	.	25c	8	8c	3	7	3	8b	4	14f	5
RRB	.	.	30c	19	23bc	4	19	5	29ab	10	25ef	5
HNT1	.	.	57c	24	126abc	76	171	108	108ab	76	116cd	35
HT	.	.	236bc	.	212ab	.	111	.	82ab	.	180abc	57
HT4	.	.	366ab	64	195ab	20	112	65	230a	38	212ab	35
HT3	.	.	259bc	88	235ab	81	93	36	113ab	11	160bcd	37
HT2	.	.	379ab	102	439a	126	238	101	247a	107	226ab	51
HT1	.	.	230bc	202	48bc	32	59	49	32ab	4	92de	50
CCSP	290	119	578a	79	400a	91	364	180	164ab	152	399a	67
Sedge												
CONT	.	.	3b	1	7c	4	5	1	5b	3	7c	2
RRB	.	.	22b	10	2c	2	5	5	12b	6	10c	4
HNT1	.	.	38b	10	24abc	16	121	44	43b	20	57ab	16
HT	.	.	4b	.	17abc	.	72	.	28b	.	42b	25
HT4	.	.	412a	178	134ab	43	67	21	107ab	53	123ab	40
HT3	.	.	13b	0	143ab	129	88	88	87b	41	102ab	51
HT2	.	.	137b	70	161a	44	166	48	77b	17	151a	32
HT1	.	.	26b	26	123ab	13	203	93	196a	20	137a	33
CCSP	63	6	17b	9	263ab	206	37	3	38b	18	99ab	64

Table 3. Continued.[a]

Plant group, treatment[bc]	Year											
	1986		1987		1988		1989		1990		All Years	
	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Legume												
CONT	.	.	4c	0	8c	4	6c	2	9	1	7c	1
RRB	.	.	12c	9	11bc	4	31bc	17	22	15	12c	3
HNT1	.	.	28bc	11	70a	20	100ab	34	50	18	62ab	12
HT	.	.	1c	.	28abc	.	35bc	.	54	.	8c	4
HT4	.	.	67abc	37	12bc	3	197a	87	46	17	64b	20
HT3	.	.	139a	25	75ab	15	211a	32	62	10	75ab	30
HT2	.	.	109a	16	125a	6	207a	34	55	22	119a	24
HT1	.	.	67abc	27	212a	132	204a	122	100	72	146a	44
CCSP	48	14	104ab	27	94a	44	54abc	16	10	2	72ab	18
Forbs												
CONT	.	.	11c	6	6c	4	11c	3	12	4	10d	2
RRB	.	.	20bc	10	14bc	11	21bc	5	34	11	17cd	4
HNT1	.	.	349ab	192	71abc	10	95ab	32	195	72	178a	55
HT	.	.	151abc	.	13bc	.	137ab	.	14	.	105ab	51
HT4	.	.	121abc	47	52abc	22	67abc	28	39	6	39bc	7
HT3	.	.	220abc	203	164a	8	218ab	175	17	5	125ab	51
HT2	.	.	302ab	127	85ab	30	318a	139	81	34	175a	60
HT1	.	.	144abc	62	358a	316	176ab	122	88	56	191a	76
CCSP	1150	124	1001a	820	192a	67	145abc	121	90	82	405a	250
Woody												
CONT	.	.	18	4	52	15	18c	5	18b	5	28d	6
RRB	.	.	110	44	35	26	125bc	49	136b	45	77cd	17
HNT1	.	.	379	204	138	73	242abc	98	77b	43	209bc	62
HT	.	.	245	.	281	.	168bc	.	344b	.	277ab	45
HT4	.	.	472	225	220	149	973a	32	880a	187	526ab	131
HT3	.	.	885	1	503	5	328abc	98	218b	26	606a	137
HT2	.	.	408	234	288	159	643ab	312	307b	106	458ab	136
HT1	.	.	264	88	296	294	561ab	9	158b	146	320abc	85
CCSP	187	140	155	103	633	219	226bc	222	560ab	480	394abc	123

Table 3. Continued.[a]

Plant group, treatment[bc]	1986 $\bar{x}$	1986 SE	1987 $\bar{x}$	1987 SE	1988 $\bar{x}$	1988 SE	1989 $\bar{x}$	1989 SE	1990 $\bar{x}$	1990 SE	All Years $\bar{x}$	All Years SE
Total												
CONT	.	.	196c	60	143d	31	188b	38	156e	15	157d	22
RRB	.	.	336c	116	272cd	106	531b	217	482de	252	387d	81
HNT1	.	.	3246ab	1057	1927abc	672	2715ab	858	1397cd	123	2321b	389
HT	.	.	1369bc	.	1161bcd	.	1762ab	.	1358cd	.	1150c	226
HT4	.	.	2891ab	234	1745abc	494	4386a	1269	3274ab	245	3000b	421
HT3	.	.	3333ab	102	3066a	531	3975a	1257	1380cd	458	2847b	497
HT2	.	.	2537ab	422	2357ab	127	4487a	349	1948bc	241	2738b	358
HT1	.	.	4303a	449	3495a	965	4459a	531	4234a	574	4123a	286
CCSP	2195	263	2939ab	829	3191a	289	3803a	759	1730bc	30	2946b	340

[a] Column means followed by the same letter within plant group were not significantly different at the 0.05 level. Means without letters were not different.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually (1985-90); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually (1985-90); CCSP=clearcut, summer site prep burn (1985).

[c] Columns with . represent missing data points or in the case of SE only 1 replication was incuded for that treatment.

Fig. 1. Mean species richness of herbaceous plants 1983-88. For clarity of presentation some burned treatments were not depicted. Those not depicted were intermediate in response.

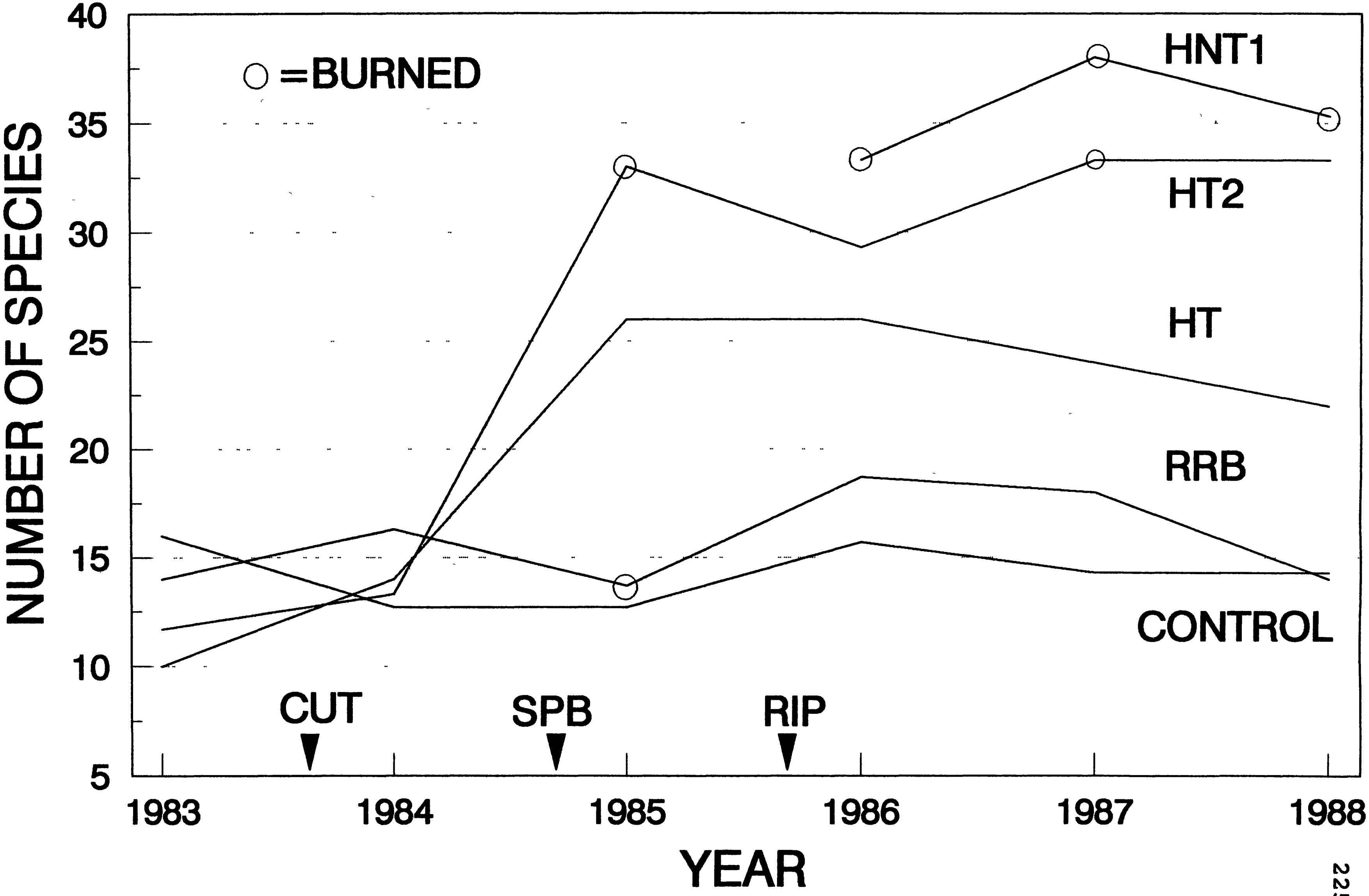
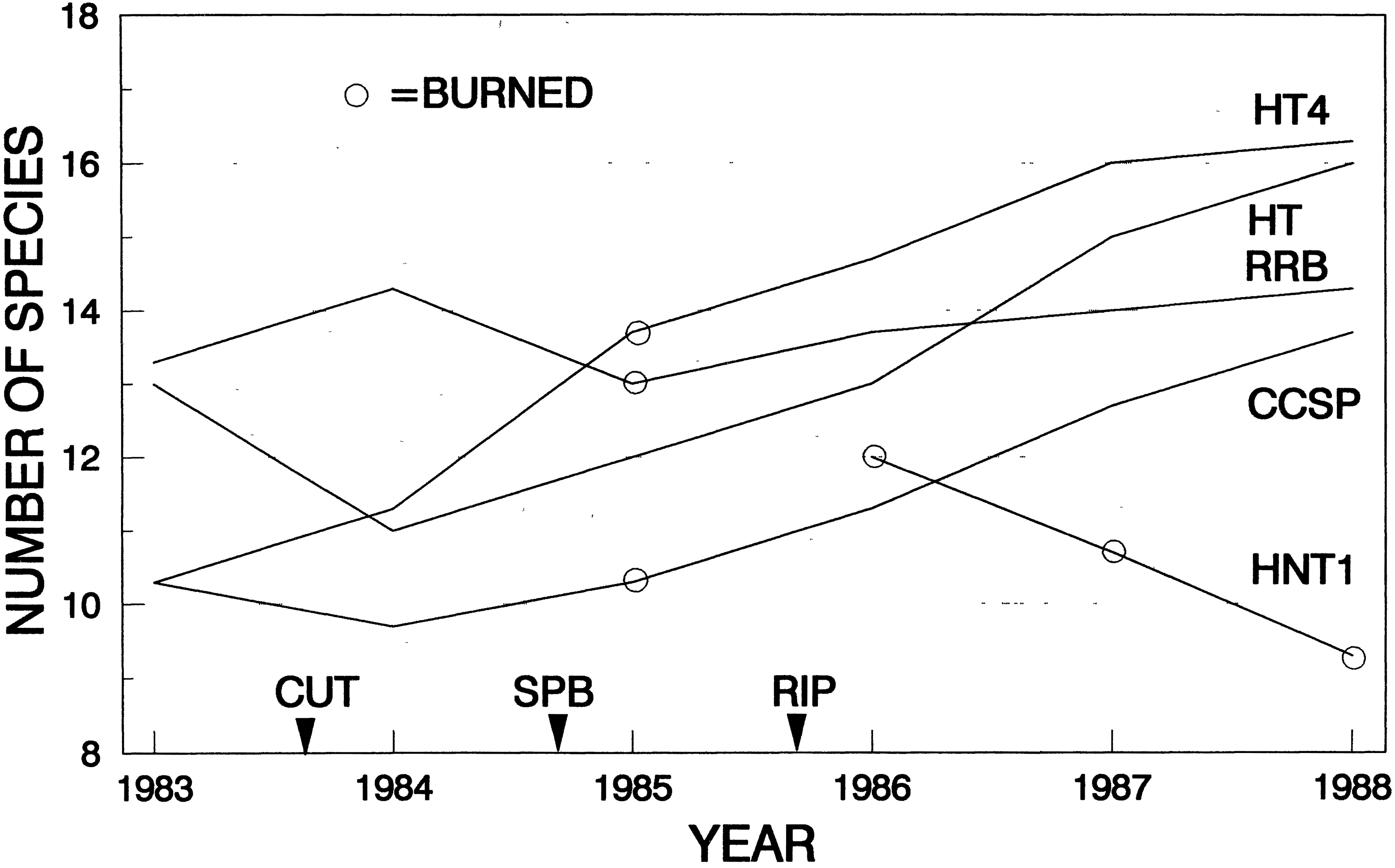

○ =BURNED
HNT1
HT2
HT
RRB
CONTROL
CUT
SPB
RIP
NUMBER OF SPECIES
YEAR
40
35
30
25
20
15
10
5
1983
1984
1985
1986
1987
1988

Fig. 2. Mean species richness of shrubs 1983-88. For clarity of presentation some burned treatments were not depicted. Those not depicted were intermediate in response.



○ =BURNED
NUMBER OF SPECIES
18
16
14
12
10
8
HT4
HT
RRB
CCSP
HNT1
CUT
SPB
RIP
1983
1984
1985
1986
1987
1988
YEAR

CHAPTER VIII

WILDLIFE USE OF OAK-PINE HABITATS ALTERED BY FIRE AND TIMBER HARVEST

Abstract: Cervid frequency of browse use and pellet-group counts of white-tailed deer (*Odocoileus virginanus*), elk (*Cervus elaphus*), and cottontail rabbit (*Sylvilagus floridanus*) were used to determine use of oak (*Quercus* spp.) - pine (*Pinus* spp.) sites subjected to a range of timber harvest and prescribed fire regimes. Deer, elk, and rabbit pellet groups fit negative binomial distributions. All distributions were characterized by low (<2) values of *k*. Sites subjected to timber harvest were used to a greater extent than forested sites. Use of a treatment was unrelated to burn frequency except immediately after a burn. Use of a given experimental unit by cervids was not independent of surrounding treatments because of small unit size (1.2- to 1.6-ha). Treatment use by rabbits was apparently unaffected by unit size. Browse utilization frequency and pellet-group counts measured different aspects of habitat use. Ranks of browse utilization frequency measured foraging frequency on a given treatment. Use related to time spent foraging on a given unit was inadequately measured by pellet-group counts.

J. WILDL. MANAGE. 00(0):000-000

Key words: clearcut, cottontail rabbit, elk, habitat manipulation, Oklahoma, Ouachita Mountains, pellet-group, prescribed fire, white-tailed deer.

The Oklahoma Department of Wildlife Conservation established the Pushmataha Forest Habitat Research Area (FHRA) in 1982 to evaluate forage response to a range of timber harvest and prescribed fire regimes. Forest openings created through commercial pine timber harvest and maintained in early secondary succession with prescribed fire were used to provide additional forage in years of mast shortfall. Induced site retrogression was compared with traditional forest management practices of regeneration clearcutting and rough reduction burns. Evaluation of this technique in a research setting offered the opportunity to assess use of varied habitat treatments by deer, elk, and rabbit. Previously established supplemental forage openings (food plots) located peripheral to the FHRA offered further comparison.

A basic problem in determining the utility of a wildlife habitat management practice is obtaining data about habitat use, preference, and response to habitat change by wild animal populations (Rollins et al. 1988). I used frequency of browse use by cervids and deer, elk, and rabbit pellet-group counts as indicators of treatment preference.

I compared browse frequency data from permanent plots to combined cervid pellet-group data. Browse use data also were used to determine relative preference of plant species.

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STUDY AREA

The 29.1-ha study area was located within the FHRA on Pushmataha Wildlife Management Area (WMA), Pushmataha County, Oklahoma (34° 32' N, 95° 21' W). The Pushmataha WMA lies in mountainous terrain along the western edge of the Ouachita Highland Province.

The Pushmataha WMA was initially established as a deer refuge in the 1940's. The Pushmataha WMA supported an average 540 ± 40 (SE) deer and 10 ± 1 elk (1983-1989) (Masters 1991a). Rabbit populations have not been monitored.

Cultural Treatments

During summer 1984, merchantable pine timber was harvested in scheduled treatments, and hardwoods selectively thinned by single stem injection using 2-4 D to approximately 9 m^2/ha basal area (BA). Prescribed burns using strip-head fires were conducted in winter 1985 and in succeeding years at appropriate intervals.

Beginning in summer 1984, 9 treatments were applied to 23 1.2- to 1.6-ha units in a completely randomized experimental design. Cultural treatments and number of replications (n) are summarized as follows:

(1) no treatment (Control) (n = 3);

(2) rough reduction winter prescribed burn - 4-year interval, 1985, 1989 (RRB) (n = 3);

(3) harvest pine timber only, winter prescribed burn, 1-year interval (HNT1) (n = 3);

(4) harvest pine timber, thin hardwoods, no burn (natural regeneration to a mixed stand) (HT) (n = 1);

(5) harvest pine timber, thin hardwoods, winter prescribed burn - 4-year interval, 1985, 1989 (HT4) (n = 3);

(6) harvest pine timber, thin hardwoods, winter prescribed burn - 3-year interval, 1985 and 1988 (HT3) (n = 2);

(7) harvest pine timber, thin hardwoods, winter prescribed burn - 2-year interval, 1985, 1987, 1989 (HT2) (n = 3); and

(8) harvest pine timber, thin hardwoods, winter prescribed burn - 1-year interval (HT1) (n = 2).

(9) clearcut and summer site prep burn - 1985 (CCSP)

($\underline{n}$ = 3);

Peripheral supplemental forage openings (1.2 to 4 ha) (food plots) were included to compare use of a traditional wildlife management technique with those under development. According to Steele and Torrie (1980:126, 139) inclusion of this additional treatment is valid in a completely randomized experimental design. The food plot treatment is summarized as follows:

(10) cultivated fertilized food plot, planted to fescue, rye, vetch and Korean lespedeza; plots were mowed each fall and disced periodically (FP) ($\underline{n}$ = 3).

Post-treatment openings were dominated by tallgrasses and included big bluestem (Andropogon gerardii), little bluestem (Schizachyrium scoparium), and to a lesser extent, Indiangrass (Sorghastrum nutans). Winged sumac (Rhus copallina) and dewberry (Rubus spp.) were predominant shrub species. The overstory was comprised of sparse (2 to 9 m^2/ha BA stems >5 cm at 1.4 m height) post oak (Q. stellata) and blackjack oak (Q. marilandica) (Masters 1991a,b). The CCSP treatment was planted to loblolly pine (P. taeda) in 1986.

Unharvested treatments were dominated by post oak, shortleaf pine (P. echinata), blackjack oak, and mockernut hickory (Carya tomentosa). Common woody understory species included tree sparkleberry (Vaccinium arboreum), poison ivy

(Toxicodendron radicans), and greenbriar (Smilax spp.). Predominant herbaceous plants were little bluestem, panicums (Panicum spp., Dicanthelium spp.), and sedges (Carex spp.). The study area and application of cultural treatments were further described by Masters (1991a,b).

METHODS

Browse Use

Use of herbaceous and woody vegetation was sampled using nested quadrats (1-m x 1-m and 4-m x 4-m) (Oosting 1956:47-50, 62). On each treatment unit, 10 permanent plots were established at 19.8-m intervals on 2 randomly located lines perpendicular to the contour. In order to avoid bias caused by influences from adjacent treatment units, I sampled $\geq$19.8 m from any edge (Oosting 1956, Mueller-Dombois and Ellenberg 1974). Data collected included species composition, density, frequency, and utilization. A modification of Krueger's (1972) preference index (RP1) combined across years (1983 to 1988) and treatments was used to rank preference of plant species used by deer and elk.

Utilization was categorized based on proportion of current annual growth (CAG) browsed. The categories were none, trace (<25% CAG browsed), moderate (25-50% CAG browsed), and heavy (>50% CAG browsed). Browse use determinations were conducted in September and October of each year because this was a critical period of the year for deer (Fenwood et al. 1984). A baseline survey was conducted in 1983.

Pellet-group Counts

Pellet-group counts have been used to determine rabbit (McKee 1972) and cervid habitat use (Loft and Kie 1988) but have received criticism (Neff 1968, Collins and Urness 1981). Criticism has stemmed from inadequate testing of the technique, biases inherent in sampling design and methodology (Neff 1968), erroneous assumptions as to what the counts mean (Collins and Urness 1981), and inappropriate statistical analysis (Bowden et al. 1969, Leopold et al. 1984, Loft and Kie 1988).

Pellet-groups may be random or non-random in distribution depending on habitat conditions and behavior of the animal (McConnell and Smith 1970). Frequency distribution is important in order to determine appropriate data transformations and statistical procedures (Bowden et al. 1969, Stormer et al. 1977, Leopold et al. 1984, Loft and Kie 1988). White-tailed deer, mule deer (Odocoileus hemionus), and elk pellet-group distributions were previously fitted to the negative binomial distribution (Bowden et al. 1969, McConnell and Smith 1970, Stormer et al. 1977). Frequency distributions of cottontail rabbit pellet-groups have not been fitted to theoretical distributions.

Pellet-group counts for white-tailed deer, elk, and cottontail rabbit were made using randomly located parallel transects in each experimental unit (_n_ = 26). Lines were 100 x 1 m (100 m^2) and located $\geq$19.8 m from any experimental unit edge. Transects were randomized each sampling period and pellet-group data were collected in May (_n_ = 26), September (_n_ = 55) and December (_n_ = 52) 1988, and in March (_n_ = 46) and April (_n_ = 61) 1989 (_n_ = total number of transects/sampling period). Sampling dates were chosen to determine possible seasonal shifts in use (May, Sep, Dec, and Mar) and response to burning treatment application (May and Apr).

All deer, elk, and rabbit fecal pellet groups within a transect were counted and recorded. A pellet group was defined as >5 pellets in a pile or trail. Pellet groups that occurred on a transect boundary were counted if >5 pellets were within the transect boundary (Kinningham et al. 1980). Pellets that exhibited charring from burn treatments were excluded because they often persisted for >1-year.

Experimental units were sampled within a 2-week period, but not all treatments were sampled in September 1988, March 1989, and April 1989. The FP treatment was the only treatment not sampled September 1988. Some experimental units were not sampled because rainfall >3 cm occurred on a single day during the sampling period and affected counts (Wallmo et al. 1962).

Temporary rather than permanent transects were used because randomization was necessary to meet statistical assumptions (White and Eberhardt 1980). Temporary plots are cost effective because plots were not cleared before counts (Freddy and Bowden 1983). Permanent plots have often been used because of pellet group persistence (Robinette et al. 1958), but where pellet groups can be accurately aged temporary plots can provide similar estimates (Freddy and Bowden 1983). In the southeastern U.S., deer fecal groups do not persist for long periods of time (Kinningham et al. 1980). A single rain can erode deer (Jenks et al. 1990b) and elk pellet groups (pers. observ.) in Oklahoma. Rabbit pellet groups may persist for longer periods. Persistence is related to type of food utilized, temperature, and weather. No definitive method of aging rabbit pellet-groups has been reported (Cochran and Stains 1961). However in warm climate with high rainfall and high dung beetle activity, persistence may not have such a confounding effect.

Cottontail rabbit pellet-group counts have not been evaluated as an index of habitat use or response to habitat change. Compared to deer and elk, rabbits have limited home range ($\simeq$2 ha), high reproductive rates, and high rates of dispersal (Chapman et al. 1982). Given the randomization and availability of all treatment types, rabbits should exhibit some treatment preference.

Analysis

Browse utilization frequency for all quadrats within an experimental unit (replication) was summed and analyzed by the Kruskal-Wallis nonparametric procedure (SAS Institute 1985). Mean ranks were separated by Duncan's multiple range test (Steele and Torrie 1980).

Pellet-group means were tested for homogeneity of variance using Levene's test (Snedecor and Cochran 1980). Pellet count frequency distributions were compared with Poisson and negative binomial distributions with a chi-square test (goodness-of-fit) and subsequently transformed for analysis as a negative binomial distribution (Ludwig and Reynolds 1988). Data were pooled in the tails of the frequency distribution for minimum expected frequency values of 1 and 3 (White and Eberhardt 1980, Ludwig and Reynolds 1988). Analysis of variance was used to compare pellet-groups among treatments. When differences were significant ($P < 0.05$), means were separated with Duncan's multiple range test (SAS Institute 1985, 1987). Pellet-group data were compared with utilization frequency data using the Spearman ranked correlation procedure.

Exploratory analysis was conducted on September pellet-group data using PROC RSQUARE in SAS to determine if variation in site treatment, habitat structure, and composition explained variation in pellet-groups (SAS Institute, 1985, 1987). Independent variables entered as subsets in regression analysis were: total basal area; hardwood basal area; pine basal area; percent overstory canopy cover; stem density and percent cover of shrubs and trees <1 m, 1-3 m; time since burned; number of times burned; September standing crop (kg/ha) of sedge, legumes, forbs, panicums, grass, woody current annual growth; total standing crop; and percent cover and density of standing crop categories (Masters 1991*a*). The best model was determined using plots of Mallows C_p statistic as an unbiased parameter estimator, where C_p was a measure of the total squared error (Mallows 1964).

RESULTS

Browse Preference

Cervids utilized 74 species of plants and 17 plant groups identified to genera. Forbs of 31 species, and additional plants identified only as members of 7 genera were browsed. Thirteen species of legumes and additional legumes identified to 1 genus (*Desmodium* spp.) were used. Utilization occurred on 29 species and an additional 7 genera of woody browse. Grass-likes utilized included panicums, sedges, and little bluestem. Rankings of relative preference revealed that woody browse was used more than forbs (Table 1).

Browse utilization did not differ among units prior to application of treatments (Masters 1991*b*). Abundance of preferred forbs (Table 1) increased ($P < 0.05$) after timber harvest and prescribed fire then declined as grass cover increased (Fig. 1) (Masters 1991*b*). Preferred browse increased ($P < 0.05$) in all except RRB, control and annual burned treatments (Fig. 2). Percent cover of preferred browse in the annual burned treatments were not different from percent cover of preferred browse on the control or RRB sites. By 1988 legumes, preferred forbs and preferred browse responded differentially by treatment (Figs. 1-3). More frequent burning intervals (1-2 years) favored legumes and preferred forbs while less frequent intervals (3-4 years) or no burning favored shrubs (Figs. 2 and 3).

Treatment Use

Mean ranks of cervid frequency of browse utilization on replicates was significantly different ($P < 0.001$) among treatments (Table 2). Annual burn and RRB treatments had significantly lower frequency of utilization than other treatments.

Frequency distributions of deer, elk, and rabbit pellet-groups fit the negative binomial distribution ($P > 0.05$). Distributions for deer and elk differed from the Poisson distribution ($P < 0.05$). In May 1988, rabbit distributions fit the Poisson, but only when groups were pooled to a minimum value of 3. In that case, rabbit pellet-groups also fit a negative binomial distribution. Values of k in the negative binomial ranged from 0.921 to 1.381 for deer, 0.936 to 1.63 for elk, and 0.696 to 1.277 for rabbit.

Deer pellet-groups differed ($P = 0.012$) among treatments only in December counts but approached significance in May (P = 0.069) and September (P=0.091) (Table 3). The HT, HT1, and CCSP had higher December counts than control or RRB treatments. Typically, highest counts were found on HT, except for the FP treatment in March. Seasonal shifts in deer pellet-group counts were evident only on HT4 where counts were higher (P = 0.029) in December and March than other seasons. Seasonal use of HT1 was somewhat lower post-burn than other seasons (P = 0.069). September pellet-group occurrence was related to hardwood BA (HDWDBA), time since burned (MOSNBURN), percent cover of shrubs (SHRBCOV), and stem density of shrubs 1-3 m (SHRB1-3), and could be predicted by the following regression equation: DEERP = 1.589 - (0.111)HDWDBA + (0.002)MOSNBURN - (0.030)SHRBCOV - (0.090)SHRB1-3, (R^2 = 0.713, P = 0.0001).

Elk pellet-group counts were different (P < 0.05) among treatments in 3 seasons (Table 4). Elk pellet-groups counts were not different in September or in April following the burning of 6 out of 10 treatments in March. Seasonal shifts (P = 0.014) in elk groups were evident on HT3. Highest counts occurred 2 months post-burn in May and were similar in other seasons. September pellet-group occurrence was related to total BA (TOTBA), overstory canopy cover (CANPYCOV), percent cover of legumes (LEGUMCOV), and stem density of shrubs <1-m (SHRB<1) and could be predicted by the following regression equation: ELKP = 1.552 -

(0.147)TOTBA - (0.057)CANPYCOV - (0.074)LEGUMCOV - (0.009)SHRB<1, (R^2 = 0.589, $\underline{P}$ = 0.0021).

In all seasons, except September, rabbit pellet-group counts were different among treatments ($\underline{P} < 0.05$) (Table 5). The CCSP sites had consistently higher pellet counts than control and RRB sites. Harvested thinned and burned treatments were similar ($\underline{P} > 0.05$) in all seasons. The only apparent seasonal shift in counts was on the FP treatment ($\underline{P}$ = 0.05). September rabbit pellet-group occurrence was related to total BA (TOTBA), overstory canopy cover (CANPYCOV), number of times a unit had been burned (TIMESBRND), and percent cover of grasses (GRASSCOV) and could be predicted by the following regression equation: RABBITP = (-0.099) + (0.100)TOTBA - (0.026)CANPYCOV - (0.123)TIMESBRND + (0.031)GRASSCOV, (R^2 = 0.817, $\underline{P}$ = 0.0001).

Cervid fecal counts (deer and elk combined) were not correlated with browse utilization frequency ($\underline{P} > 0.05$). Both methods ranked habitat use differently (Table 2). Clearcut sites and HT (naturally regenerated sites) were preferred over RRB treatments seasonally in both methods (Table 2).

DISCUSSION

The primary values associated with controlled burning and overstory removal were increased availability of preferred food items for deer, elk, and rabbit. Winter prescribed fire at 1- or 2-year intervals favored legumes and other preferred forbs. Less frequent burning or no burning allowed woody browse species preferred by deer to increase on retrogressed sites (Landers 1987). A prescribed burning rotation at 2- to 4-year intervals on retrogressed sites will allow growth of preferred deer, elk, and rabbit foods.

Browse use by cervids on a treated area was probably related to percent cover of preferred browse and shrub species richness (Masters 1991b). Woody browse is the major component of deer diets in all months except May on areas subjected to heavy cattle grazing in southeastern Oklahoma (Jenks et al. 1990a). However when hard mast is available in fall and winter it comprises the major portion of deer diets (Fenwood et al. 1985). Presence of preferred forbs, panicums, and sedges on a treatment probably affected use because of the selective foraging nature of deer (Vangilder et al. 1982).

Screening, bedding, or escape cover may be important because deer were flushed frequently out of beds only in the HT and CCSP treatments. The shrub component on HT and CCSP treatments in the 0-1 m and 1-3 m categories was primarily pine saplings (Masters 1991b). Pines probably provided a more dense horizontal cover, but this parameter was not measured in this study. The presence of cover on HT and CCSP treatments may have increased use on these areas. Deer use increases on recent clearcuts but is limited to 100 m from cover on large clearcuts (Tomm et al. 1981). As pine stands develop in height on regeneration areas, deer use of the central portion of the stand will increase. All portions of large (128-276 ha) 4-5 year old pine stands were used in a southeast Oklahoma study (Melchoirs et al. 1985).

Pellet-group counts have compared favorably with other techniques to determine relative habitat use for white-tailed deer (Rollins et al. 1988), mule deer (Leopold et al. 1984, Loft and Kie 1988), and elk (Edge and Marcum 1989). Valid criticisms have been made of using pellet-group counts to assess habitat use because fecal group deposition often occurs soon after leaving bedding areas and while moving to feeding and from feeding areas (Collins and Urness 1981). Relative use is comparable, but percent use may not be valid because of differential deposition rates in response to feeding and bedding, and changes in deposition due to seasonal change in forage quality (Loft and Kie 1988).

Caution should be used in interpretation of habitat use from pellet-group data (Rowland et al. 1984), particularly when use is similar between habitat types (Loft and Kie 1988). Inferences of habitat preference assume that pellet-group deposition is a linear function of time spent within a given habitat type and that defecation rates were similar among types. This assumption may be incorrect (Collins and Urness 1981).

The parameter of k gives a measure of the degree of clumping (contagion) of the distribution and is useful for making inferences about pellet-group data (White and Eberhardt 1980). The low values of k reported here indicate distributions clumped according to site treatment by deer, elk, and rabbit, which suggested that treatments were used differentially. Lack of significant differences in most seasons by deer, despite markedly higher means suggest that use of a given experimental unit (replicate) may have been influenced by adjacent treatments or that sampling intensity was too low.

Harvested, thinned, and burned treatments consistently had higher deer, elk, and rabbit pellet counts than control and RRB treatments. Burning regime (1-, 2-, 3-, or 4-year intervals) did not affect deer and rabbit pellet-group counts on retrogressed sites. These treatments were not consistently different from FP treatments although higher means and significant differences in some seasons suggested that retrogressed sites were used to a greater extent. Deer and elk pellet-group data were consistent with observations by Raskevitz et al. (1991) that deer and elk use open areas to a greater extent than forested areas. Rabbit pellet-group counts were also higher on retrogressed sites than on forested sites and corroborate findings by McKee (1972). Higher pellet-group counts on harvested sites were related to more abundant and diverse forage production on these sites compared to control and RRB treatments (Masters 1991_a_).

Use of a given experimental unit by cervids was apparently not independent of surrounding treatments. Comparison with browse utilization frequency and general observations indicated that higher pellet counts of deer and elk were found on treatment units where deer and elk bedded. Use related to time spent foraging on a given unit was inadequately measured by pellet-group counts. Deer, and to a lesser extent elk, were frequently flushed from beds mid-day in the HT and CCSP treatments. Both the HT and CCSP treatments had abundant sapling (1-3 m) pines. Use of these treatments was probably related to the presence of pines as screening and bedding cover. The high pellet group counts on HT and CCSP are consistent with observations that deer and elk normally defecate soon after leaving beds (Collins and Urness 1981). Deer were rarely flushed mid-day on other treatments but were observed at night on harvested and burned treatments when spotlight counts were conducted. Elk were observed on all treatment units except RRB. The results of this study suggest that natural regeneration (HT) without initial burning for site preparation provides preferred habitat for foraging, bedding cover, and escape cover.

Pellet groups that persisted from previous burns were noted during all sampling periods. Pellets were typically charcoaled and did not erode following heavy rains (i.e., rate of >3 cm/hr). Rabbit pellet-group counts in December were probably higher as a result of pellet group persistence. Most likely rabbit pellets persisted for longer periods of time because diet quality declined in winter and increased in fiber content (Cochran and Stains 1961).

Burning of treatments in March caused deer and elk to use other treatments more than previously suggesting that unburned areas are important during the 1- to 2-month interval prior to green up of burned areas. Deer apparently shifted use on the HT4 in response to the March controlled burn. One month after burning, deer and elk pellet-group counts on all retrogressed and burned treatments dropped from preburn levels. Rabbit groups were similar before burning presumably because they were better able to utilize the short regrowth on burned sites. Elk use of FP treatments increased but not significantly.

Site retrogression is a viable alternative to traditional food plot strategies. Harvested sites were used as frequently or possibly to a greater extent than food plots. Commercial timber harvest produces income as well as preferred forage. Food plot management strategies necessitate capital expenditures for equipment and annual costs associated with seed and fertilizer.

Further research should focus on larger treatment areas using radio telemetry. Treatments should include HT, RRB, and CCSP in addition to one or more of the retrogressed and burned treatments because all burn frequencies apparently had similar use.

MANAGEMENT IMPLICATIONS

Browse quality and quantity are limited in the Ouachita Highlands (Segelquist and Pennington 1968, Fenwood et al. 1984, Masters 1991a). Site retrogression through timber harvest and use of prescribed fire will increase use by deer, elk, and rabbits on poor quality sites. Cover is often overlooked as an important component of deer habitat in the Southeast. This study demonstrates that deer and elk will use unburned naturally regenerated areas or areas clearcut and planted to pine as screening and bedding cover when located adjacent to forested or harvested and burned sites. Although pellet-counts do not accurately portray total habitat use they are useful for determining relative habitat use when interpreted with caution.

Preference for the HT or naturally regenerated sites has important implications for using natural regeneration as a forest management strategy. Rough reduction burns and clearcutting are often justified from purported benefits to deer and other wildlife. Deer, elk, and rabbit use of the RRB treatment does not support this justification. Later hazard reduction burns may provide beneficial cumulative effects but should be evaluated through long-term studies.

Clearcuts planted to pine can be beneficial but the long-term loss of mast producing capability must be addressed by providing additional foraging areas. Naturally regenerated stands of mixed oak and pine can provide forage and cover and still have the potential for mast production as the stand matures. I recommend a management strategy that periodically creates unburned natural regeneration areas in contoured blocks for cover, within a larger mosaic of mature timber and burned retrogressed sites.

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Table 1. Relative rankings of preferred cervid food plants based on a summed preference index for all years and treatments.

Browse	Index	Forbs	Index
Smilax spp.	808	*Lespedeza* spp.	322
Ulmus alata	745	*Aster patens*	311
Amelanchier arborea	448	*Solidago ulmifolia*	201
Vitis spp.	422	*Monarda fistulosa*	135
Vaccinium spp.	201	*Phytolacca americana*	128
Hypericum spp.	195	*Conyza canadensis*	120
Rhus glabra	167	*Solanum carolinense*	116
Rhus copallina	159	*Aster* spp.	106
Nyssa sylvatica	103		
Rubus spp.	103		

Table 2. Ranks of cervid pellet-group and browse utilization frequency estimates of treatment use on Pushmataha Forest Habitat Research Area, September 1988.

Treatment	Browse Utilization Frequency	Pellet Groups
HT3	9a	5abc
HT	8ab	9a
HT2	6.5abc	1c
CCSP	6.5abc	8ab
CONT	5abc	3c
HT4	4abcd	6abc
HT1	3bcd	7ab
HNT1	2cd	4bc
RRB	1d	2c
	P=0.001	P=0.02

[a] Ranks with the same letter are not significantly different, Kruskal-Wallis nonparametric test ($P < 0.05$).

[b] HT3 = harvest pine timber, thin hardwoods, winter prescribed burn at 3 year intervals; HT = harvest pine timber, thin hardwoods; HT2 = harvest pine timber, thin hardwoods, winter prescribed burn at 2 year intervals; CCSP = clearcut, windrow logging slash, summer site prep burn, rip; CONT = control, no treatment; HT4 = harvest pine timber, thin hardwoods, winter prescribed burn at 4 year intervals; HT1 = harvest pine timber, thin hardwoods, winter prescribed burn at 1 year intervals; HNT1 = harvest pine timber only, winter prescribed burn at 1 year intervals; RRB = rough reduction burn in winter, at 4 year intervals.

Table 3. White-tailed deer pellet groups/ha on experimental units subjected to timber harvest and periodic prescribed fire, 1988-1989.[a]

	Month									
	May		Sep		Dec		Mar		Apr	
Treatment[b]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
CONT	33	0	42	0	17c	0	0	.	56	0
RRB	33	0	42	0	17c	0	75	0	67	0
HNT1	33	0	100	0	117abc	0	308	0	125	0
HT	500	.	550	.	450a	.	.	.	300	.
HT4	67	0	100	0	317ab	0	400	.	69	0
HT3	350	0	100	0	50bc	0	.	.	83	0
HT2	300	0	67	0	150abc	0	250	.	67	0
HT1	350	0	275	0	125abc	0	438	0	25	.
CCSP	167	0	450	0	250ab	0	.	.	317	0
FP	300	0	.	.	250ab	0	450	.	33	.

[a] Column means followed by the same letter within month were not significantly different at the 0.05 level, means without letters were not different. Means were from untransformed data and standard errors from negative binomial transformed data.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; CCSP = clearcut, summer site prep burn (1985); FP = food plot planted to fescue, rye, vetch, and Korean lespedeza, and mowed early fall.

Table 4. Elk pellet groups/ha on experimental units subjected to timber harvest and periodic prescribed fire, 1988-1989.[a]

	Month									
	May		Sep		Dec		Mar		Apr	
Treatment[b]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
CONT	33bc	0	33	0	0c	0	50abc	.	33	0
RRB	0c	0	33	0	0c	0	8c	0	0	0
HNT1	33bc	0	50	0	17c	0	17bc	0	25	0
HT	200ab	.	150	.	300a	.	.	.	200	.
HT4	67abc	0	133	0	67bc	0	250a	.	17	0
HT3	550a	0	75	0	150ab	0	.	.	50	0
HT2	233ab	0	0	0	133ab	0	0c	.	67	0
HT1	300a	0	100	0	125ab	0	150ab	0	25	.
CCSP	433a	0	142	0	283a	0	.	.	167	0
FP	233abc	0	.	.	183ab	0	50abc	.	567	.

[a] Column means followed by the same letter within month were not significantly different at the 0.05 level, means without letters were not different. Means were from untransformed data and standard errors from negative binomial transformed data.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; CCSP = clearcut, summer site prep burn (1985); FP = food plot planted to fescue, rye, vetch, and Korean lespedeza, and mowed early fall.

Table 5. Cottontail rabbit pellet groups/ha on experimental units subjected to timber harvest and periodic prescribed fire, 1988-1989.[a]

	Month									
	May		Sep		Dec		Mar		Apr	
Treatment[b]	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
CONT	0b	0	42	0	0d	0	0c	.	11bc	0
RRB	33ab	0	50	0	17d	0	0c	0	0c	0
HNT1	167ab	0	100	0	167abc	0	125b	0	338a	0
HT	100ab	.	100	.	150bc	.	.	.	150ab	.
HT4	167ab	0	217	0	250abc	0	275ab	.	167ab	0
HT3	250ab	1	350	0	200abbc	0	.	.	133abc	0
HT2	333a	0	150	0	400ab	0	250ab	.	133abc	0
HT1	350a	0	150	0	500a	0	513a	0	150ab	.
CCSP	267a	0	450	0	583a	0	.	.	417a	0
FP	33ab	0	.	.	67c	0	250ab	.	67abc	.

[a] Column means followed by the same letter within month were not significantly different at the 0.05 level, means without letters were not different. Means were from untransformed data and standard errors from negative binomial transformed data.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; CCSP = clearcut, summer site prep burn (1985); FP = food plot planted to fescue, rye, vetch, and Korean lespedeza, and mowed early fall.

Fig. 1. Percent cover of preferred forbs 1983-88. For clarity of presentation some burned treatments were not depicted. Those not depicted were intermediate in response.

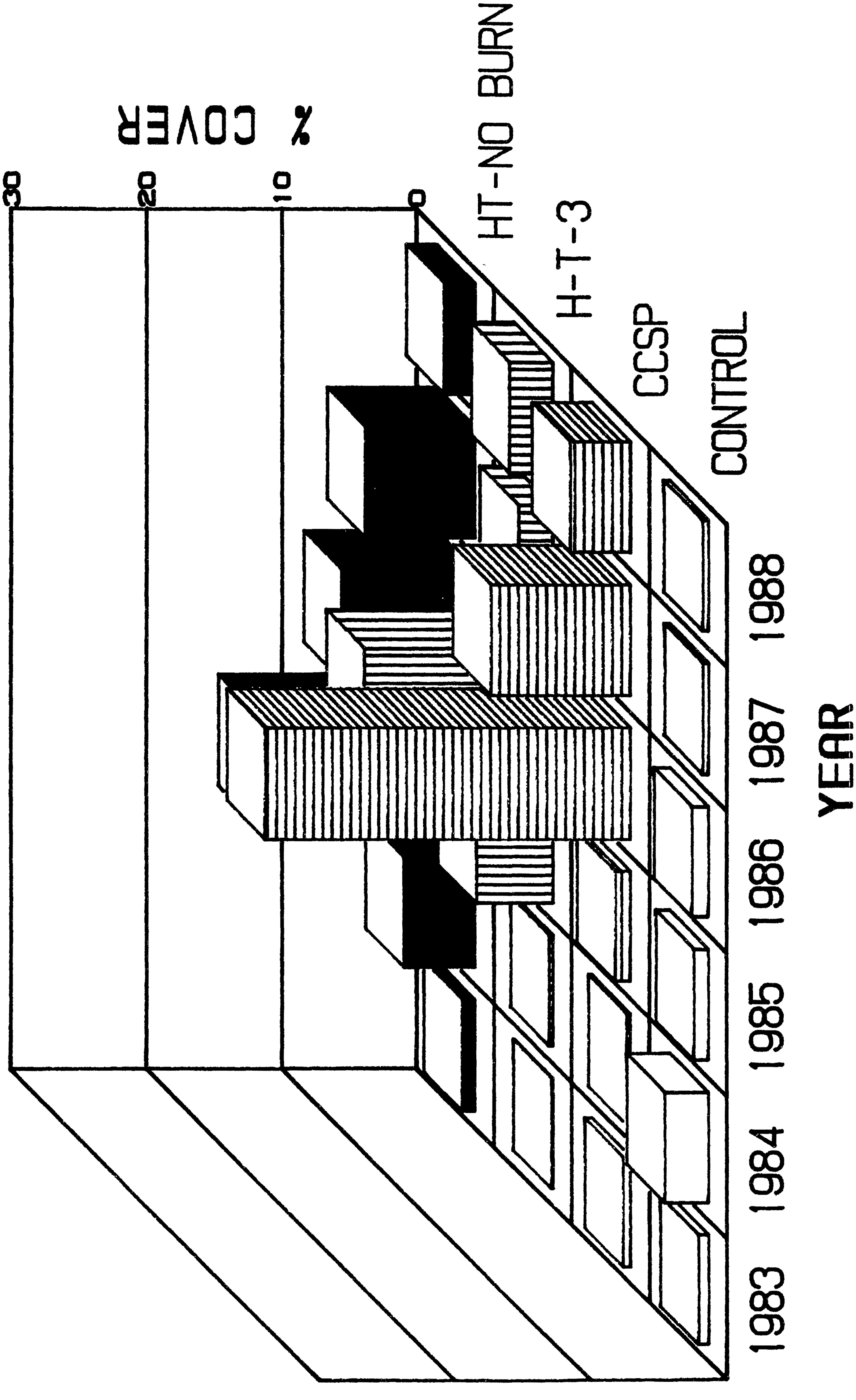

% COVER
0
10
20
30
HT-NO BURN
H-T-3
CCSP
CONTROL
1983
1984
1985
1986
1987
1988
YEAR

Fig. 2. Percent cover of preferred browse 1983-88. For clarity of presentation some burned treatments were not depicted. Those not depicted were intermediate in response.

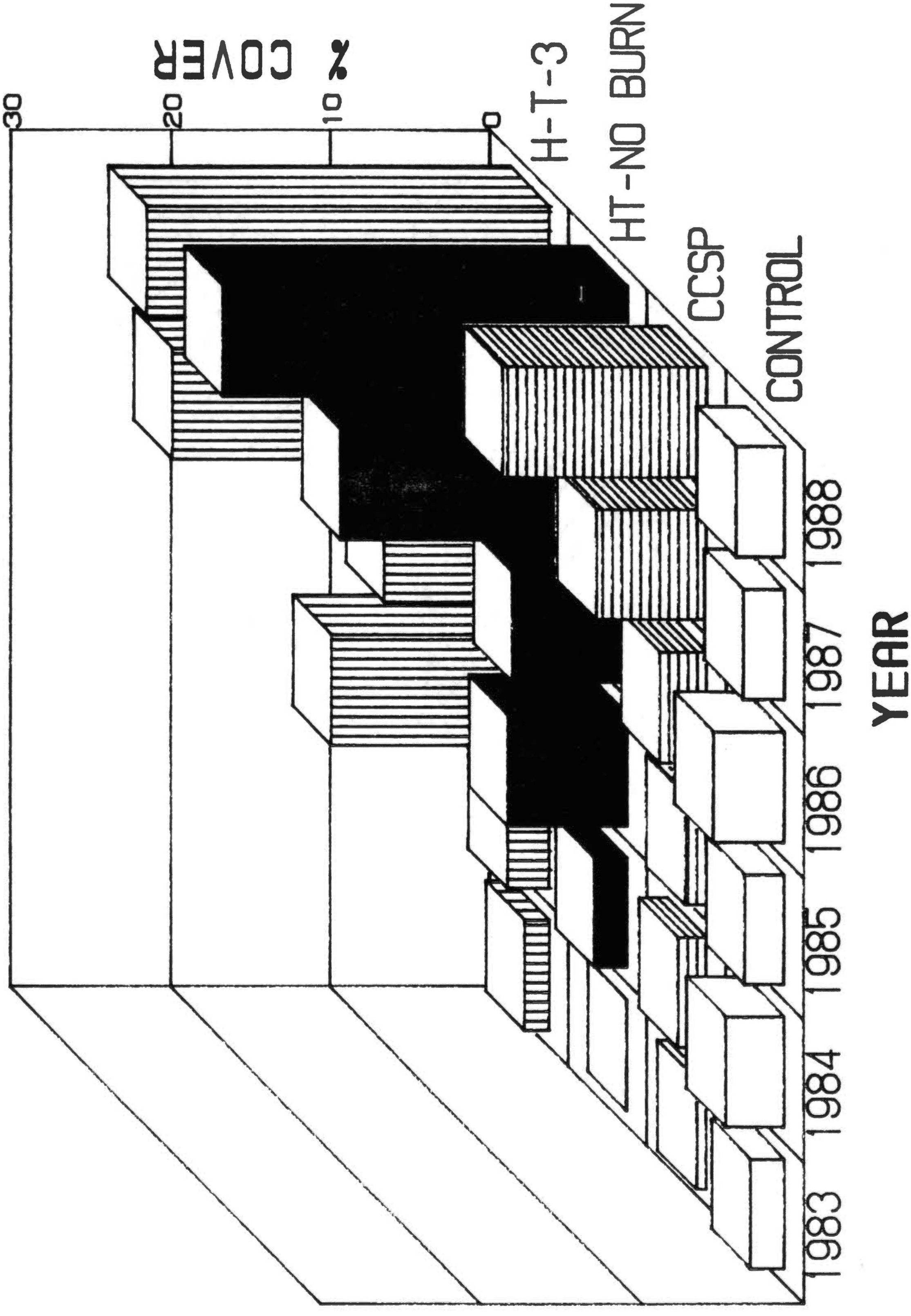
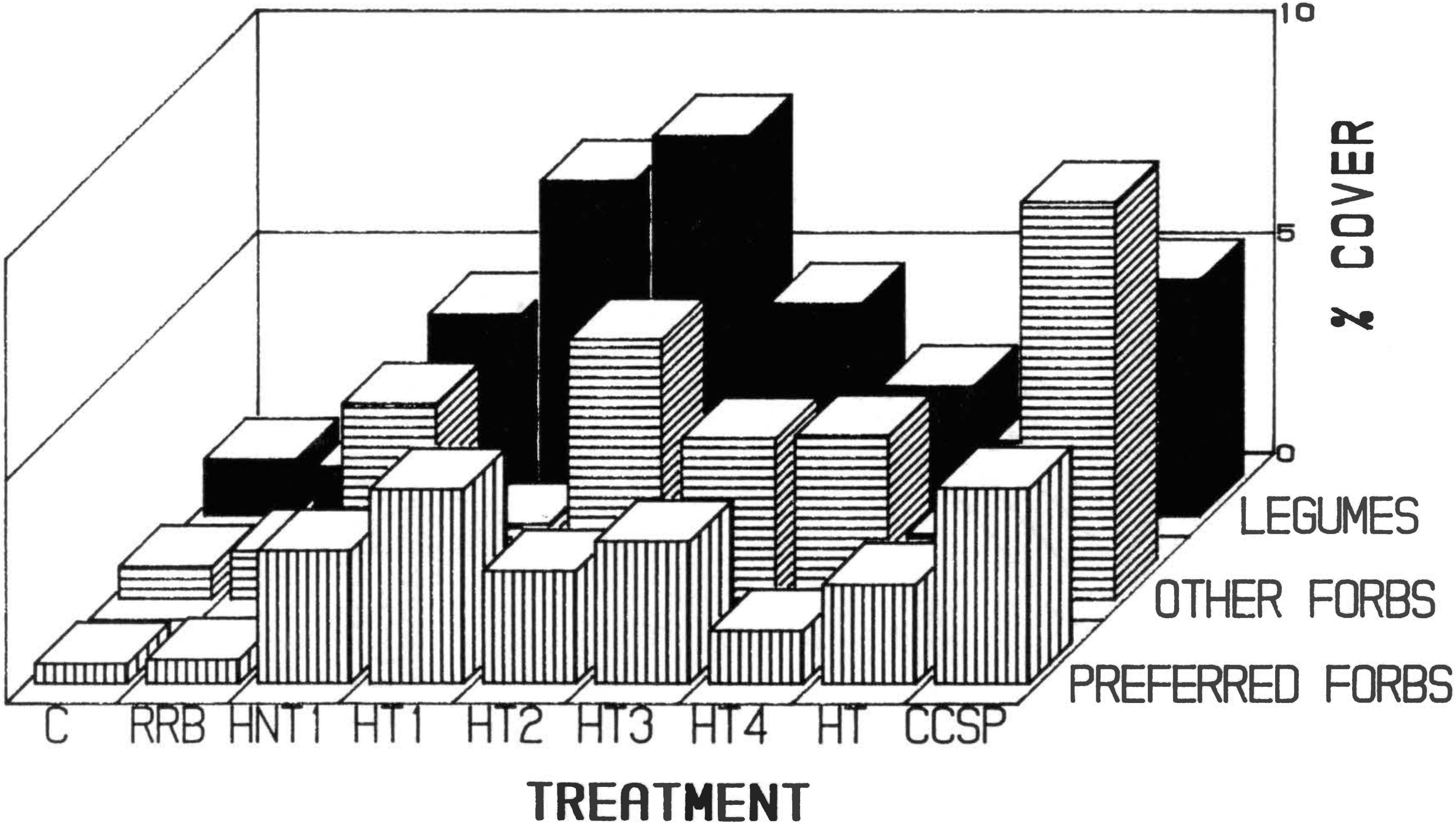

% COVER
30
20
10
0
H-T-3
HT-NO BURN
CCSP
CONTROL
1983
1984
1985
1986
1987
1988
YEAR

Fig. 3. Percent cover of preferred forbs, other forbs, and legumes after all burn intervals had been completed in 1988.


10
5
0
% COVER
LEGUMES
OTHER FORBS
PREFERRED FORBS
C
RRB
HNT1
HT1
HT2
HT3
HT4
HT
CCSP
TREATMENT

APPENDIXES

APPENDIX A

WATER-YEAR RAINFALL DATA

1978 - 1990

Table 1. Monthly and annual water-year rainfall (cm) on Pushmataha Forest Habitat Research Area 1978-90.

WATER YEAR	MONTH												
	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	TOTAL
7879	3.71	3.68	5.87	7.75	12.78	19.99	7.9	31.32	6.99	9.80	4.72	7.49	122.04
7980	13.16	2.64	5.72	6.50	5.16	5.23	14.4	20.14	6.96	1.70	0.43	21.44	105.70
8081	14.99	3.99	5.44	3.56	11.96	7.26	8.2	20.37	15.27	13.13	11.48	2.01	117.76
8182	23.65	6.10	0.41	15.60	5.44	4.27	6.0	26.64	8.00	9.40	1.63	0.74	113.90
8283	7.29	15.19	20.27	6.20	9.50	8.28	7.9	22.05	11.38	1.35	4.75	4.17	118.77
8384	13.34	14.35	4.52	4.47	9.96	15.62	6.7	12.37	14.05	8.46	4.06	21.41	129.30
8485	48.03	11.28	17.35	4.22	13.06	14.27	19.5	8.41	14.88	7.67	2.24	10.92	172.50
8586	14.27	29.64	1.96	0.53	12.09	7.01	21.9	26.21	21.77	3.33	11.30	14.07	164.26
8687	8.08	9.25	4.80	10.06	11.79	9.09	1.8	18.85	13.31	6.86	7.95	17.27	119.09
8788	9.55	18.59	19.89	4.09	5.21	13.69	9.9	3.12	4.55	15.90	10.62	3.10	118.20
8889	5.82	9.30	9.19	11.38	12.90	14.81	6.1	15.82	25.02	14.88	3.84	16.74	145.86
8990	2.51	0.53	2.59	21.74	23.57	20.27	34.80	34.77	4.29	18.24	10.67	13.89	187.88

Table 2. Seasonal and annual water-year rainfall (cm) on Pushmataha Forest Habitat Research Area 1978-90.

	SEASON				
WATER YEAR	OCT-DEC	JAN-MARCH	APRIL-JUNE	JULY-SEPT	TOTAL
7879	13.26	40.51	46.25	22.02	122.04
7980	21.51	16.89	41.58	23.57	105.70
8081	24.41	22.78	43.84	26.62	117.76
8182	30.15	25.30	40.67	11.76	113.90
8283	42.75	23.98	41.40	10.26	118.77
8384	32.21	30.05	33.12	33.93	129.30
8485	76.66	31.55	42.82	20.83	172.50
8586	45.87	19.63	69.95	28.70	164.26
8687	22.12	30.94	33.96	32.08	119.09
8788	48.03	22.99	17.63	29.62	118.20
8889	24.31	39.09	46.99	35.46	145.86
8990	5.64	65.58	73.86	42.80	187.88

APPENDIX B

FIRE BEHAVIOR PARAMETERS FOR 1988 PRESCRIBED BURNS

FIRE BEHAVIOR PARAMETERS FOR 1988 PRESCRIBED BURNS

INTRODUCTION

Studies on effects of prescribed fire on vegetation often do not provide fire behavior and fuel parameters. Therefore comparison of the results from different studies may be misleading (Alexander 1982). Fire behavior parameters are useful in predicting effects of fire on vegetation and may be used to increase management effectiveness (Van Wagner 1973).

Characterization of fire behavior using Byram's (1959) equation is tedious at best for most land managers. Flame length is easier to measure and may be used as an estimator of fireline intensity (Alexander 1982, Byram 1959) and a predictor of scorch height (Van Wagner 1973). However, flame length is difficult to accurately measure and may be prone to considerable observer bias (Johnson 1982, McMahon 1985, Sneeuwajagt and Frandsen 1977). Observer bias may be reduced by using height reference markers. I compared these techniques in an effort to determine their possible use as a tool for land managers.

METHODS

Prescribed burns using strip-head fires were conducted starting in winter 1985 on the Pushmataha Forest Habitat Research Area. A complete description of the study area and history of cultural treatments application are found in Chapters III and IV. Methodology for sampling fuels, weather, and conducting and sampling fires generally follow Alexander (1982), Byram (1959), Rothermel (1983), and Wade (1989).

Fire behavior was measured on burns conducted in 1988. Each burn treatment was replicated twice. Treatments codes and descriptions are summarized as follows:

1. HT1 - harvest pine timber, selectively thin hardwoods, and winter prescribed burn annually from 1985 to 1988.
2. HT3 - harvest pine timber, selectively thin hardwoods, and winter prescribed burn in 1985 and 1988.
3. HNT1 - harvest pine timber, no-thinning of hardwoods, and winter prescribed burn annually from 1985 to 1988.

Vegetation Prior to 1988 Burns

After timber harvest and prescribed fire in 1985, vegetation on HT1 and HT3 was dominated by big bluestem (Andropogon gerardii), little bluestem (Schizachyrium scoparium), and to a lesser extent, Indiangrass (Sorghastrum nutans). The HNT1 treatment overstory was dominated by post oak, with some blackjack oak, and mockernut hickory. Canopy cover was measured the previous September using a grided sighting tube at 90 locations per replication. Mean canopy cover for HT1, HT3, and HNT1 treatments was respectivley 5, 11, and 24 percent.

Fuel and Weather Measurements

Fuel was sampled <1 hour before burning in 6 to 9 0.5- X 0.5-m quadrats per plot. I hand separated fuels into 1-hr fine (dead), green herbaceous, and 10-hr woody components. Standing 1-hr fine fuels and green herbaceous fuels were clipped to 2.5 cm above ground level. The 10-hr woody fuels included small twigs, bark and woody fragments (<2.5 cm diameter) from residual logging slash. Fuels were weighed immediately after collection, later dried at 72°C to a constant weight, and reweighed to calculate percent moisture. The fuel bed of HT1 was discontinuous, with 22 percent of the ground cover in rock and bare ground. Fuel beds of HT3 and HNT1 were more continuous, with 13 percent and 6 percent rock and bare ground, respectively. The 3 fuel beds differed in fine, woody, and green fuel load characteristics. Fire weather was measured with a belt weather kit. Relative humidity, temperature, cloud cover, and wind speed were recorded the day before burning, prior to, during, and immediately upon completion of each experimental burn. Weather and fuel bed characteristics are presented in Table 1.

Fire Measurements

Controlled burns were started at 0900 CST and were completed by 1630 CST, March 1, 1988. Backfires were ignited and then sampled. The same procedure was followed for flankfires and headfires on each replicate. An approaching front arrived late in the afternoon and the last 2 units were burned under a light misting rain.

Fireline intensity was calculated by Byram's (1959) formula for fireline intensity (I_B=hwr), where I_B is frontal fire intensity (kW/m), h is net heat of combustion (kJ/kg) adjusted for percent moisture and heat of vaporization, w is fuel consumed (kg/m^2), and r is rate of spread (m^2/sec) (Table 3). Rate of spread on each unit was measured by timing 1 to 3 10-m runs of headfires and 3 to 5 5-m runs for backfires and 1 to 3 5-m runs for flankfires.

Fireline intensity was also calculated from flame length using $I_{FL}=259.833(L)^{2.174}$, where L is flame length (m) (Alexander 1982). Flame length was estimated using height reference markers located on snags within each unit.

After the fires residual duff (Table 2), litter and woody fuel were collected using 5 0.5- X 0.5-m quadrats placed at random in each backfire, flankfire, and headfire area. Fuel high heat of combustion was determined with a bomb calorimeter for pre- and post-burn fuels.

ANALYSIS

One way analysis of variance was used to determine differences in fuel characteristics, the above fire behavior parameters for headfires, flankfires and backfires, and remaining duff among fuel beds at the 0.05 probability level.

Fireline intensity from Byrams equation and estimated from flame length were compared using a paired T-test of replicate means (n=2) for subsampled headfires, flankfires and backfires. Paired comparisons were considered significant at the 0.10 probability level (two-tailed).

RESULTS

Although canopy cover and fuel characteristics were different, fire behavior parameters for all typefires were not (Tables 1-3). This was because of changing weather patterns and little actual difference in fuels (primarily cured tall grasses) available for the combustion process (Masters and Engle 1991).

Calculated fireline intensity and measured rate of spread were not significantly different ($\underline{P} < 0.05$) among fuel types. Although fuel loading and fuel moisture were different among fuel beds, fireline intensity was not different because of varying weather conditions and probably little difference in fuel available for the combustion process.

Calculated fireline intensity (I_B) was somewhat different from I_{FL} in all fuel types (Table 4). Flame length fireline intensity (I_{FL}) versus (I_B) were similar in 6 out of 9 (66.7%) paired comparisons. Considerable variation in I_{FL} was evidenced by large standard errors and masked additional differences from I_B (Table 4). The wide variances resulted from changing weather conditions and the inherent spatio-temporal variation of flame length estimates. The magnitude of difference between the HNT1 flankfire and HT3 headfire comparisons was unacceptable, although statistically they did not differ (Table 4).

Flame length measurements have some use in predicting fireline intensity and are considerably less time consuming than measurements required for calculating Byram's (1959) fireline intensity (Table 4). However, flame length derived fireline intensity for headfires are problematic because of the subjectivity in estimating headfire flame lengths.

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Table 1. Fuel and weather conditions before burning on retrogressed oak-pine sites in the Ouachita Mountains of southeastern Oklahoma, March 1, 1988.[1]

TREATMENT[2]

	HT1			HT3			HNT1		
	x	SE	Range	x	SE	Range	x	SE	Range
Heat of combustion (kJ/kg)	17440	152	15770-18802	17050	718	8543-22487	17310	859	16448-18166
Fuel load (kg/ha)									
Fine fuels	1150b	25	240-2240	1500a	77	480-3480	855c	47	0-1600
Woody fuels[3]	1580ab	221	0-9880	1300b	23	0-4200	2100a	50	0-9560
Green fuels	80b	14	0-720	35c	19	0-240	100a	4	0-360
1 hr. fuel moist. (%)	15	2	0-26	12	2	3-26	15	2	9-29
Weighted fuel moist. (%)	17a	3	3-33	20a	4	10-36	19b	1	9-44
Air temp.(° C)	14	0	13-15	14	1	12-15	14	1	13-15
Wind speed (km/h)	5	0	1-16	6	0	1-13	6	0	3-10
Rel. humidity (%)	56a	0	56-57	39b	0	32-43	56a	2	52-57

---

[1] Row means followed by the same letter are not significantly different at the 0.05 level. Ranges given are for subsamples within replicates.

[2] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

[3] Woody fuels were primarily 3.5 year old residual logging slash comprised of bark, small twigs and limbs < 2.5 cm diameter.

Table 2. Duff (kg/ha) remaining after controlled burning.[1]

	TREATMENT[2]					
	HT1		HT3		HNT1	
TYPEFIRE	x	SE	x	SE	x	SE
backfire	65b	(31)	582a	(26)	2b	(2)
flankfire	62b	(62)	752a	(184)	2b	(2)
headfire	42b	(38)	534a	(166)	40b	(24)

[1] Row means followed by the same letter within typefire are not significantly different at the 0.05 level.

[2] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 3. Fire behavior parameters and Byram's fireline intensity for retrogressed oak-pine sites.

Typefire and Treatment[1]	Net Heat of combustion (H) (kJ/kg)		Fuel consumed (w) (kg/m²)		Rate of spread (r) (m/s)		Frontal fire intensity (I) (kW/m)	
	x	SE	x	SE	x	SE	x	SE
Backfire								
HT1	15171	(677)	0.176	(0.057)	0.016	(0.002)	41	(8)
HT3	13801	(2276)	0.178	(0.017)	0.018	(0.0003)	45	(12)
HNT1	15588	(884)	0.279	(0.015)	0.020	(0.008)	90	(44)
Flankfire								
HT1	16529	(681)	0.227	(0.015)	0.031	(0.003)	114	(1)
HT3	16201	(179)	0.188	(0.008)	0.035	(0.0007)	105	(1)
HNT1	15588	(884)	0.174	(0.013)	0.039	(0.014)	105	(35)
Headfire								
HT1	15618	(230)	0.192	(0.030)	0.293	(0.040)	903	(270)
HT3	15929	(163)	0.210	(0.041)	0.191	(0.019)	628	(68)
HNT1	15588	(884)	0.226	(0.016)	0.218	(0.079)	808	(378)

Table 3. Continued.

[1] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 4. A comparison of mean fireline intensity calculated from Byram's equation (I_B) and predicted from flame length (I_{FL}) on retrogressed oak-pine sites.[1]

Typefire and Treatment[2]	I_B (kW/m)		I_{FL} (kW/m)		Prob > ¦T¦
	x	SE	x	SE	I_B vs I_{FL}
Backfire					
HT1	41	(8)	36	(1)	ns
HT3	45	(12)	66	(0)	ns
HNT1	90	(44)	50	(38)	*
Flankfire					
HT1	114	(1)	194	(105)	ns
HT3	105	(1)	144	(0)	*
HNT1	105	(35)	303	(214)	ns
Headfire					
HT1	903	(270)	2194	(136)	*
HT3	628	(68)	1202	(147)	ns
HNT1	808	(378)	756	(457)	ns

[1] Paired comparisons based upon two-tailed T-test; ns = non significant; * = $\underline{P} < 0.10$.

[2] HT1 = harvest pine timber, thin hardwoods, winter burn annually; HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

APPENDIX C

BASAL AREA AND CANOPY COVER RESPONSE TO TIMBER HARVEST AND FIRE

Table 1. Hardwood, pine, and total basal area (m^2/ha) of stems > 5 cm dbh, and percent canopy cover change after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1983 to 1990.[a]

	Treatment[b]																	
Parameter,	CONTROL		RRB		HNT1		HT		HT4		HT3		HT2		HT1		CCSP	
Year	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
Hardwood Basal Area																		
1983	14	1	12	1	.	.	14	.	11	2	9	1	10	2	.	.	11	1
1984	14a	1	12ab	1	.	.	8bc	.	8bc	1	5c	0	6c	2	.	.	7c	1
1985	14a	1	11a	1	.	.	5ab	.	3bc	1	3bc	0	3bc	1	.	.	1c	0
1986	14a	1	11ab	1	9ab	2	6b	.	2c	1	2cd	0	2c	1	3c	0	0d	0
1987	14a	1	11ab	1	9ab	2	6b	.	2c	1	2cd	0	2c	0	2c	0	0d	0
1988	14a	1	11ab	1	8b	2	6b	.	2c	1	2cd	0	2c	1	2c	0	0d	0
1989	14a	1	10ab	1	8ab	2	7b	.	2c	1	2cd	0	2c	1	2c	0	0d	0
1990	14a	1	10ab	1	8ab	2	7b	.	2c	1	2cd	0	2c	1	2c	0	0d	0
Pine Basal Area																		
1983	13	3	14	2	.	.	11	.	13	2	17	1	16	3	.	.	13	1
1984	13a	3	14a	2	.	.	1b	.	1b	1	1b	0	2ab	1	.	.	2b	1
1985	13a	3	14a	2	.	.	1ab	.	1b	1	0b	0	2ab	1	.	.	0b	0
1986	13a	3	14a	2	0bc	0	2ab	.	1bc	1	0bc	0	2ab	1	0c	0	0c	0
1987	13a	3	14a	1	0bc	0	2ab	.	1bc	1	1bc	1	2ab	1	0c	0	0c	0
1988	13a	3	14a	1	0dc	0	2ab	.	1bcd	1	1cd	1	2abc	1	0d	0	0d	0
1989	13a	3	14a	1	0bc	0	1ab	.	1bc	1	1bc	1	2ab	1	0c	0	2ab	1
1990	13a	3	14a	1	0cd	0	2bc	.	1cd	1	1cd	0	2bc	1	0d	0	4ab	1
Total Basal Area																		
1983	27	2	26	1	.	.	25	.	23	1	26	2	26	1	.	.	24	1
1984	26a	2	25a	1	.	.	9b	.	9b	2	5b	0	8b	2	.	.	9b	1
1985	27a	2	25a	1	.	.	7ab	.	4bc	2	3bc	1	5bc	1	.	.	1c	1
1986	27a	2	25ab	1	9bc	2	8bc	.	3d	1	3de	1	5cd	1	3de	0	0e	0
1987	27a	2	24ab	1	9bc	2	8bc	.	3cd	1	3d	1	4cd	1	2de	0	0e	0
1988	27a	2	24ab	1	8bc	2	8bc	.	3cd	1	3de	1	4cd	1	2de	0	0e	0
1989	27a	2	24a	1	8ab	2	9ab	.	3bc	1	3c	1	4bc	1	2c	0	2c	1
1990	27a	2	24a	1	8ab	2	9ab	.	3bc	1	3c	1	4bc	1	2c	0	4bc	1

Table 1. Continued.

Treatment[b]

Parameter,	CONTROL		RRB		HNT1		HT		HT4		HT3		HT2		HT1		CCSP	
Year	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE	X	SE
Percent Canopy Cover																		
1985	77a	2	67ab	4	.	.	23abc	.	7cd	4	6cd	4	14bcd	6	.	.	4d	4
1986	82a	1	73ab	6	30bcd	8	32abc	.	9def	5	7def	4	15cde	7	6ef	6	0f	0
1987	86a	3	79ab	4	31bc	8	33abc	.	12cd	6	11cd	7	19cd	9	5de	4	0e	0
1988	85a	3	84a	4	35ab	7	29bc	.	11cde	6	7de	4	19bcd	8	8de	6	0e	0
1989	85a	1	80a	5	31ab	6	39ab	.	11cd	5	9cd	5	17bc	5	8cd	5	2d	1
1990	87a	2	78ab	4	31bcd	6	45abc	.	12de	6	10de	7	19cde	7	8e	5	14de	0

[a] Row means followed by the same letter within category are not significantly different at the 0.01 level, based on the Kruskal-Wallis nonparametric test. Ranks of treatment means were separated using Duncans multiple range test.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually; HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; CCSP=clearcut, summer site prep burn (1985).

APPENDIX D

DEER BROWSE NUTRIENT RESPONSE TO TIMBER HARVEST, FIRE, AND RAINFALL

Table 1. Nutrient response of elmleaf goldenrod after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. Means are unadjusted for rainfall.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Crude Protein										
CONTROL	7.1b	0.7	6.8d	0.2	6.4	0.1	5.2d	0.2	6.0	0.1
RRB	6.3b	0.5	7.7cd	0.2	6.0	0.8	5.1d	0.2	6.4	0.5
HNT1	.	.	7.5d	0.5	6.4	0.2	5.8c	0.1	6.2	0.4
HT	7.4b	.	7.8bcd	.	6.3	.	5.7c	.	5.8	.
HT4	8.2ab	0.4	8.4ab	0.3	5.9	0.4	6.2b	0.2	6.4	0.1
HT3	8.9a	0.0	.	.	6.7	1.0	6.5b	0.2	5.8	0.8
HT2	7.4ab	0.8	8.4abc	0.2	6.4	0.4	6.5b	0.2	6.2	0.4
HT1	.	.	7.5d	0.5	5.7	0.2	6.5b	0.0	6.0	0.5
CCSP	9.1a	0.8	9.3a	0.2	6.4	0.4	7.3a	0.1	6.9	0.0
ADF										
CONTROL	38.3	1.9	36.6a	1.5	39.5	2.2	43.7a	2.0	41.5	1.6
RRB	37.3	0.9	35.0ab	2.0	37.9	1.9	42.3a	1.4	39.2	1.7
HNT1	.	.	35.9a	0.5	34.7	0.8	37.6b	0.6	32.8	1.5
HT	36.4	.	31.2bcd	.	37.0	.	38.1ab	.	36.0	.
HT4	34.6	0.4	30.2cd	1.3	36.0	1.7	36.4bcd	1.2	32.9	0.6
HT3	35.4	3.1	.	.	30.7	0.7	33.6d	1.0	35.8	5.0
HT2	38.4	1.6	34.4abc	1.7	34.1	2.1	34.3cd	0.6	32.4	0.7
HT1	.	.	33.0abcd	1.3	35.8	0.2	37.9bc	3.2	34.2	1.5
CCSP	37.9	1.3	30.6d	0.2	34.6	0.6	35.3bcd	1.7	32.7	0.4
ASH										
CONTROL	7.0ab	0.1	7.2	0.3	7.6a	0.3	6.5	0.1	7.8	0.1
RRB	6.8ab	0.4	7.0	0.6	7.2ab	0.2	6.8	0.4	8.8	1.3
HNT1	.	.	6.6	0.1	6.5cde	0.2	7.0	0.2	7.3	0.2
HT	6.3b	.	6.6	.	6.5cde	.	6.0	.	6.5	.
HT4	6.3b	0.3	6.1	0.1	6.0e	0.1	6.4	0.2	7.0	0.2
HT3	6.3b	0.4	.	.	6.6bc	0.3	6.5	0.5	6.7	0.2
HT2	6.3b	0.2	6.5	0.1	7.8abc	1.2	6.5	0.2	7.1	0.3
HT1	.	.	6.3	0.5	6.1de	0.3	6.4	0.2	6.7	0.2
CCSP	7.4a	0.1	6.3	0.1	6.0e	0.2	5.8	0.2	6.7	0.6

Table 1. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
TDN										
CONTROL	61.0	1.7	62.5cd	1.4	59.9	2.0	56.1e	1.8	58.1	1.4
RRB	61.9	0.8	64.0cd	1.8	61.3	1.7	57.3de	1.3	60.2	1.5
HNT1	.	.	58.8e	0.6	64.3	0.8	61.6cd	0.5	66.0	1.3
HT	62.8	.	67.5ab	.	62.2	.	61.3cd	.	63.1	.
HT4	64.3	0.3	68.4a	1.2	63.1	1.5	62.7abc	1.1	66.0	0.5
HT3	63.6	2.9	.	.	67.9	0.6	65.3a	0.9	63.2	4.6
HT2	60.9	1.5	64.5bc	1.6	64.8	1.9	64.7ab	0.6	66.4	0.6
HT1	.	.	60.9de	1.3	63.2	0.1	61.3bc	3.0	64.7	1.3
CCSP	61.4	1.2	68.0a	0.2	64.4	0.5	63.7abc	1.6	66.1	0.4
Ca										
CONTROL	1.11a	0.03	1.18	0.04	1.31a	0.05	1.10a	0.07	1.30	0.05
RRB	1.09a	0.06	1.03	0.08	1.08ab	0.07	1.10a	0.06	1.40	0.16
HNT1	.	.	0.99	0.02	1.02bc	0.03	1.14a	0.04	1.07	0.03
HT	0.85b	.	0.91	.	0.94bcd	.	0.91bc	.	0.92	.
HT4	0.84b	0.03	0.97	0.04	0.91bcd	0.09	0.97ab	0.03	1.02	0.06
HT3	0.97ab	0.09	.	.	1.04ab	0.00	0.91bc	0.05	1.00	0.05
HT2	0.87b	0.05	1.11	0.03	1.09ab	0.07	0.99ab	0.05	1.00	0.05
HT1	.	.	0.98	0.17	0.88cd	0.05	0.90bc	0.03	1.02	0.07
CCSP	0.84b	0.06	0.94	0.05	0.86d	0.05	0.85c	0.03	0.94	0.23
P										
CONTROL	0.11	0.00	0.11d	0.01	0.11	0.01	0.08e	0.01	0.08c	0.00
RRB	0.12	0.00	0.17ab	0.01	0.13	0.03	0.09de	0.01	0.11abc	0.01
HNT1	.	.	0.17b	0.01	0.14	0.00	0.11cd	0.00	0.12ab	0.01
HT	0.12	.	0.14cd	.	0.11	.	0.09de	.	0.10bc	.
HT4	0.15	0.01	0.20a	0.02	0.13	0.01	0.12b	0.00	0.13a	0.01
HT3	0.15	0.01	.	.	0.15	0.03	0.12bc	0.01	0.11abc	0.02
HT2	0.12	0.01	0.20a	0.02	0.15	0.01	0.14ab	0.01	0.14a	0.01
HT1	.	.	0.16bc	0.01	0.15	0.00	0.14ab	0.00	0.13ab	0.01
CCSP	0.12	0.01	0.15bcd	0.01	0.12	0.01	0.13ab	0.01	0.11abc	0.00

Table 1. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Mg										
CONTROL	0.23	0.01	0.21	0.02	0.26	0.01	0.20	0.02	0.23a	0.01
RRB	0.21	0.01	0.22	0.01	0.20	0.01	0.20	0.02	0.23a	0.01
HNT1	.	.	0.20	0.03	0.16	0.01	0.18	0.01	0.17bc	0.01
HT	0.25	.	0.27	.	0.22	.	0.22	.	0.20ab	.
HT4	0.24	0.01	0.25	0.01	0.19	0.02	0.23	0.01	0.17c	0.01
HT3	0.25	0.04	.	.	0.20	0.05	0.22	0.00	0.16c	0.02
HT2	0.21	0.00	0.20	0.02	0.21	0.03	0.20	0.00	0.16c	0.02
HT1	.	.	0.24	0.02	0.23	0.01	0.23	0.01	0.17bc	0.01
CCSP	0.22	0.03	0.25	0.04	0.21	0.03	0.22	0.03	0.18abc	0.00
K										
CONTROL	1.83ab	0.04	1.82a	0.03	1.80	0.08	1.61	0.01	1.85	0.01
RRB	1.89a	0.04	1.81ab	0.06	1.77	0.13	1.55	0.13	2.04	0.08
HNT1	.	.	1.71abc	0.08	1.74	0.06	1.77	0.07	1.87	0.05
HT	1.80ab	.	1.77ab	.	1.81	.	1.54	.	1.90	.
HT4	1.82ab	0.11	1.60bc	0.04	1.69	0.03	1.65	0.05	1.85	0.02
HT3	1.57c	0.03	.	.	1.74	0.01	1.80	0.08	1.54	0.23
HT2	1.58bc	0.08	1.69abc	0.09	1.76	0.03	1.75	0.08	1.86	0.06
HT1	.	.	1.58c	0.00	1.67	0.10	1.79	0.07	1.77	0.07
CCSP	1.69abc	0.04	1.44c	0.10	1.55	0.17	1.58	0.08	1.79	0.01
Ca/P										
CONTROL	10.1a	0.3	11.2a	1.0	12.3	0.3	13.6ab	2.0	15.7	1.1
RRB	9.4ab	0.8	6.2b	0.6	9.4	2.3	12.7a	0.6	12.3	1.9
HNT1	.	.	6.0bc	0.4	7.1	0.3	10.7ab	0.7	9.0	0.6
HT	7.1bc	.	6.5ab	.	8.5	.	10.1bc	.	9.2	.
HT4	5.8c	0.8	4.8c	0.2	7.0	0.1	7.8cd	0.2	7.8	0.4
HT3	6.6c	0.4	.	.	7.4	1.2	7.6de	0.2	9.3	1.3
HT2	7.5abc	1.1	5.6bc	0.3	7.3	0.7	7.4def	1.0	7.5	1.1
HT1	.	.	6.1ab	0.6	6.0	0.1	6.4f	0.2	8.2	0.8
CCSP	6.9c	0.4	6.5ab	0.6	7.2	0.8	6.5ef	0.1	9.1	2.6

Table 1. Continued.

[a] Column means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP=clearcut, summer site prep burn (1985); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 2. Nutrient response of stiff sunflower after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. Means are unadjusted for rainfall.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Crude Protein										
CONTROL	7.2	0.6	8.1	0.8	7.9	0.5	6.5cde	0.8	6.8	0.4
RRB	6.3	0.9	8.3	0.2	6.9	0.3	6.2de	0.4	5.8	0.3
HNT1	.	.	7.0	0.5	6.0	0.3	6.2cde	0.5	6.2	0.4
HT	7.8	.	9.9	.	8.8	.	6.2e	.	6.3	.
HT4	9.4	1.1	9.5	0.5	7.4	0.3	7.2bcd	0.3	6.4	0.6
HT3	12.2	2.1	.	.	7.2	0.5	7.9ab	0.1	6.9	0.5
HT2	8.8	0.7	10.8	1.4	7.1	0.5	7.5abc	0.5	6.8	0.3
HT1	.	.	8.6	1.8	6.8	0.2	7.0bcde	0.5	6.0	0.8
CCSP	7.5	0.5	10.7	0.5	7.8	0.2	9.3a	0.3	8.5	0.2
ADF										
CONTROL	41.8	1.3	34.8	3.4	34.6	1.7	43.7	5.2	40.8a	3.2
RRB	38.4	1.9	42.4	8.6	36.0	1.1	42.5	1.9	39.7a	1.7
HNT1	.	.	31.7	3.0	36.9	1.7	37.7	1.4	34.5c	0.8
HT	45.1	.	36.7	.	37.2	.	37.5	.	37.1ab	.
HT4	39.6	0.6	37.2	2.5	36.2	0.9	41.1	4.4	35.8abc	1.1
HT3	45.0	4.9	.	.	36.8	0.9	39.8	4.1	35.3bc	0.4
HT2	46.2	1.9	31.8	3.6	38.5	3.1	41.2	3.0	34.4c	0.4
HT1	.	.	36.0	4.1	35.7	0.7	41.3	5.9	33.8c	0.4
CCSP	46.3	4.1	38.2	0.9	38.3	0.6	41.4	2.9	38.4ab	1.3
Ash										
CONTROL	14.6	0.9	17.6	2.3	18.4	0.6	16.1	2.6	19.1	1.7
RRB	17.6	0.6	17.0	1.4	19.1	0.4	15.0	1.0	21.9	0.7
HNT1	.	.	18.8	1.2	17.5	0.9	15.9	0.7	21.8	1.2
HT	13.8	.	15.4	.	16.8	.	14.2	.	18.1	.
HT4	12.8	1.7	15.3	1.0	17.9	0.4	16.2	1.5	20.8	0.3
HT3	12.9	1.0	.	.	17.8	0.8	18.1	0.0	19.0	0.2
HT2	13.6	0.9	18.9	1.6	17.1	0.7	16.9	1.0	20.6	0.2
HT1	.	.	16.0	2.4	18.3	1.1	16.7	0.9	19.8	1.8
CCSP	14.4	1.8	15.3	0.9	17.2	0.2	16.7	0.3	17.2	1.9

Table 2. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
TDN										
CONTROL	57.8	1.2	64.2	3.0	64.4	1.5	56.0	4.7	58.7c	2.9
RRB	60.9	1.7	57.2	7.8	63.1	1.0	57.2	1.7	59.7c	1.6
HNT1	.	.	67.0	2.7	62.3	1.5	61.5	1.3	65.6a	1.4
HT	54.8	.	62.4	.	62.0	.	61.8	.	62.0bc	.
HT4	59.8	0.5	62.0	2.2	62.9	0.8	58.5	4.0	63.3abc	1.0
HT3	54.8	4.6	.	.	62.3	0.8	59.6	3.7	63.7ab	0.4
HT2	53.8	1.7	66.9	3.3	60.7	2.8	58.3	2.7	64.6a	0.4
HT1	.	.	63.0	3.7	63.3	0.6	58.3	5.4	65.1a	0.3
CCSP	53.6	3.8	61.1	0.8	61.0	0.5	58.2	2.6	60.9bc	1.2
Ca										
CONTROL	2.67	0.34	4.00	1.12	3.96	0.24	2.95	0.41	4.01	0.59
RRB	4.08	0.18	4.28	0.12	3.80	0.33	3.07	0.37	4.08	0.44
HNT1	.	.	4.62	0.20	3.98	0.14	3.29	0.13	4.88	0.41
HT	2.77	.	3.31	.	3.38	.	2.66	.	4.04	.
HT4	2.38	0.31	3.74	0.60	3.87	0.16	3.70	0.40	4.59	0.22
HT3	2.41	0.46	.	.	3.58	0.03	3.65	0.07	3.96	0.17
HT2	2.17	0.14	4.99	0.57	3.82	0.42	3.45	0.11	4.52	0.28
HT1	.	.	3.67	0.46	4.12	0.34	3.31	0.19	4.16	0.79
CCSP	2.14	0.06	2.80	0.30	3.55	0.09	3.04	0.13	3.71	0.45
P										
CONTROL	0.08c	0.01	0.11	0.01	0.09d	0.00	0.09bc	0.01	0.08	0.01
RRB	0.08bc	0.00	0.11	0.00	0.10cd	0.00	0.09bc	0.00	0.08	0.01
HNT1	.	.	0.10	0.01	0.09d	0.00	0.09b	0.01	0.09	0.00
HT	0.09bc	.	0.14	.	0.12a	.	0.07c	.	0.08	.
HT4	0.14a	0.03	0.16	0.02	0.12ab	0.00	0.09bc	0.01	0.09	0.01
HT3	0.15a	0.03	.	.	0.11ab	0.01	0.10ab	0.01	0.10	0.01
HT2	0.16a	0.02	0.15	0.02	0.12a	0.01	0.11ab	0.01	0.09	0.01
HT1	.	.	0.13	0.02	0.11ab	0.00	0.10ab	0.00	0.09	0.01
CCSP	0.11ab	0.00	0.15	0.01	0.11bc	0.00	0.12a	0.01	0.10	0.01

Table 2. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Mg										
CONTROL	0.44	0.06	0.68	0.12	0.71	0.07	0.58	0.08	0.43	0.04
RRB	0.58	0.07	0.48	0.08	0.55	0.08	0.53	0.03	0.59	0.07
HNT1	.	.	0.53	0.03	0.50	0.04	0.47	0.06	0.48	0.03
HT	0.63	.	0.48	.	0.30	.	0.73	.	0.50	.
HT4	0.48	0.03	0.45	0.03	0.48	0.07	0.57	0.02	0.46	0.04
HT3	0.33	0.04	.	.	0.53	0.02	0.65	0.05	0.47	0.02
HT2	0.53	0.01	0.53	0.03	0.51	0.01	0.55	0.03	0.47	0.03
HT1	.	.	0.55	0.03	0.45	0.06	0.56	0.01	0.50	0.02
CCSP	0.44	0.14	0.58	0.10	0.54	0.03	0.68	0.08	0.42	0.10
K										
CONTROL	2.20	0.14	2.07	0.11	1.95	0.19	1.84cd	0.12	2.24bcd	0.04
RRB	2.00	0.13	2.40	0.31	2.23	0.13	1.85cd	0.13	2.09d	0.06
HNT1	.	.	1.84	0.20	1.99	0.04	1.90cd	0.06	2.27ab	0.02
HT	1.86	.	2.16	.	2.60	.	1.75d	.	2.23bcd	.
HT4	2.23	0.04	2.20	0.27	2.27	0.10	2.02bc	0.03	2.17bcd	0.07
HT3	2.17	0.30	.	.	2.38	0.05	2.23ab	0.17	2.18cd	0.02
HT2	2.62	0.33	2.22	0.25	2.41	0.32	2.35a	0.18	2.25abc	0.02
HT1	.	.	2.06	0.27	2.29	0.13	2.13ab	0.09	2.37a	0.03
CCSP	2.35	0.21	2.25	0.17	2.25	0.15	2.48a	0.11	2.47a	0.13
Ca/P										
CONTROL	33.1a	1.9	37.2abcd	10.5	45.6a	1.9	33.9	3.5	49.8	4.7
RRB	48.0a	0.8	38.9ab	1.1	39.4abc	3.6	35.4	3.7	51.9	7.7
HNT1	.	.	48.5a	4.2	42.7ab	2.1	35.7	3.7	56.3	3.6
HT	30.8ab	.	23.6cd	.	28.2e	.	38.0	.	50.5	.
HT4	19.6bc	5.6	24.4cd	5.9	33.3cde	2.4	40.9	2.1	53.9	6.1
HT3	16.1c	0.1	.	.	31.2de	1.1	36.9	4.4	41.9	3.9
HT2	14.3c	3.0	34.2abc	1.4	31.3cde	4.3	33.0	3.9	49.7	6.9
HT1	.	.	29.9bcd	2.3	36.0bcd	4.5	33.0	1.8	45.9	3.7
CCSP	18.7bc	1.3	19.6d	3.2	33.4cde	1.5	24.9	2.5	37.1	0.7

Table 2. Continued.

[a] Row means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP=clearcut, summer site prep burn (1985); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 3. Nutrient response of greenbriar after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. Means are unadjusted for rainfall.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Crude Protein										
CONTROL	7.9b	0.3	9.1	1.0	9.9	0.5	10.0abcd	0.1	10.1	0.4
RRB	7.5b	0.5	9.2	1.0	8.9	0.3	9.0cde	0.4	11.0	0.1
HNT1	.	.	9.9	0.5	8.0	0.2	9.4bcde	1.0	9.6	0.5
HT	8.1b	.	13.3	.	8.2	.	8.0e	.	9.8	.
HT4	11.5a	0.4	10.8	1.0	9.1	0.6	9.5bcde	0.4	10.8	0.6
HT3	10.6a	1.5	.	.	9.4	0.1	11.6a	0.3	8.4	0.1
HT2	10.5a	0.1	10.2	0.6	9.8	1.0	8.7de	0.2	10.3	0.3
HT1	.	.	10.6	0.1	8.9	0.6	10.5abc	1.1	9.2	0.8
CCSP	10.7a	0.4	12.9	1.9	10.7	1.2	10.7ab	0.3	10.3	0.2
ADF										
CONTROL	45.0	2.0	38.9	6.8	33.8	0.5	37.3a	2.4	30.7a	0.4
RRB	50.0	2.4	36.7	6.8	32.4	0.7	31.1abc	1.6	29.9abc	0.4
HNT1	.	.	28.7	1.4	29.5	0.9	28.0cd	1.1	26.6bcd	0.3
HT	46.0	.	25.8	.	30.9	.	30.1abc	.	30.0ab	.
HT4	44.3	2.5	31.8	3.2	28.7	0.4	34.8ab	3.5	25.4d	0.5
HT3	42.2	3.1	.	.	31.7	0.9	29.4bcd	0.6	27.5cd	1.5
HT2	43.6	2.7	27.9	0.3	28.5	1.1	27.4d	0.7	25.7d	0.2
HT1	.	.	27.9	0.2	30.9	3.6	27.7d	0.5	25.9d	0.5
CCSP	44.4	0.7	32.4	7.6	28.0	2.3	37.3ab	5.7	26.1d	0.9
ASH										
CONTROL	5.5	0.2	6.0	0.7	7.4a	0.3	7.6a	0.3	7.8a	0.1
RRB	5.3	0.3	6.4	0.6	6.9ab	0.2	6.8ab	0.2	7.3ab	0.2
HNT1	.	.	7.0	0.6	6.3bc	0.5	6.2bc	0.2	6.3bc	0.1
HT	4.8	.	5.4	.	6.2abc	.	5.7c	.	6.2c	.
HT4	5.4	0.2	5.2	0.1	6.0cd	0.1	6.2bc	0.3	5.7c	0.3
HT3	4.9	0.1	.	.	5.6cd	0.3	6.2bc	0.4	6.3bc	0.0
HT2	5.7	0.5	5.4	0.2	5.9cd	0.2	5.8c	0.2	6.1c	0.4
HT1	.	.	5.9	0.2	6.2bc	0.3	6.2bc	0.2	6.6bc	0.7
CCSP	5.0	0.4	5.0	0.4	5.4d	0.1	5.9c	0.2	5.8c	0.1

Table 3. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
TDN										
CONTROL	54.8	1.8	60.4	6.2	65.1	0.5	61.9d	2.2	67.9d	0.3
RRB	50.2	2.2	62.4	6.2	66.4	0.6	67.6bcd	1.4	68.7bcd	0.3
HNT1	.	.	69.7	1.3	69.0	0.9	70.4ab	1.0	71.7abc	0.3
HT	54.0	.	72.4	.	67.7	.	68.5bcd	.	68.5cd	.
HT4	55.5	2.3	66.9	2.9	69.7	0.4	64.2cd	3.2	72.8a	0.4
HT3	57.4	2.9	.	.	67.0	0.8	69.0abc	0.5	70.8ab	1.4
HT2	56.1	2.4	70.5	0.3	69.9	1.0	70.9a	0.6	72.5a	0.2
HT1	.	.	70.5	0.2	67.7	3.2	70.7a	0.4	72.3a	0.5
CCSP	55.4	0.6	66.3	6.9	70.4	2.1	61.9cd	5.2	72.1a	0.8
Ca										
CONTROL	1.03	0.09	1.14	0.13	1.63	0.11	1.53a	0.12	1.67	0.07
RRB	0.86	0.07	1.27	0.12	1.42	0.08	1.40ab	0.10	1.42	0.03
HNT1	.	.	1.34	0.05	1.40	0.12	1.23bcd	0.07	1.31	0.23
HT	1.09	.	1.18	.	1.48	.	1.27bcd	.	1.38	.
HT4	0.96	0.08	1.19	0.04	1.34	0.06	1.45a	0.01	1.10	0.07
HT3	0.82	0.01	.	.	1.37	0.17	1.13d	0.08	1.36	0.08
HT2	1.00	0.12	1.18	0.06	1.35	0.08	1.28bc	0.03	1.15	0.10
HT1	.	.	1.31	0.18	1.45	0.04	1.16cd	0.01	1.35	0.14
CCSP	0.99	0.19	0.81	0.10	1.20	0.10	1.25bcd	0.03	1.30	0.04
P										
CONTROL	0.09c	0.01	0.10	0.01	0.10	0.00	0.09	0.01	0.09	0.00
RRB	0.10bc	0.01	0.11	0.01	0.10	0.01	0.08	0.01	0.11	0.00
HNT1	.	.	0.12	0.01	0.10	0.00	0.10	0.01	0.11	0.01
HT	0.11bc	.	0.15	.	0.09	.	0.09	.	0.11	.
HT4	0.13a	0.01	0.13	0.01	0.11	0.01	0.10	0.01	0.10	0.01
HT3	0.12ab	0.00	.	.	0.11	0.00	0.11	0.01	0.10	0.01
HT2	0.12ab	0.01	0.12	0.01	0.12	0.00	0.10	0.00	0.10	0.01
HT1	.	.	0.13	0.01	0.11	0.00	0.11	0.01	0.11	0.00
CCSP	0.12ab	0.00	0.14	0.02	0.12	0.02	0.09	0.00	0.10	0.01

Table 3. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Mg										
CONTROL	0.15	0.01	0.21	0.03	0.25a	0.02	0.23	0.01	0.20	0.03
RRB	0.17	0.03	0.23	0.02	0.22ab	0.01	0.24	0.01	0.23	0.02
HNT1	.	.	0.19	0.01	0.20bcd	0.01	0.19	0.02	0.21	0.03
HT	0.17	.	0.20	.	0.11e	.	0.20	.	0.26	.
HT4	0.18	0.01	0.23	0.02	0.17de	0.02	0.19	0.02	0.17	0.01
HT3	0.16	0.00	.	.	0.20abc	0.00	0.20	0.01	0.19	0.01
HT2	0.16	0.01	0.19	0.03	0.19cd	0.01	0.19	0.01	0.17	0.02
HT1	.	.	0.20	0.02	0.18cde	0.01	0.17	0.00	0.19	0.01
CCSP	0.18	0.03	0.17	0.02	0.18cde	0.01	0.18	0.02	0.14	0.01
K										
CONTROL	1.42abc	0.07	1.59ab	0.18	1.58a	0.02	1.74a	0.02	1.63ab	0.04
RRB	1.56a	0.06	1.72a	0.08	1.54a	0.10	1.49abc	0.15	1.73a	0.06
HNT1	.	.	1.45abc	0.09	1.40abc	0.20	1.39abcd	0.06	1.57abc	0.09
HT	1.18bc	.	1.19c	.	1.36ab	.	1.08d	.	1.18e	.
HT4	1.50a	0.10	1.09c	0.14	1.30abc	0.04	1.20bcd	0.15	1.34cde	0.07
HT3	1.40abc	0.07	.	.	1.08c	0.03	1.50ab	0.06	1.27de	0.14
HT2	1.50ab	0.07	1.27bc	0.15	1.17bc	0.07	1.20cd	0.11	1.38bcde	0.11
HT1	.	.	1.18c	0.13	1.25abc	0.04	1.44abc	0.09	1.48abcd	0.21
CCSP	1.11c	0.02	1.50abc	0.09	1.12bc	0.06	1.28bcd	0.11	1.16e	0.02
Ca/P										
CONTROL	12.1	1.5	11.4	0.4	15.8ab	0.8	17.9ab	3.8	18.6	0.8
RRB	8.7	1.5	11.6	1.3	14.2abc	0.1	18.1a	2.1	13.3	0.3
HNT1	.	.	11.1	1.2	14.0abc	1.2	12.4bc	1.0	12.9	3.52
HT	9.9	.	7.9	.	16.4a	.	14.1ab	.	12.5	.
HT4	7.2	0.5	9.3	0.8	12.7bc	1.1	15.1ab	1.0	11.2	2.1
HT3	6.8	0.1	.	.	12.5c	1.5	9.9c	1.1	14.4	1.6
HT2	8.3	0.6	9.9	0.7	11.7c	1.0	13.2abc	0.6	11.4	1.3
HT1	.	.	10.4	1.1	13.2bc	0.4	11.1c	0.4	12.8	0.7
CCSP	8.4	1.5	5.6	0.0	10.8c	1.8	13.4abc	0.7	13.7	0.3

Table 3. Continued.

[a] Row means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP=clearcut, summer site prep burn (1985); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 4. Nutrient response of winged sumac after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. Means are unadjusted for rainfall.^{a}

Nutrient, Treatment^b	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Crude Protein										
CONTROL	7.1	.	7.5	1.0	8.7ab	0.3	9.6	1.1	8.3	0.9
RRB	6.8	0.0	11.6	3.9	7.0c	0.0	8.2	0.3	8.1	0.7
HNT1	.	.	8.6	0.9	7.3bc	0.3	8.4	0.5	7.2	0.3
HT	11.7	.	10.8	.	7.5abc	.	8.1	.	9.7	.
HT4	10.3	1.5	10.9	1.1	8.2abc	0.5	9.7	0.3	8.4	0.8
HT3	10.5	0.4	.	.	8.6ab	0.8	9.0	0.4	8.6	0.9
HT2	10.1	0.4	10.9	0.8	8.0abc	0.5	9.1	0.5	8.7	1.0
HT1	.	.	10.3	0.1	7.1c	0.4	8.9	0.2	7.9	0.2
CCSP	11.5	0.8	12.6	1.1	9.3a	0.6	10.3	0.4	10.0	0.6
ADF										
CONTROL	23.6	.	21.6	0.1	21.8	0.4	22.1	0.7	18.2	0.4
RRB	27.9	0.1	22.4	6.4	18.9	0.8	19.4	1.8	18.1	0.4
HNT1	.	.	17.5	0.7	19.1	0.9	20.1	1.7	17.1	0.8
HT	22.0	.	13.7	.	15.6	.	18.1	.	16.0	.
HT4	32.4	4.0	21.1	2.7	18.8	2.1	27.7	2.7	17.3	0.5
HT3	21.6	2.1	.	.	21.3	0.2	24.4	3.2	16.6	1.1
HT2	28.0	2.9	16.2	1.2	16.6	0.7	21.0	0.8	17.8	2.2
HT1	.	.	15.9	1.0	19.8	0.7	20.5	0.8	16.6	0.2
CCSP	26.0	2.7	18.2	3.3	18.7	1.0	23.2	2.4	17.9	0.8
ASH										
CONTROL	5.2	.	4.8	0.6	4.7	0.5	4.6	0.5	4.8	0.7
RRB	5.5	0.3	4.8	0.5	4.3	0.1	4.7	0.3	5.3	1.1
HNT1	.	.	4.8	0.2	5.0	0.2	4.7	0.2	4.8	0.3
HT	5.1	.	4.3	.	4.4	.	4.6	.	5.2	.
HT4	5.5	0.6	4.7	0.3	4.7	0.1	5.0	0.1	4.7	0.1
HT3	5.0	0.3	.	.	4.4	0.4	4.8	0.3	4.4	0.1
HT2	4.2	0.2	4.5	0.3	4.2	0.4	4.6	0.2	4.5	0.1
HT1	.	.	4.3	0.2	5.2	0.2	4.2	0.2	5.2	0.3
CCSP	5.2	0.3	4.8	0.9	4.1	0.1	4.5	0.2	4.6	0.1

Table 4. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
TDN										
CONTROL	74.4	.	76.2	0.1	76.1	0.4	75.7	0.7	79.3	0.4
RRB	70.5	0.1	75.4	5.9	78.7	0.8	78.2	1.6	79.3	0.4
HNT1	.	.	80.0	0.7	78.5	0.8	77.5	1.6	80.3	0.8
HT	75.8	.	83.4	.	81.7	.	79.5	.	81.4	.
HT4	66.3	3.7	76.7	2.5	78.8	1.9	70.7	2.5	80.1	0.4
HT3	76.2	1.9	.	.	76.5	0.2	73.7	3.0	80.8	0.9
HT2	70.4	2.6	81.2	1.1	80.8	0.6	76.8	0.7	79.7	2.0
HT1	.	.	81.4	0.9	77.8	0.7	77.2	0.8	80.7	0.1
CCSP	72.2	2.4	79.3	3.0	78.9	0.9	74.7	2.2	79.7	0.8
Ca										
CONTROL	1.37	.	1.23	0.25	1.18	0.23	1.06	0.25	1.06	0.21
RRB	1.18	0.07	1.20	0.17	0.93	0.01	0.83	0.20	0.94	0.07
HNT1	.	.	1.17	0.04	1.24	0.09	0.90	0.09	0.97	0.04
HT	1.06	.	0.84	.	1.04	.	1.11	.	0.81	.
HT4	1.01	0.08	1.10	0.02	1.06	0.05	1.05	0.06	0.91	0.04
HT3	1.03	0.09	.	.	1.04	0.03	0.87	0.21	0.90	0.02
HT2	0.93	0.09	1.03	0.12	0.81	0.07	0.97	0.16	0.88	0.01
HT1	.	.	0.97	0.01	1.08	0.15	0.61	0.07	1.03	0.06
CCSP	0.97	0.07	0.78	0.11	0.93	0.12	0.78	0.03	0.88	0.08
P										
CONTROL	0.07c	.	0.08c	0.00	0.10c	0.00	0.09d	0.01	0.09d	0.00
RRB	0.12bc	0.01	0.12bc	0.02	0.10c	0.01	0.10cd	0.01	0.10cd	0.01
HNT1	.	.	0.17ab	0.02	0.13ab	0.01	0.11bcd	0.01	0.11cd	0.01
HT	0.14ab	.	0.13bc	.	0.11bc	.	0.09d	.	0.19a	.
HT4	0.16a	0.01	0.22a	0.05	0.14a	0.01	0.13ab	0.01	0.14abc	0.01
HT3	0.15a	0.00	.	.	0.14a	0.01	0.12abc	0.01	0.14abc	0.04
HT2	0.14ab	0.01	0.22a	0.01	0.12abc	0.00	0.11bcd	0.01	0.11cd	0.01
HT1	.	.	0.18ab	0.01	0.14ab	0.02	0.13a	0.00	0.16ab	0.02
CCSP	0.12bc	0.01	0.17ab	0.00	0.13ab	0.01	0.13a	0.00	0.17ab	0.01

Table 4. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Mg										
CONTROL	0.18c	.	0.17	0.04	0.17	0.05	0.17	0.05	0.14	0.04
RRB	0.18c	0.00	0.17	0.05	0.12	0.00	0.13	0.02	0.14	0.02
HNT1	.	.	0.15	0.01	0.16	0.01	0.16	0.01	0.12	0.01
HT	0.21a	.	0.16	.	0.14	.	0.18	.	0.11	.
HT4	0.20ab	0.00	0.18	0.01	0.16	0.02	0.19	0.01	0.14	0.02
HT3	0.19bc	0.01	.	.	0.14	0.01	0.17	0.04	0.12	0.01
HT2	0.19bc	0.01	0.15	0.01	0.12	0.00	0.14	0.01	0.13	0.00
HT1	.	.	0.15	0.02	0.13	0.02	0.13	0.01	0.15	0.01
CCSP	0.23a	0.00	0.17	0.02	0.16	0.03	0.15	0.01	0.13	0.00
K										
CONTROL	0.70	.	0.86	0.03	0.75	0.16	0.79	0.14	0.82	0.12
RRB	1.19	0.01	0.98	0.03	1.00	0.03	0.73	0.07	1.07	0.16
HNT1	.	.	0.83	0.07	0.92	0.04	0.96	0.12	0.90	0.05
HT	1.01	.	0.95	.	0.84	.	0.70	.	1.32	.
HT4	1.31	0.14	0.86	0.14	0.95	0.05	1.04	0.11	0.94	0.06
HT3	1.00	0.09	.	.	0.92	0.07	1.12	0.02	0.90	0.13
HT2	1.12	0.13	0.91	0.06	0.92	0.03	0.99	0.11	0.96	0.04
HT1	.	.	0.89	0.13	1.00	0.04	1.17	0.02	0.93	0.08
CCSP	0.94	0.08	1.21	0.12	0.84	0.02	1.17	0.05	1.02	0.01
Ca/P										
CONTROL	19.6	.	14.8a	3.7	11.8	2.3	12.2	4.1	11.8a	2.3
RRB	9.9	0.2	10.1a	0.3	9.8	0.6	8.2	2.1	9.3ab	0.9
HNT1	.	.	7.0abc	1.0	9.6	1.5	8.3	1.3	9.1ab	0.2
HT	7.6	.	6.5ab	.	9.5	.	12.3	.	4.3e	.
HT4	6.2	0.6	5.6bcd	1.3	7.5	0.6	8.4	0.9	6.4cde	0.2
HT3	6.9	0.6	.	.	7.4	0.4	7.2	1.2	7.0bcd	2.2
HT2	6.8	0.8	4.7d	0.6	6.6	0.5	9.0	1.9	8.3bc	0.4
HT1	.	.	5.4bcd	0.4	8.0	0.3	4.7	0.5	6.5cde	0.4
CCSP	8.1	0.8	4.6cd	0.6	7.0	0.7	6.1	0.4	5.2de	0.8

Table 4. Continued.

[a] Row means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP=clearcut, summer site prep burn (1985); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 5. Nutrient response of winged elm after timber harvest in summer 1984, and periodic prescribed fire on oak-pine sites in the Ouachita Mountains from 1985 to 1989. Means are unadjusted for rainfall[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Crude Protein										
CONTROL	7.2cd	0.4	9.1	1.0	10.0	0.2	9.8ab	0.6	9.6bc	0.2
RRB	7.0d	0.5	10.1	0.9	9.4	0.4	8.8bcd	0.2	10.0ab	0.1
HNT1	.	.	9.4	0.6	8.9	0.8	8.3cd	0.2	8.1d	0.2
HT	7.0d	.	11.3	.	9.4	.	8.3d	.	10.3a	.
HT4	8.2abc	0.3	12.7	2.1	9.7	0.4	9.3abc	0.2	9.3c	0.2
HT3	8.8ab	0.7	.	.	10.6	0.2	10.5a	0.2	8.3d	0.6
HT2	7.7bcd	0.2	11.0	0.4	9.2	0.5	9.2abcd	0.2	9.4c	0.2
HT1	.	.	14.4	.	8.7	0.2	9.7abcd	1.3	7.8d	0.9
CCSP	11.0a	0.8	13.5	0.2	10.5	0.3	10.6a	0.4	10.0ab	0.1
ADF										
CONTROL	43.7	4.4	35.5	5.9	32.8	0.6	38.9	7.3	30.8	0.9
RRB	47.5	1.7	31.9	3.8	29.7	0.3	30.6	0.8	28.2	0.8
HNT1	.	.	28.3	0.6	30.4	1.2	26.7	2.2	26.8	1.3
HT	51.8	.	28.6	.	27.6	.	33.9	.	26.7	.
HT4	47.4	1.3	29.7	4.6	26.8	1.0	46.4	3.2	26.1	0.8
HT3	45.3	2.1	.	.	29.7	2.6	34.3	1.1	28.3	2.1
HT2	47.1	0.2	27.0	0.8	28.4	1.2	32.7	2.6	26.4	0.5
HT1	.	.	24.2	.	28.3	1.3	37.5	13.9	26.0	0.3
CCSP	48.4	0.3	24.8	0.9	29.0	1.9	42.7	7.9	29.8	0.8
ASH										
CONTROL	8.0	0.5	9.0	1.0	9.7	0.4	10.4	0.4	10.7	0.1
RRB	7.3	0.5	10.1	0.1	11.1	0.3	10.3	0.7	12.4	0.9
HNT1	.	.	9.3	0.1	9.3	0.4	11.0	1.0	11.3	0.7
HT	6.1	.	8.8	.	8.5	.	8.7	.	9.2	.
HT4	7.5	0.3	9.3	0.4	9.7	0.8	10.0	0.5	10.7	0.6
HT3	8.2	0.1	.	.	7.6	1.0	10.8	0.3	10.9	0.6
HT2	6.7	0.7	10.1	0.4	9.0	0.1	9.2	0.5	10.3	0.1
HT1	.	.	9.8	.	9.2	1.1	11.3	0.9	11.3	0.2
CCSP	7.9	0.9	8.7	0.0	8.8	0.5	9.4	0.5	9.1	0.5

Table 5. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
TDN										
CONTROL	56.1	4.0	63.6	5.4	66.0	0.5	60.4	6.6	67.8	0.8
RRB	52.6	1.6	66.9	3.5	68.9	0.3	68.0	0.7	70.2	0.7
HNT1	.	.	70.1	0.6	68.2	1.1	71.6	2.0	71.5	1.2
HT	48.7	.	69.8	.	70.8	.	65.1	.	71.5	.
HT4	52.7	1.2	68.8	4.2	71.4	0.9	53.7	2.9	72.1	0.7
HT3	54.6	1.9	.	.	68.8	2.4	64.7	1.1	70.1	2.0
HT2	52.9	0.2	71.3	0.7	70.0	1.1	66.2	2.4	71.8	0.5
HT1	.	.	73.8	.	70.2	1.1	61.7	12.7	72.2	0.2
CCSP	51.7	0.3	73.3	0.8	69.5	1.7	57.0	7.2	68.7	0.8
Ca										
CONTROL	1.48	0.04	1.57	0.18	1.71ab	0.08	1.82a	0.15	1.71ab	0.08
RRB	1.31	0.09	1.64	0.11	1.90a	0.02	1.67ab	0.09	1.78a	0.06
HNT1	.	.	1.53	0.05	1.53bc	0.03	1.70ab	0.08	1.74ab	0.15
HT	1.16	.	1.29	.	1.67ab	.	1.40cd	.	1.37c	.
HT4	1.20	0.13	1.50	0.03	1.84a	0.12	1.55abc	0.12	1.51bc	0.08
HT3	1.33	0.08	.	.	1.40c	0.02	1.39cd	0.10	1.52abc	0.06
HT2	1.30	0.09	1.67	0.13	1.52bc	0.04	1.37cd	0.04	1.41c	0.02
HT1	.	.	1.40	.	1.69a	0.06	1.48bc	0.04	1.54bc	0.01
CCSP	1.37	0.08	1.18	0.07	1.49c	0.10	1.27d	0.10	1.47c	0.09
P										
CONTROL	0.09	0.01	0.11	0.01	0.12	0.01	0.11	0.00	0.10	0.01
RRB	0.11	0.00	0.13	0.01	0.12	0.01	0.11	0.00	0.12	0.01
HNT1	.	.	0.14	0.02	0.13	0.01	0.10	0.00	0.10	0.01
HT	0.10	.	0.12	.	0.12	.	0.10	.	0.10	.
HT4	0.13	0.02	0.20	0.06	0.14	0.01	0.12	0.01	0.11	0.01
HT3	0.11	0.00	.	.	0.15	0.00	0.11	0.01	0.12	0.00
HT2	0.10	0.00	0.17	0.02	0.13	0.01	0.12	0.01	0.10	0.00
HT1	.	.	0.17	.	0.14	0.00	0.11	0.00	0.11	0.01
CCSP	0.14	0.01	0.17	0.01	0.14	0.00	0.12	0.00	0.11	0.00

Table 5. Continued.[a]

Nutrient, Treatment[b]	Year									
	1985		1986		1987		1988		1989	
	X	SE	X	SE	X	SE	X	SE	X	SE
Mg										
CONTROL	0.18	0.01	0.22	0.01	0.30a	0.00	0.28a	0.01	0.26a	0.01
RRB	0.21	0.03	0.23	0.01	0.27ab	0.01	0.25abc	0.01	0.25ab	0.02
HNT1	.	.	0.20	0.01	0.22cd	0.01	0.21c	0.02	0.21bcd	0.01
HT	0.19	.	0.18	.	0.19d	.	0.24bc	.	0.10d	.
HT4	0.22	0.01	0.23	0.01	0.21cd	0.01	0.22c	0.01	0.24ab	0.01
HT3	0.22	0.05	.	.	0.20cd	0.02	0.25abc	0.02	0.21bcd	0.01
HT2	0.20	0.01	0.23	0.01	0.22cd	0.01	0.22c	0.01	0.22abcd	0.02
HT1	.	.	0.22	.	0.23bc	0.02	0.28ab	0.02	0.23abc	0.01
CCSP	0.21	0.02	0.21	0.00	0.22bc	0.01	0.24abc	0.01	0.19cd	0.01
K										
CONTROL	0.69	0.06	0.73	0.03	0.85	0.01	0.96	0.09	0.99bc	0.01
RRB	0.73	0.03	0.83	0.02	0.85	0.03	0.86	0.04	1.09a	0.01
HNT1	.	.	0.84	0.06	0.96	0.07	0.94	0.14	0.98bc	0.06
HT	0.65	.	0.75	.	1.04	.	0.80	.	1.06ab	.
HT4	0.72	0.08	0.94	0.18	0.88	0.03	0.96	0.02	1.04ab	0.03
HT3	0.75	0.07	.	.	0.88	0.03	1.02	0.01	0.86c	0.07
HT2	0.71	0.02	0.74	0.06	0.88	0.08	0.80	0.09	1.02abc	0.02
HT1	.	.	0.89	.	0.91	0.06	0.99	0.09	0.94bc	0.10
CCSP	0.81	0.06	0.92	0.10	0.85	0.01	0.96	0.07	0.86c	0.03
Ca/P										
CONTROL	16.5	0.9	14.7a	0.5	14.3ab	0.0	17.2a	1.7	17.3	1.7
RRB	11.6	1.1	13.0ab	1.2	15.9a	0.7	15.6ab	0.4	14.9	0.9
HNT1	.	.	11.0abc	1.2	12.0bcde	0.9	16.5a	1.1	16.9	1.2
HT	11.6	.	10.8abc	.	13.9abc	.	14.0abc	.	13.7	.
HT4	10.1	2.4	8.9bc	2.2	13.0abcd	1.5	13.1bc	1.6	13.9	1.2
HT3	12.7	1.4	.	.	9.7e	0.5	12.1c	0.4	12.7	0.5
HT2	12.5	0.6	10.1bc	0.4	11.8cde	1.0	11.3c	1.0	13.6	0.5
HT1	.	.	8.2c	.	12.1bcde	0.5	12.9bc	0.9	14.1	1.2
CCSP	10.2	0.7	7.2c	0.7	10.9de	0.7	10.9c	1.1	13.4	0.9

Table 5. Continued.

[a] Row means followed by the same letter within nutrient category are not significantly different at the 0.05 level.

[b] Control = no treatment; RRB = rough reduction burn (1985, 1989); CCSP=clearcut, summer site prep burn (1985); HT = harvest pine timber, thin hardwoods, no burn; HT4 = harvest pine timber, thin hardwoods, winter burn 4 year cycle (1985, 1989); HT3 = harvest pine timber, thin hardwoods, winter burn 3 year cycle (1985, 1988); HT2 = harvest pine timber, thin hardwoods, winter burn 2 year cycle (1985, 1987, 1989); HT1 = harvest pine timber, thin hardwoods, winter burn annually; HNT1 = harvest pine timber, no thinning of hardwoods, winter burn annually.

Table 6. Elmleaf goldenrod Pearson correlation coefficients for nutrient response and overstory characteristics on Pushmataha Forest Habitat Research Area 1985-1989.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Crude Protein				
1985	-0.571**	-0.603***	-0.507**	-0.539**
1986	-0.610***	-0.643***	-0.501**	-0.624***
1987	-0.024	-0.014	-0.030	0.036
1988	-0.840***	-0.884***	-0.710***	-0.859***
1989	-0.017	-0.067	0.027	-0.013
ADF				
1985	0.171	0.202	0.134	0.200
1986	0.535**	0.590***	0.417*	0.551***
1987	0.590***	0.483**	0.608**	0.513**
1988	0.770***	0.744***	0.706***	0.774***
1989	0.744***	0.619***	0.752***	0.720***
IVDMD				
1986	0.614***	0.599***	0.613***	0.545**
ASH				
1985	0.264	0.191	0.308	0.288
1986	0.675***	0.552***	0.689***	0.684***
1987	0.460**	0.405*	0.451**	0.538***
1988	0.301	0.312	0.258	0.369*
1989	0.624***	0.534**	0.618***	0.654***
TDN				
1985	-0.172	-0.203	-0.135	-0.201
1986	-0.275	-0.438**	-0.102	-0.288
1987	-0.591***	-0.485**	-0.609***	-0.514**
1988	-0.768***	-0.743***	-0.703***	-0.772***
1989	-0.745***	-0.620***	-0.752***	-0.722***

Table 6. Continued.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Ca				
1985	0.820***	0.757***	0.818***	0.789***
1986	0.461**	0.373*	0.473**	0.449**
1987	0.642***	0.634***	0.572***	0.634***
1988	0.582***	0.658***	0.453**	0.634***
1989	0.793***	0.678***	0.788***	0.779***
P				
1985	-0.476**	-0.431*	-0.482**	-0.508**
1986	-0.486**	-0.442**	-0.459**	-0.487**
1987	-0.334	-0.305	-0.317	-0.279
1988	-0.781***	-0.798***	-0.679***	-0.761***
1989	-0.532**	-0.438*	-0.544**	-0.469**
Mg				
1985	-0.238	-0.195	-0.258	-0.270
1986	-0.207	-0.279	-0.120	-0.224
1987	0.336	0.225	0.390*	0.356*
1988	-0.285	-0.380*	-0.173	-0.307
1989	0.829***	0.715***	0.818***	0.800***
K				
1985	0.597***	0.567**	0.582**	0.571**
1986	0.703***	0.750***	0.570***	0.757***
1987	0.323	0.336	0.273	0.370*
1988	-0.288	-0.233	-0.303	-0.226
1989	0.459**	0.420*	0.431*	0.501**

[a] * = P >|r|< 0.10, ** = P >|r|< 0.05, *** = P >|r|< 0.01, otherwise non-significant.

Table 7. Stiff sunflower Pearson correlation coefficients for nutrient response and overstory characteristics on Pushmataha Forest Habitat Research Area 1985-1989.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Crude Protein				
1985	-0.537**	-0.514**	-0.522**	-0.535**
1986	-0.415*	-0.507**	-0.273	-0.398*
1987	0.076	-0.139	0.248	0.060
1988	-0.519**	-0.699***	-0.309	-0.544***
1989	-0.185	-0.277	-0.083	-0.250
ADF				
1985	-0.412	-0.376	-0.417	-0.352
1986	0.048	-0.082	0.162	-0.014
1987	-0.423**	-0.417**	-0.377*	-0.399*
1988	0.153	0.123	0.162	0.208
1989	0.588***	0.479**	0.603***	0.599***
IVDMD				
1986	0.377	0.562**	0.156	0.421*
ASH				
1985	0.566**	0.451*	0.632***	0.513**
1986	0.254	0.278	0.198	0.260
1987	0.426**	0.275	0.502**	0.324
1988	-0.253	-0.367*	-0.129	-0.248
1989	0.189	0.229	0.131	0.200
TDN				
1985	0.413	0.379	0.416	0.353
1986	-0.048	0.083	-0.162	0.013
1987	0.427**	0.421**	0.380*	0.402*
1988	-0.156	-0.125	-0.164	-0.210
1989	-0.561***	-0.422*	-0.605***	-0.571***

Table 7. Continued.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Ca				
1985	0.626***	0.514**	0.684***	0.551***
1986	0.225	0.188	0.229	0.211
1987	0.115	0.155	0.066	-0.002
1988	-0.319	-0.412*	-0.205	-0.319
1989	-0.099	-0.016	-0.156	-0.137
P				
1985	-0.660***	-0.684***	-0.596**	-0.644***
1986	-0.453**	-0.533**	-0.317	-0.440*
1987	-0.688***	-0.772***	-0.533***	-0.647***
1988	-0.472**	-0.584***	-0.325	-0.484**
1989	-0.385*	-0.445**	-0.285	-0.376*
Mg				
1985	0.105	0.129	0.077	0.138
1986	0.267	0.158	0.331	0.237
1987	0.499**	0.351	0.562**	0.467**
1988	-0.199	-0.361*	-0.041	-0.256
1989	0.203	0.086	0.274	0.259
K				
1985	-0.228	-0.229	-0.212	-0.184
1986	0.025	-0.003	0.048	0.044
1987	-0.318	-0.339	-0.261	-0.241
1988	-0.591***	-0.639***	-0.484**	-0.567***
1989	-0.342	-0.304	-0.329	-0.416*

[a] * = P >|r|< 0.10, ** = P >|r|< 0.05, *** = P >|r|< 0.01, otherwise non-significant.

Table 8. Greenbriar Pearson correlation coefficients for nutrient response and overstory characteristics on Pushmataha Forest Habitat Research Area 1985-1989.[a]

Nutrient (%), Year	Overstory Characteristic			
	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Crude Protein				
1985	-0.840***	-0.812***	-0.807***	-0.842***
1986	-0.459**	-0.497**	-0.366	-0.431*
1987	-0.019	-0.191	0.129	0.008
1988	-0.244	-0.305	-0.165	-0.275
1989	0.256	0.051	0.396*	0.239
ADF				
1985	0.464*	0.441*	0.453*	0.435*
1986	0.406*	0.375*	0.379*	0.377*
1987	0.598***	0.571***	0.548***	0.575***
1988	0.181	0.074	0.250	0.155
1989	0.840***	0.722***	0.829***	0.82***
IVDMD				
1986	0.077	0.096	0.378*	0.377*
ASH				
1985	0.160	0.196	0.119	0.146
1986	0.456**	0.546**	0.319	0.469**
1987	0.809***	0.747***	0.762***	0.766***
1988	0.779***	0.705***	0.753***	0.763***
1989	0.816***	0.785***	0.763***	0.801***
TDN				
1985	-0.466*	-0.442*	-0.454*	-0.436*
1986	-0.406*	-0.375*	-0.378*	-0.377*
1987	-0.599***	-0.572***	-0.550***	-0.576***
1988	-0.181	-0.075	-0.250	-0.156
1989	-0.839***	-0.724***	-0.827***	-0.820***

Table 8. Continued.[a]

Nutrient (%), Year	Overstory Characteristic			
	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Ca				
1985	-0.092	-0.036	-0.132	-0.057
1986	0.241	0.322	0.141	0.254
1987	0.535***	0.561***	0.448**	0.506**
1988	0.552***	0.453**	0.574***	0.553***
1989	0.619***	0.653***	0.509**	0.593***
P				
1985	-0.706***	-0.720***	-0.647***	-0.751***
1986	-0.520**	-0.505**	-0.464**	-0.511**
1987	-0.306	-0.364*	-0.220	-0.304
1988	-0.473**	-0.425**	-0.460**	-0.479**
1989	-0.248	-0.233	-0.228	-0.254
Mg				
1985	-0.200	-0.177	-0.205	-0.219
1986	0.306	0.155	0.392*	0.274
1987	0.687***	0.628***	0.653***	0.622***
1988	0.673***	0.519**	0.727***	0.656***
1989	0.381*	0.362*	0.348	0.366*
K				
1985	0.380	0.420*	0.322	0.314
1986	0.627***	0.496**	0.653***	0.591***
1987	0.706***	0.655***	0.663***	0.699***
1988	0.597***	0.562***	0.561***	0.587***
1989	0.707***	0.714***	0.609***	0.720***

[a] * = P >|r|< 0.10, ** = P >|r|< 0.05, *** = P >|r|< 0.01, otherwise non-significant.

Table 9. Winged sumac Pearson correlation coefficients for nutrient response and overstory characteristics on Pushmataha Forest Habitat Research Area 1985-1989.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Crude Protein				
1985	-0.751***	-0.759***	-0.716***	-0.675***
1986	-0.345	-0.479**	-0.171	-0.389*
1987	-0.188	-0.277	-0.087	-0.138
1988	-0.355	-0.368*	-0.302	-0.380*
1989	-0.131	-0.241	-0.023	-0.111
ADF				
1985	0.006	0.058	-0.031	-0.046
1986	0.383	0.243	0.453*	0.305
1987	0.227	0.216	0.205	0.176
1988	-0.365*	-0.408*	-0.286	-0.426**
1989	0.306	0.265	0.298	0.355
IVDMD				
1986	-0.016	0.157	-0.171	0.067
ASH				
1985	0.237	0.308	0.177	0.159
1986	0.147	0.077	0.188	0.093
1987	0.077	0.177	-0.024	0.003
1988	0.025	-0.051	0.084	-0.013
1989	0.296	0.147	0.376*	0.302
TDN				
1985	-0.004	-0.056	0.034	0.007
1986	-0.385	-0.243	-0.455*	-0.306
1987	-0.228	-0.218	-0.205	-0.178
1988	0.363*	0.407*	0.284	0.424**
1989	-0.320	-0.279	-0.309	-0.370*

Table 9. Continued.[a]

Nutrient (%), Year	Overstory Characteristic			
	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Ca				
1985	0.764***	0.808***	0.703***	0.743***
1986	0.576***	0.526**	0.534**	0.522**
1987	0.268	0.373*	0.136	0.234
1988	0.147	0.172	0.109	0.076
1989	0.399*	0.320	0.407*	0.351
P				
1985	-0.588**	-0.447*	-0.666***	-0.613**
1986	-0.634***	-0.555**	-0.609***	-0.646***
1987	-0.724***	-0.654***	-0.686***	-0.716***
1988	-0.709***	-0.691***	-0.638***	-0.686***
1989	-0.519**	-0.559***	-0.414*	-0.539**
Mg				
1985	-0.552**	-0.594**	-0.500*	-0.498*
1986	0.094	-0.108	0.262	0.025
1987	0.136	0.121	0.129	0.124
1988	-0.014	0.000	-0.024	-0.084
1989	0.304	0.102	0.426*	0.264
K				
1985	-0.066	0.010	-0.118	-0.004
1986	-0.174	-0.280	-0.052	-0.211
1987	-0.287	-0.195	-0.330	-0.274
1988	-0.734***	-0.680***	-0.690***	-0.720***
1989	0.007	-0.083	0.078	0.056

[a] * = P >|r|< 0.10, ** = P >|r|< 0.05, *** = P >|r|< 0.01, otherwise non-significant.

Table 10. Winged elm Pearson correlation coefficients for nutrient response and overstory characteristics on Pushmataha Forest Habitat Research Area 1985-1989.[a]

Nutrient (%), Year	Overstory Characteristic			
	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Crude Protein				
1985	-0.602***	-0.627***	-0.543**	-0.591***
1986	-0.561**	-0.648***	-0.411*	-0.568**
1987	-0.005	-0.060	0.042	0.008
1988	-0.241	-0.321	-0.147	-0.273
1989	0.375*	0.200	0.470**	0.392*
ADF				
1985	-0.267	-0.198	-0.307	-0.249
1986	0.498**	0.539**	0.395*	0.499**
1987	0.518**	0.510**	0.462**	0.539***
1988	-0.202	-0.277	-0.116	-0.215
1989	0.566***	0.399*	0.629***	0.520**
IVDMD				
1986	0.318	0.276	0.309	0.275
ASH				
1985	0.088	0.051	0.112	0.091
1986	0.115	-0.113	0.284	0.069
1987	0.496**	0.365*	0.546***	0.490**
1988	0.119	0.085	0.135	0.158
1989	0.362*	0.285	0.376*	0.421*
TDN				
1985	0.269	0.201	0.308	0.251
1986	-0.496**	-0.537**	-0.393*	-0.497**
1987	-0.519**	-0.512**	-0.462**	-0.540***
1988	0.201	0.276	0.115	0.214
1989	-0.562***	-0.396*	-0.624***	-0.517**

Table 10. Continued.[a]

	Overstory Characteristic			
Nutrient (%), Year	Total Basal Area	Hardwood Basal Area	Pine Basal Area	Percent Canopy Cover
Ca				
1985	0.337	0.227	0.406*	0.410*
1986	0.379	0.248	0.433*	0.347
1987	0.472**	0.337	0.528***	0.486**
1988	0.666***	0.635***	0.617***	0.679***
1989	0.657***	0.661***	0.564***	0.657***
P				
1985	-0.421*	-0.483**	-0.343	-0.452*
1986	-0.504**	-0.519**	-0.422*	-0.543**
1987	-0.550***	-0.504**	-0.522**	-0.560***
1988	-0.474**	-0.507**	-0.394*	-0.493**
1989	-0.022	-0.012	-0.027	-0.029
Mg				
1985	-0.273	-0.325	-0.213	-0.311
1986	0.074	-0.140	0.238	0.007
1987	0.799***	0.727***	0.762***	0.752***
1988	0.388*	0.295	0.423**	0.342
1989	0.408*	0.300	-0.129	0.381*
K				
1985	-0.208	-0.256	-0.156	-0.245
1986	-0.260	-0.266	-0.218	-0.307
1987	-0.111	0.071	-0.252	-0.095
1988	-0.056	0.038	-0.129	-0.042
1989	0.371*	0.358	0.332	0.416*

[a] * = $P > |r| < 0.10$, ** = $P > |r| < 0.05$, *** = $P > |r| < 0.01$, otherwise non-significant.

Table 11. Rainfall patterns which best explain year to year variation in nutrient content of elmleaf goldenrod.

	Positive[ab]		Negative[bc]	
Nutrient	Month(s)	r	Month(s)	r
Crude Protein	Apr & Sep	0.652***	July	-0.520***
ADF	March	0.280**	May	-0.386***
Ash	July & Sep	0.342***	August	-0.231***
TDN	Mar & May	0.298**	Mar & Aug	-0.186
Ca	July-Sep	0.281**	Mar & Apr	-0.150
P	Apr & May	0.552***	Mar & July	-0.546***
Mg	Apr & Aug	0.330***	July & Sep	-0.384***
K	Mar & Sep	0.330***	August	-0.296**

[a] Higher amounts of rainfall in this period are associated with increased content of this nutrient.

[b] * = Probability >|r|< 0.05, ** = Probability >|r|< 0.01, *** = Probability >|r|< 0.001, otherwise non-significant.

[c] Higher amounts of rainfall in this period are associated with decreased content of this nutrient.

Table 12. Rainfall patterns which best explain year to year variation in nutrient content of stiff sunflower.

	Positive[ab]		Negative[bc]	
Nutrient	Month(s)	r	Month(s)	r
Crude Protein	April	0.496***	July	-0.439***
ADF	March	0.334***	May & July	-0.511***
Ash	July-Sept	0.660***	April	-0.414***
TDN	May & July	0.514***	March	-0.323***
Ca	May & July	0.616***	Mar & Apr	-0.316**
P	Apr & May	0.449***	July	-0.493***
Mg	August	0.317**	Mar & Sept	-0.310**
K	Mar & Sept	0.218*	Mar & Aug	-0.205*

[a] Higher amounts of rainfall in this period are associated with increased content of this nutrient.

[b] * = Probability >|r|< 0.05, ** = Probability >|r|< 0.01, *** = Probability >|r|< 0.001, otherwise non-significant.

[c] Higher amounts of rainfall in this period are associated with decreased content of this nutrient.

Table 13. Rainfall patterns which best explain year to year variation in nutrient content of greenbriar.

	Positive[ab]		Negative[bc]	
Nutrient	Month(s)	r	Month(s)	r
Crude Protein	Mar - Aug	0.253**	March	-0.073
ADF	Mar & Apr	0.514***	July-Sept	-0.739***
Ash	July-Sept	0.470***	April	-0.381***
TDN	July-Sept	0.739***	Mar & Apr	-0.515***
Ca	July-Sept	0.739***	Mar & Apr	-0.556***
P	Apr & May	0.493***	July	-0.481***
Mg	August	0.282**	March	-0.176***
K	June & Jul	0.152	August	-0.075

[a] Higher amounts of rainfall in this period are associated with increased content of this nutrient.

[b] * = Probability >|r|< 0.05, ** = Probability >|r|< 0.01, *** = Probability >|r|< 0.001, otherwise non-significant.

[c] Higher amounts of rainfall in this period are associated with decreased content of this nutrient.

Table 14. Rainfall patterns which best explain year to year variation in nutrient content of winged sumac.

	Positive[ab]		Negative[bc]	
Nutrient	Month(s)	r	Month(s)	r
Crude Protein	April	0.506***	July & Sep	-0.379***
ADF	April	0.281**	May & July	-0.635***
Ash	Total	0.201*	August	-0.215*
TDN	May & July	0.635***	Mar & Apr	-0.391***
Ca	Apr & Sept	0.236*	July	-0.311**
P	Mar-May	0.491***	July	-0.402***
Mg	Mar & Apr	0.452***	July-Sept	-0.607***
K	Mar & Apr	0.225*	Aug & Sept	-0.242*

[a] Higher amounts of rainfall in this period are associated with increased content of this nutrient.

[b] * = Probability >|r|< 0.05, ** = Probability >|r|< 0.01, *** = Probability >|r|< 0.001, otherwise non-significant.

[c] Higher amounts of rainfall in this period are associated with decreased content of this nutrient.

Table 15. Rainfall patterns which best explain year to year variation in nutrient content of winged elm.

	Positive[ab]		Negative[bc]	
Nutrient	Month(s)	r	Month(s)	r
Crude Protein	May & Aug	0.487***	March	-0.444***
ADF	Mar & Apr	0.509***	May & July	-0.708***
Ash	July-Sept	0.644***	Total	-0.366***
TDN	May & July	0.707***	Mar & Apr	-0.509***
Ca	July-Sept	0.437***	Mar & Apr	-0.432***
P	May & Aug	0.495***	March	-0.528***
Mg	July & Aug	0.283**	Total	-0.344***
K	July-Sept	0.576***	April	-0.440***

[a] Higher amounts of rainfall in this period are associated with increased content of this nutrient.

[b] * = Probability >|r|< 0.05, ** = Probability >|r|< 0.01, *** = Probability >|r|< 0.001, otherwise non-significant.

[c] Higher amounts of rainfall in this period are associated with decreased content of this nutrient.

Table 16. The influence of winter prescribed burning (1985, 1989) and timber harvest (1984) on early fall nutrient response of elmleaf goldenrod on oak-pine sites in the Ouachita Mountains from 1985 to 1989.[a]

Nutrient (%), Effects[b]	Year				
	1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Crude Protein					
Burn	0.05	0.77**	-0.42	0.22	0.52
Harvest	1.12	0.87**	-0.08	0.82**	-0.01
B x H	0.78	-0.14	0.02	0.32	0.08
ADF					
Burn	-1.37	-1.30	-1.30	-1.57	-2.73
Harvest	-2.27	-5.13	-2.23	-5.77**	-5.93**
B x H	-0.40	0.30	0.27	-0.17	-0.40
Ash					
Burn	0.10	-0.04	-0.47	0.33	0.77
Harvest	-0.60	-0.75	-1.20***	-0.43	-1.50
B x H	-0.10	-0.12	-0.07	0.03	-0.23
TDN					
Burn	1.20	1.16	1.17	1.33	2.48
Harvest	2.10	4.60	2.03	5.30**	5.42**
B x H	0.33	-0.30	0.25	0.07	0.77
Ca					
Burn	-0.01	-0.05	-0.13	0.03	0.10
Harvest	-0.26***	-0.17	-0.27**	-0.16	-0.38***
B x H	0.00	0.20	0.10	0.06	0.00
P					
Burn	0.02	0.06***	0.02	0.02**	0.03***
Harvest	0.02***	0.03**	0.00	0.02**	0.02**
B x H	0.01	0.00	0.00	0.01*	0.00

Table 16. Continued.[a]

Nutrient (%), Effects[b]	Year 1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Mg					
Burn	-0.01	-0.01	-0.04*	0.00	0.01
Harvest	0.03	0.05	-0.02	0.02	-0.05**
B x H	0.01	-0.01	0.02	0.01	-0.02
K					
Burn	0.04	-0.09	-0.07	0.02	0.06
Harvest	-0.04	-0.13*	-0.03	0.01	-0.07
B x H	-0.02	-0.08	-0.05	0.09	-0.12**
Ca/P					
Burn	-0.94	-3.32***	-2.19	-1.56	-2.38
Harvest	-3.27***	-3.03**	-3.09	-4.16**	-5.48***
B x H	-0.29	1.62*	0.65	-0.71	-2.51

[a] Response is on a per unit basis (%). * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$.

[b] Main effects from 2 levels of burning (no burn and burn at 4 year intervals), 2 levels of timber harvest (harvest and no harvest), and interaction of burning and timber harvest (B x H).

Table 17. The influence of winter prescribed burning (1985, 1989) and timber harvest (1984) on early fall nutrient response of stiff sunflower on oak-pine sites in the Ouachita Mountains from 1985 to 1989.[a]

Nutrient (%) Effects[b]	Year				
	1985	1986	1987	1988	1989
	Response	Response	Response	Response	Response
Crude Protein					
Burn	0.38	-0.10	-1.18	0.34	-0.47
Harvest	1.83	1.50	0.68	0.33	0.07
B x H	1.26	-0.27	-0.19	0.67	0.57
ADF					
Burn	-4.43	4.07	0.25	1.15	-1.22
Harvest	2.27	-1.63	1.42	-3.82	-3.82
B x H	-1.07	-3.54	-1.22	2.42	-0.12
Ash					
Burn	1.04	-0.33	0.92	0.47	2.73
Harvest	-2.81	-1.98	-1.38	-0.36	-1.03
B x H	-2.04	0.24	0.22	1.54	-0.07
TDN					
Burn	4.03	-3.68	-0.23	1.10	1.18
Harvest	-2.07	1.48	-1.30	3.53	3.45
B x H	0.97	3.24	1.13	-2.24	0.15
Ca					
Burn	0.51	0.35	0.16	0.58	0.31
Harvest	-0.08*	-0.62	-0.25	0.17	0.27
B x H	-0.90*	0.07	0.32	0.46	0.24
P					
Burn	0.03	0.01	0.00	0.01	0.00
Harvest	0.03	0.04**	0.03***	-0.01	0.00
B x H	0.02	0.01	-0.01	0.02	0.00

Table 17. Continued.[a]

Nutrient (%), Effects[b]	Year 1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Mg					
Burn	-0.01	-0.12	0.02	-0.10	0.06
Harvest	0.05	-0.11	-0.24	0.10	-0.03
B x H	-0.15	0.08	0.17	-0.11	-0.10
K					
Burn	0.09	0.19	-0.03	0.14	-0.10
Harvest	-0.06	-0.05	0.34	0.04	0.03
B x H	0.28	-0.15	-0.30	0.26	0.04
Ca/P					
Burn	1.88	1.24	-0.58	2.21	2.74
Harvest	-15.33**	-14.03	-11.79**	4.81	1.32
B x H	-13.04**	-0.48	5.69	0.68	0.62

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[a] Response is on a per unit basis (%). * = $\underline{P} < 0.10$, ** = $\underline{P} < 0.05$, *** = $\underline{P} < 0.01$.

[b] Main effects from 2 levels of burning (no burn and burn at 4 year intervals), 2 levels of timber harvest (harvest and no harvest), and interaction of burning and timber harvest (B x H).

Table 18. The influence of winter prescribed burning (1985, 1989) and timber harvest (1984) on early fall nutrient response of greenbriar on oak-pine sites in the Ouachita Mountains from 1985 to 1989.[a]

Nutrient (%), Effects[b]	Year 1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Crude Protein					
Burn	1.53**	-1.16	0.04	0.07	0.95
Harvest	2.10***	2.93	-0.77	-0.78*	-0.22
B x H	1.87***	-1.30	0.97	1.25**	0.05
ADF					
Burn	1.63	1.88	-1.78**	-0.80	-2.70***
Harvest	2.40	-9.02	-3.28***	-1.77	-2.57***
B x H	-3.37	4.08	-0.42	5.47	-1.90***
Ash					
Burn	0.15	0.13	-0.35	-0.17	-0.47
Harvest	-0.32	-0.90	-1.05**	-1.23***	-1.56***
B x H	0.42	-0.30	0.12	0.67*	0.00
TDN					
Burn	-1.53	-1.73	1.63**	0.72	2.50***
Harvest	2.23	8.23	2.97***	1.62	2.33***
B x H	3.07	-3.74	0.40	-5.02	1.77***
Ca					
Burn	-0.15	0.07	-0.18	0.04	-0.27**
Harvest	0.08	-0.02	-0.11	-0.11	-0.30***
B x H	0.02	-0.06	0.04	0.15	-0.01
P					
Burn	0.02	-0.01	0.01	0.00	0.01
Harvest	0.03***	0.04	0.00	0.01	0.01
B x H	0.00	-0.02	0.01	0.01	-0.01

Table 18. Continued.[a]

Nutrient (%), Effects[b]	Year				
	1985	1986	1987	1988	1989
	Response	Response	Response	Response	Response
Mg					
Burn	0.01	0.03	0.01	0.00	0.03
Harvest	0.01	-0.01	-0.10***	-0.04	0.00
B x H	-0.01	0.00	0.05**	-0.01	-0.06
K					
Burn	0.23	0.03	-0.05	-0.07	0.13
Harvest	-0.16	0.24**	-0.23**	-0.47**	-0.42***
B x H	0.09	-0.12	-0.01	0.18	-0.03
Ca/P					
Burn	-3.06	0.81	-2.70**	0.61	-3.34*
Harvest	-1.81	-2.90	-0.42	-3.39	-4.09**
B x H	0.35	0.61	-1.10	0.42	1.96

[a] Response is on a per unit basis (%). * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$.

[b] Main effects from 2 levels of burning (no burn and burn at 4 year intervals), 2 levels of timber harvest (harvest and no harvest), and interaction of burning and timber harvest (B x H).

Table 19. The influence of winter prescribed burning (1985, 1989) and timber harvest (1984) on early fall nutrient response of winged sumac on oak-pine sites in the Ouachita Mountains from 1985 to 1989.[a]

Nutrient (%), Effects[b]	Year				
	1985	1986	1987	1988	1989
	Response	Response	Response	Response	Response
Crude Protein					
Burn	-0.84	2.06	-0.54	0.10	-0.77
Harvest	4.01	1.26	0.00	0.00	0.87
B x H	-0.59	-1.99	1.21	1.50	-0.53
ADF					
Burn	7.37	4.06	0.18	3.42	0.63
Harvest	1.47	-4.64	-3.13	2.15	-1.50
B x H	3.07	3.31	3.03	6.15	0.70
Ash					
Burn	0.37	0.24	0.00	0.23	0.00
Harvest	-0.03	-0.31	0.05	0.20	-0.10
B x H	0.07	0.19	0.30	0.17	-0.50
TDN					
Burn	-6.70	-3.72	-0.19	-3.16	-0.62
Harvest	1.47	4.23	2.86	-1.89	1.45
B x H	-2.80	-3.02	-2.74	-5.64	-0.65
Ca					
Burn	-0.12	0.11	-0.12	-0.14	-0.01
Harvest	-0.24	-0.25	-0.01	0.13	-0.14
B x H	0.07	0.14	0.14	0.17	0.11
P					
Burn	0.04*	0.06	0.01	0.03**	-0.02
Harvest	0.06**	0.07	0.03**	0.01	0.07***
B x H	-0.01	0.03	0.02*	0.01	-0.06**

Table 19. Continued.[a]

Nutrient (%), Effects[b]	Year				
	1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Mg					
Burn	-0.01***	0.01	-0.02	0.02	0.01
Harvest	0.03***	0.00	0.00	0.03	-0.02
B x H	0.01***	0.01	0.03	0.03	0.03
K					
Burn	0.40	0.02	0.18	0.14	0.07
Harvest	0.22	-0.01	0.02	0.11	0.19
B x H	-0.10	-0.10	-0.07	0.20	-0.31
Ca/P					
Burn	-5.51***	-2.75	-1.98	-3.99	-0.20
Harvest	-7.83***	-6.38	-2.35	0.13	-5.21**
B x H	4.17***	1.90	-0.01	0.04	2.31

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[a] Response is on a per unit basis (%). * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$.

[b] Main effects from 2 levels of burning (no burn and burn at 4 year intervals), 2 levels of timber harvest (harvest and no harvest), and interaction of burning and timber harvest (B x H).

Table 20. The influence of winter prescribed burning (1985, 1989) and timber harvest (1984) on early fall nutrient response of winged elm on oak-pine sites in the Ouachita Mountains from 1985 to 1989.[a]

Nutrient (%), Effects[b]	Year				
	1985 Response	1986 Response	1987 Response	1988 Response	1989 Response
Crude Protein					
Burn	0.53	1.20	-0.18	0.02	-0.33
Harvest	0.50	2.40	-0.18	-0.48	-0.03
B x H	0.67	0.17	0.45	0.98	-0.70**
ADF					
Burn	-0.30	-1.25	-2.97*	2.08	-1.57
Harvest	4.03	-4.52	-4.03***	5.35	-3.07**
B x H	-4.07	2.38	1.20	10.38	1.00
Ash					
Burn	0.35	0.80	1.32	0.57	1.62
Harvest	-0.88	-0.50	-1.32	-1.00	-1.55
B x H	1.02	-0.33	-0.30	0.70	-0.08
TDN					
Burn	0.27	1.15	1.77*	-1.90	1.50
Harvest	-3.67	4.08	3.70***	-4.83	2.77**
B x H	3.70	-2.15	-1.13	-9.53	-0.95
Ca					
Burn	-0.07	0.14	0.18	0.00	0.10
Harvest	-0.22	-0.21	-0.05	-0.27	-0.31**
B x H	0.10	0.07	-0.01	0.15	0.03
P					
Burn	0.03	0.05	0.01	0.01	0.02
Harvest	0.01	0.04	0.01	0.00	-0.01
B x H	0.00	0.03	0.01	0.01	-0.01

Table 20. Continued.[a]

Nutrient (%), Effects[b]	Year				
	1985	1986	1987	1988	1989
	Response	Response	Response	Response	Response
Mg					
Burn	0.03	0.03	0.00	-0.03*	0.07***
Harvest	0.01	-0.02	-0.09***	-0.04**	-0.08***
B x H	0.00	0.02	0.02**	0.01	0.07***
K					
Burn	0.06	0.14	-0.08**	0.03	0.04
Harvest	-0.03	0.07	0.11***	-0.03	0.01
B x H	0.02	0.05	-0.08**	0.13	-0.06**
Ca/P					
Burn	-3.18	-1.76	0.36	-1.24	-1.10
Harvest	-3.23	-4.06	-1.59	-7.16	-2.34
B x H	1.71	-0.14	-1.23	0.33	1.28

[a] Response is on a per unit basis (%). * = $P < 0.10$, ** = $P < 0.05$, *** = $P < 0.01$.

[b] Main effects from 2 levels of burning (no burn and burn at 4 year intervals), 2 levels of timber harvest (harvest and no harvest), and interaction of burning and timber harvest (B x H).

APPENDIX E

A PARTIAL LIST OF PLANTS OCCURRING ON PUSHMATAHA FOREST HABITAT RESEARCH AREA

Table 1. A partial list of plants occurring on Pushmataha Forest Habitat Research Area.

GROUP *Scientific name*	*Common name*
GRASSES	
Andropogon elliottii	Elliott bluestem
A. gerardi	big bluestem
A. virginicus	broomsedge bluestem
A. ternarius	split beard bluestem
Aristida pupurescens	arrowfeather threeawn
Axonopus affinis	carpetgrass
Bromus purgans	Canada brome
B. secalinus	cheat
Chasmanthium latifolium	broad-leaved uniola
C. laxum	spikegrass
Danthonia spicata	poverty oats
Dichanthelium spp.	low panicums
D. aciculare	narrowleaf panicum
D. acuminatum	woolly panicum
Digitaria violascens	violet crabgrass
Elymus sp.	wild rye
Eragrostis spectabilis	purple lovegrass
Festuca pratensis	fescue
Gymnopogon ambiguus	bearded skelton grass
Leptoloma cognatum	Fall witchgrass
Lolium perenne	perennial rye
Muhlenbergia sp.	muhlenbergia
Panicum spp.	panicum
P. anceps	beaked panicum
P. capillare	witchgrass
P. linearifolium	slimleaf panicum
P. virgatum	switchgrass
Paspalum sp.	paspalum
P. floridanum	Florida paspalum
Setaria geniculata	foxtail
Sorghastrum nutans	Indian grass
Sporobolus sp.	dropseed
Stipa avenacea	porcupine-grass
Schizachyrium scoparium	little bluestem
Tridens flavus	purpletop
SEDGES	
Carex spp.	sedge
Cyperus spp.	flatsedge
Rynchospora sp.	beakrush

Table 1. Continued.

GROUP *Scientific name*	*Common name*
RUSHES	
Juncus spp.	rush
FERNS	
Polystichum acrostichoides	Christmas fern
Pteridium aquilinum	braken fern
FORBS	
Acalypha gracilens	three-seed mercury
Achillea millefolium	yarrow
Agalinis fasiculata	pink gerardia
Agave virginica	agave
Allium canadense	wild onion
Ambrosia artemesifolia	common ragweed
Antennaria plantaginifolia	pussytoes
Asclepias sp.	milkweed
Asclepias varigata	white milkweed
Aster spp.	aster
A. paludosis	purple aster
A. patens	late purple aster
A. turbinellus	prairie aster
Aureolaria pectinata	fox glove
Boltonia diffusa	false starwort
Bidens sp.	beggarweed
Callirhoe digitata	fringed poppy mallow
Cardamine parviflora	smallflower bittercress
Chenopodium album	pigweed
Cirsium carolinianum	smallhead thistle
Conyza canadensis	horseweed
Coreopsis grandiflora	tickseed
C. tinctoria	plains tickseed
Croton capitatus	croton
Crotonopsis elliptica	crotonopsis
Daucus carota	wildcarrot
Diodia teres	poor joe
Echinacea purpurea	coneflower
Erechtites hieracifolia	fireweed
Erigeron strigosus	daisy fleabane
Eryngium yuccifolium	yucca-leaf eryngo
Euphorbia sp.	spurge
Eupatorium capillifolium	dogfennel
E. coelestinum	mist flower
E. rugosum	white snakeroot
Galium pilosum	hariry bedstraw

Table 1. Continued.

GROUP Scientific name	Common name
Geranium carolinianum	Carolina cranesbill
Gnapthalium obtusifolium	cudweed
Hedyotis purpurea	purple bluet
Helianthus hirsutus	stiff-leaf sunflower
H. silphoides	sunflower
Heterotheca graminifolia	golden aster
Hieracium gronovii	hawkweed
Iva angustifolia	sumpweed
Krigia dandelion	Krigia Dandelion
Lactuca canadensis	wild lettuce
Lechea tenuifolia	lechea
Lepidium virginicum	pepperbush
Liatris aspera	tall gayfeather
L. elegans	beautiful gayfeather
L. squarrosa	gayfeather
Lobelia spicata	lobelia
Ludwigia alternifolia	bushy seedbox
L. palustris	marsh seedbox
Monardia russeliana	spotted horsemint
Nothoscordum bivalve	crow poison
Oxalis stricta	yellow wood sorrel
O. violacea	violet wood sorrel
Penstemon sp.	beardtongue
Phlox pilosa	prairie phlox
Phytolacca americana	pokeweed
Plantago aristata	bracted plantain
P. lanceolata	English plantain
Polygonum pensylvanicum	smartweed
Prunella vulgaris	prunella
Pycnanthemum tenuifolium	narrow-leaf mt. mint
Pyrrhopappus carolinianus	field dandelion
Ranunculus sp.	buttercup
Rhexia virginica	meadow beauty
Rudbeckia hirta	black-eyed susan
Ruellia humilis	low ruellia
Rumex crispus	sour dock
Scutellaria ovata	skullcap
Senecio sp.	groundsel
Solanum carolinense	Carolina horse nettle
S. elaeagnifolium	false nettle
S. ptycanthum	black niteshade
Solidago sp.	goldenrod
S. caesia	bluestem goldenrod
S. canadensis	field goldenrod

Table 1. Continued.

GROUP Scientific name	Common name
S. ulmifolia	elmleaf goldenrod
Specularia perfoliata	venus looking-glass
Sisyrinchium campestre	blue-eyed grass
Tradescantia ohiensis	Ohio spiderwort
Valerianelia radiata	beaked cornsalad
Verbascum thapsus	mullen
Verbenia sp.	verbena
Verbesina helianthoides	wingstem
Vernonia sp.	ironweed
Viola pedata	bird's foot violet
Yucca glauca	yucca
LEGUMES	
Astragalus sp.	milkvetch
Amphicarpa bracteata	hog peanut
Baptisia nuttallianus	wild indigo
Clitoria mariana	butterfly pea
Cassia fasciculata	partridge pea
Crotalaria sagittalis	crotalaria
Desmodium spp.	beggar weed
D. nudiflorum	beggar weed
Galactia volubilis	downy milk pea
Lespedeza cuneata	Sericea lespedeza
Lespedeza hirta	bush lespedeza
Lespedeza intermedia	intermediate lespedeza
Lespedeza procumbens	prostrate lespedeza
Lespedeza repens	reclining lespedeza
Lespedeza striata	kobe lespedeza
Lespedeza violacea	violet lespedeza
Lespedeza virginica	slender lespedeza
Rhynchosia latifolia	snout bean
Schrankia uncinata	sensitive briar
Strophostyles umbellata	trailing wild bean
Stylosanthes biflora	pencil flower
Tephrosia virginiana	goats rue
VINES	
Ampelopsis arborea	peppervine
Berchemia scandens	Alabama supple-jack
Cocculus carolinus	Carolina moonseed
Parthenocissus quinquefolia	Virginia creeper
Smilax bona-nox	catbriar
Smilax rotundifolia	common greenbriar
Toxicodendron radicans	poison ivy

Table 1. Continued.

GROUP Scientific name	Common name
Vitis palmata	cat grape
V. rotundifolia	muscadine
WOODY	
Shrubs	
Andrachne phyllanthoides	maidenbush
Baccharus halimifolia	groundsel-tree
Callicarpa americana	American beautyberry
Ceanothus americanus	New Jersey tea
Elaeagnus angustifolius	Russian olive
Euonymus americanus	strawberry bush
Hypericum densiflorium	St. John's Wort
H. drummondii	nits & lice
Ilex decidua	deciduous holly
Opuntia macrorhiza	prickly pear
Rhus aromatica	fragrant sumac
R. copallina	winged sumac
R. glabra	smooth sumac
Rosa carolina	Carolina rose
R. multiflora	multifloria rose
Rubus spp.	dewberry/blackberry
Symphoricarpos orbiculatus	buckbrush, coralberry
Vaccinium arboreum	tree sparkleberry
V. pallidum	lowbush blueberry
Viburnum rufidulum	black haw
Trees	
Albizia julibrissen	mimosa
Amelanchier arborea	serviceberry
Bumelia lanuginosa	chittamwood
Carya texana	black hickory
C. tomentosa	mockernut hickory
Celtis laevigata	Sugarberry
C. tenuifolia	Georgia hackberry
Cornus florida	flowering dogwood
Crataegus sp.	hawthorne
Diospyros virginiana	persimmon
Fraxinus pennsylvanica	green ash
Juniperus virginiana	eastern red cedar
Morus alba	white mulberry
Morus rubra	red mulberry
Nyssa sylvatica	black gum
Pinus echinata	shortleaf pine
P. taeda	loblolly pine
Populus deltoides	cottonwood

Table 1. Continued.

GROUP Scientific name	Common name
Prunus angusifolia	Chickasaw plum
P. serotina	black cherry
Quercus marilandica	blackjack oak
Q. nigra	water oak
Q. phellos	willow oak
Q. stellata	post oak
Q. velutina	black oak
Salix nigra	black willow
Ulmus alata	winged elm

APPENDIX F

FREQUENCY DISTRIBUTIONS OF ELK, DEER, AND RABBIT PELLET GROUPS FITTED TO POISSON AND NEGATIVE BINOMIAL DISTRIBUTIONS

Table 1. Comparative fits of expected Poisson and negative binomial distributions with the observed distribution of elk pellet groups on the Pushmataha Forest Habitat Research Area during 1988 and 1989.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
May 1988			
0	9	3.80	9.00
1	5	7.31	5.81
2	4	7.03	3.81
3	2	4.50	2.50
4	3	2.17	1.65
5	1	1.20	1.09
6	1		2.13
7	0		
8	1		
	26	$\chi^2 = 13.58$	$\chi^2 = 1.34$
		D.F.= 4	D.F.= 4
		$P < 0.01$	$P > 0.05$
			$k = 0.97$
Sept. 1988			
0	33	27.56	33.00
1	12	19.04	12.82
2	5	6.58	5.29
3	4	1.82	2.23
4	1		1.66
	55	$\chi^2 = 9.63$	$\chi^2 = 1.73$
		D.F.= 2	D.F.= 2
		$P < 0.01$	$P > 0.05$
			$k = 0.89$

Table 1. Continued.[a]

Month/year, groups/plot	Frequency Distribution		
	Observed	Poisson	Negative Binomial
Dec. 1988			
0	25	17.05	25.00
1	10	19.01	12.66
2	10	10.60	6.66
3	4	3.94	3.55
4	0	1.40	1.90
5	2		1.02
6	1		1.20
	52	$\chi^2 = 9.85$	$\chi^2 = 5.16$
		D.F.= 3	D.F.= 4
		$P < 0.01$	$P > 0.05$
			$k = 0.93$
March 1989			
0	27	24.49	27.00
1	11	15.44	12.27
2	7	4.87	4.50
3	0	1.21	2.23
4	1		
	46	$\chi^2 = 2.50$	$\chi^2 = 2.20$
		D.F.= 2	D.F.= 1
		$P > 0.05$	$P > 0.05$
			$k = 1.63$
April 1989			
0	38	28.23	38.00
1	12	21.75	11.83
2	7	8.38	5.37
3	1	2.64	2.69
4	1		1.41
7	2		1.71
	61	$\chi^2 = 8.68$	$\chi^2 = 1.73$
		D.F.= 2	D.F.= 3
		$P < 0.025$	$P > 0.05$
			$k = 0.52$

Table 1. Continued.[a]

Month/year, groups/plot	Frequency Distribution: Observed	Poisson	Negative Binomial
All Months			
0	132	95.17	132.01
1	50	88.03	53.90
2	33	40.71	26.06
3	11	12.55	13.25
4	6	3.54	6.90
5	3		3.65
6	2		1.95
7	2		1.05
8	1		1.24
	240	χ^2 =63.32	χ^2 = 3.67
		D.F.= 3	D.F.= 6
		P < 0.001	P > 0.05
			k = 0.73

[a] Data were pooled in both tails so that expected frequencies were either <1 or <3. If pooling made a difference the more conservative value (3) was used for pooling tails of the observed distribution.

Table 2. Comparative fits of expected Poisson and negative binomial distributions with the observed distribution of deer pellet groups on the Pushmataha Forest Habitat Research Area during 1988 and 1989.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
May 1988			
0	9	4.26	9.00
1	5	7.71	6.07
2	4	6.97	3.95
3	2	4.20	6.98
4	2	2.86	
5	4		
	26	$\chi^2 = 12.08$ D.F.= 3 $P < 0.01$	$\chi^2 = 0.34$ D.F.= 1 $P > 0.05$ $k = 1.08$
Sept. 1988			
0	24	14.32	24.00
1	14	19.27	13.12
2	5	12.96	7.48
3	8	5.81	4.32
4	0	2.63	2.52
5	1		1.47
6	2		2.09
7	0		
8	0		
9	1		
	55	$\chi^2 = 14.41$ D.F.= 3 $P < 0.005$	$\chi^2 = 7.07$ D.F.= 4 $P > 0.05$ $k = 0.92$

Table 2. Continued.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
Dec. 1988			
0	18	10.54	18.00
1	13	16.82	13.33
2	6	13.43	8.51
3	7	7.14	5.14
4	5	2.85	3.02
5	1	1.22	1.74
6	2		2.27
	52	$\chi^2 = 14.48$	$\chi^2 = 3.07$
		D.F.= 4	D.F.= 4
		$P < 0.01$	$P > 0.05$
			$k = 1.38$
March 1989			
0	13	3.39	13.00
1	4	8.84	9.16
2	8	11.52	6.57
3	8	10.02	4.74
4	3	6.54	3.43
5	2	3.41	2.49
6	4	2.29	1.80
7	3		1.31
8	0		3.50
9	1		
	46	$\chi^2 = 48.20$	$\chi^2 = 12.24$
		D.F.= 5	D.F.= 6
		$P < 0.001$	$P > 0.05$
			$k = 0.97$
April 1989			
0	30	21.72	30.00
1	13	22.43	15.25
2	10	11.58	7.75
3	2	3.99	3.94
4	6	1.28	4.06
	61	$\chi^2 = 25.63$	$\chi^2 = 2.86$
		D.F.= 3	D.F.= 2
		$P < 0.001$	$P > 0.05$
			$k = 1.00$

Table 2. Continued.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
All Months			
0	94	47.85	94.00
1	49	77.16	55.65
2	33	62.21	34.08
3	27	33.44	21.11
4	16	13.48	13.14
5	8	4.35	8.21
6	8	1.50	5.14
7	3		3.22
8	0		2.02
9	2		1.27
10	0		2.16
	240	$\chi^2 = 161.20$ D.F.= 5 $P < 0.001$	$\chi^2 = 9.31$ D.F.= 8 $P > 0.05$ $k = 0.94$

[a] Data were pooled in both tails so that expected frequencies were either <1 or <3. If pooling made a difference the more conservative value (3) was used for pooling tails of the observed distribution.

Table 3. Comparative fits of expected Poisson and negative binomial distributions with the observed distribution of rabbit pellet groups on the Pushmataha Forest Habitat Research Area during 1988 and 1989.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
May 1988			
0	9	4.97	9.00
1	6	8.23	6.49
2	6	6.80	4.17
3	0	6.00	2.57
4	2		1.55
5	2		2.23
6	0		
7	1		
	26	$\chi^2 = 4.12$	$\chi^2 = 3.81$
		D.F.= 2	D.F.= 3
		$P > 0.05$	$P > 0.05$
			$k = 1.28$
Sept. 1988			
0	21	12.16	21.00
1	14	18.35	13.68
2	9	13.85	8.34
3	5	6.97	4.97
4	2	2.63	2.93
5	1	1.05	1.71
6	0		2.37
7	2		
8	0		
9	1		
	55	$\chi^2 = 18.21$	$\chi^2 = 0.82$
		D.F.= 4	D.F.= 4
		$P < 0.005$	$P > 0.05$
			$k = 1.15$

Table 3. Continued.[a]

	Frequency Distribution		
Month/year, groups/plot	Observed	Poisson	Negative Binomial
Dec. 1988			
0	15	5.17	15.00
1	11	11.94	11.16
2	9	13.78	7.94
3	4	10.60	5.55
4	6	6.11	3.86
5	2	2.82	2.66
6	1	1.58	1.83
7	1		1.26
8	1		2.73
9	0		
10	0		
11	0		
12	2		
	52	$\chi^2 = 32.14$	$\chi^2 = 2.40$
		D.F.= 5	D.F.= 6
		$P < 0.001$	$P > 0.05$
			$k = 1.10$
March 1989			
0	19	7.74	19.00
1	8	13.79	9.51
2	6	12.29	5.80
3	2	7.30	3.75
4	3	3.26	7.93
5	6	1.62	
6	0		
7	2		
	46	$\chi^2 = 51.11$	$\chi^2 = 2.25$
		D.F.= 4	D.F.= 2
		$P < 0.001$	$P > 0.05$
			$k = 0.70$

Table 3. Continued.[a]

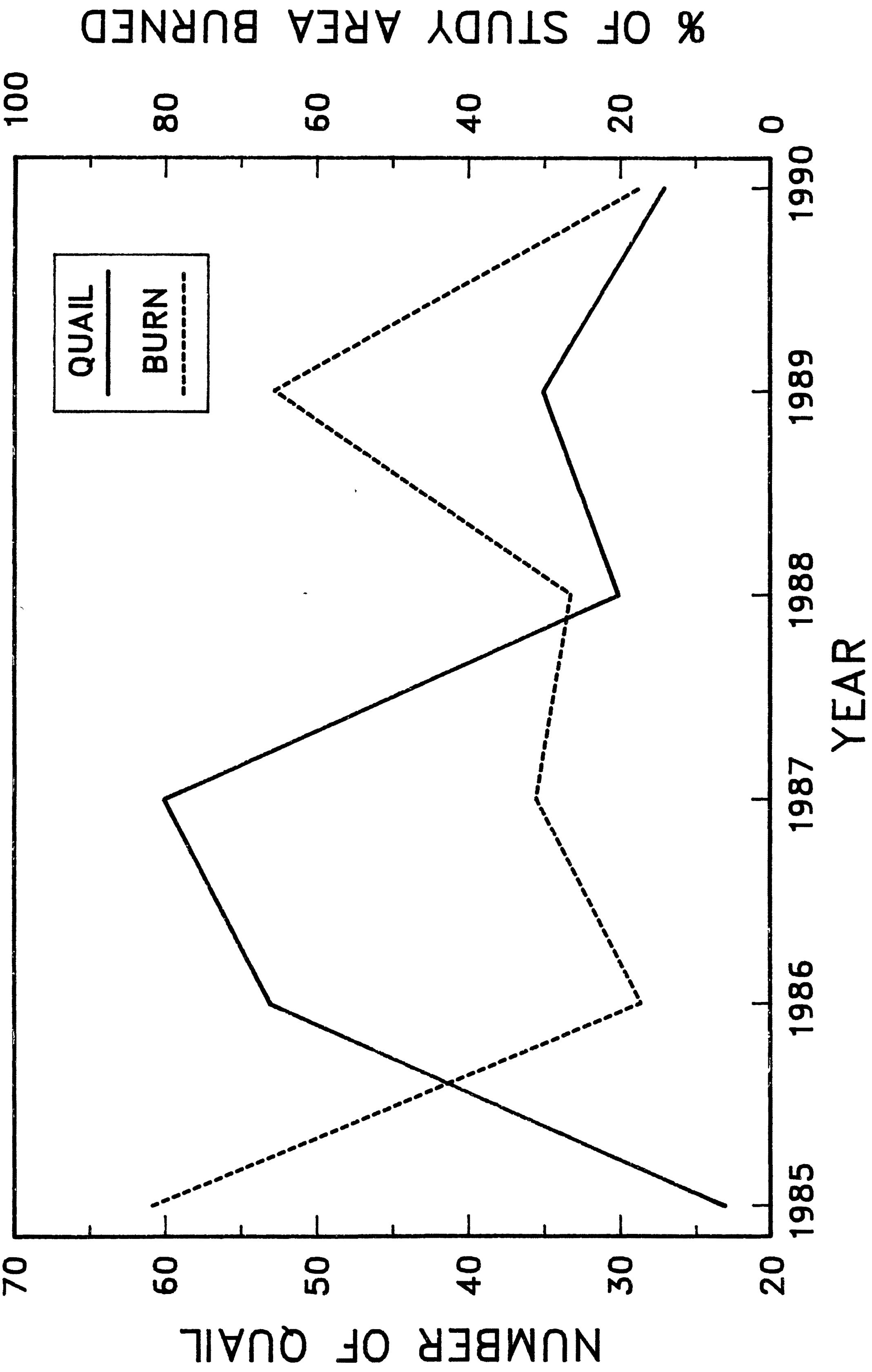
Month/year, groups/plot	Frequency Distribution Observed	Poisson	Negative Binomial
April 1989			
0	22	12.04	22.00
1	17	19.53	15.00
2	6	15.85	9.46
3	7	8.58	5.81
4	3	3.48	3.52
5	3	1.52	2.11
6	2		1.26
7	0		1.83
8	0		
9	0		
10	1		
	61	$\chi^2 = 28.21$ D.F.= 4 $P < 0.001$	$\chi^2 = 3.04$ D.F.= 5 $P > 0.05$ $k = 1.18$
All Months			
0	86	40.51	85.99
1	56	72.07	55.44
2	36	64.11	35.55
3	18	38.02	22.75
4	16	16.91	14.55
5	14	6.02	9.30
6	3	2.36	5.94
7	6		3.79
8	1		2.42
9	1		1.55
10	1		2.73
11	0		
12	2		
	240	$\chi^2 = 145.49$ D.F.= 5 $P < 0.001$	$\chi^2 = 7.32$ D.F.= 8 $P > 0.05$ $k = 1.01$

[a] Data were pooled in both tails so that expected frequencies were either <1 or <3. If pooling made a difference the more conservative value (3) was used for pooling tails of the observed distribution.

APPENDIX G

QUAIL POPULATION RESPONSE ON PUSHMATAHA FOREST HABITAT RESEARCH AREA

Fig. 1. Quail population response 1984-90 on the Pushmataha Forest Habitat Research Area.


NUMBER OF QUAIL
20
30
40
50
60
70
% OF STUDY AREA BURNED
0
20
40
60
80
100
YEAR
1985
1986
1987
1988
1989
1990
QUAIL
BURN

VITA

Ronald Edward Masters

Candidate for the Degree of

Doctor of Philosophy

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