Review Article

Fire Effects on Wildlife in the Central Hardwoods and Appalachian Regions, USA

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ABSTRACT

Fire is being prescribed and used increasingly to promote ecosystem restoration (e.g., oak woodlands and savannas) and to manage wildlife habitat in the Central Hardwoods and Appalachian regions, USA. However, questions persist as to how fire affects hardwood forest communities and associated wildlife, and how fire should be used to achieve management goals. We provide an up-to-date review of fire effects on various wildlife species and their habitat in the Central Hardwoods and Appalachians. Documented direct effects (i.e., mortality) on wildlife are rare. Indirect effects (i.e., changes in habitat quality) are influenced greatly by light availability,

RESUMEN

El fuego prescrito está siendo propuesto y utilizado cada vez más para promover la restauración de los ecosistemas (por ej. los arbustales de robles y sabanas) y para manejar el hábitat de la fauna silvestre en los Bosques Centrales de Latifoliadas y en los Apalaches en EEUU. Sin embargo, persiste el interrogante en como el fuego afecta a las comunidades del bosque de latifoliadas y su fauna asociada, y cómo el fuego debería ser utilizado para lograr objetivos de manejo. Nosotros realizamos una revisión actualizada de los efectos del fuego en varias especies de fauna silvestre y su hábitat en los Bosques Centrales de Latifoliadas y los Apalaches. La documentación sobre los efectos directos del fuego (por ej., mortalidad) en la fauna silvestre son raros. Los efectos indirectos (por ej., cambios en la calidad del hábitat) son influenciados grandemente por la disponibilidad de luz, y la frecuencia y la in-

fire frequency, and fire intensity. Unless fire intensity is great enough to kill a portion of the overstory, burning in closed-canopy forests has provided little benefit for most wildlife species in the region because it doesn't result in enough sunlight penetration to elicit understory response. Canopy reduction through silvicultural treatment has enabled managers to use fire more effectively. Fire intensity must be kept low in hardwoods to limit damage to many species of overstory trees. However, wounding or killing trees with fire benefits many wildlife species by allowing increased sunlight to stimulate understory response, snag and subsequent cavity creation, and additions of large coarse woody debris. In general, a fire-return interval of 2 yr to 7 yr benefits a wide variety of wildlife species by providing a diverse structure in the understory, increasing browse, forage, and soft mast, and creating snags and cavities. Historically, dormant-season fire was most prevalent in these regions, and it still is when most prescribed fire is implemented in hardwood systems as burn-days are relatively few in the growing season of May through August because of shading from leaf cover and high fuel moisture. Late growing-season burning increases the window for burning, and better control on woody composition is possible. Early growing-season fire may pose increased risk for some species, especially herpetofauna recently emerged from winter hibernacula (April) or forest songbirds that nest in the understory (May to June). However, negative population-level effects are unlikely unless the

tensidad del fuego. A menos que la intensidad del fuego sea lo suficientemente grande como para matar una porción del estrato superior, las quemas en bosques con el canopeo cerrado han aportado poco beneficio a la mayoría de las especies de fauna silvestre en la región, porque no permiten la penetración de suficiente de luz solar para obtener una respuesta en el sotobosque. La reducción del canopeo a través de tratamientos silviculturales ha permitido a los gestores utilizar el fuego en forma más efectiva. La intensidad del fuego debe ser mantenida baja en bosques de latifoliadas para limitar el daño a algunas especies arbóreas del estrato superior. Sin embargo, hiriendo o matando árboles mediante su quema puede beneficiar a muchas especies de la fauna silvestre, al permitir así la entrada de la luz solar para estimular la respuesta del sotobosque, la creación de árboles muertos en pie y la subsecuente formación de cavidades en ellos, y la adición de restos leñosos gruesos. En general, un intervalo de retorno del fuego de 2 años a 7 años beneficia a una amplia variedad de especies de la fauna silvestre, proporcionando una estructura diversa en el sotobosque, incrementando el ramoneo, el forraje, y los frutos carnosos, y creando troncos muertos en pié y cavidades en ellos. Históricamente, el fuego en la temporada de dormancia era más preponderante en estas regiones, y todavía lo es cuando la mayoría de los fuegos prescriptos se implementan en sistemas de latifoliadas, dado que los días de quema son relativamente pocos en la temporada de crecimiento de mayo hasta agosto debido a la sombra de la cobertura de hojas y el alto contenido de humedad de los combustibles. Las quemas durante la temporada tardía de crecimiento incrementan la ventana de prescripción, y es posible un mejor control en la composición de leñosas. Los fuegos al principio de la temporada de crecimiento pueden ocasionar mayores riesgos para algunas especies, especialmente para la herpetofauna recién emergida de la hibernación (abril) o a los pájaros cantores del bosque que anidan en el sotobosque (mayo a junio). Sin embargo, efectos negativos a nivel de población son im-

burned area is relatively large and early growing-season fire is used continually. We did not find evidence that fire is leading to population declines for any species, including Endangered Species Act (ESA)-listed species (e.g., Indiana bat [*Myotis sodalis* Mill. Allen] or northern long-eared bat [*M. septentrionalis* Trouess.]). Instead, data indicate that fire can enhance habitat for bats by increasing suitability of foraging and day-roost sites. Similarly, concern over burning and displacement of woodland salamanders (Plethodontidae), another taxa of heightened conservation concern, is alleviated when fire is prescribed along ecologically appropriate aspect and slope gradients and not forced into mesic, high site index environments where salamanders are most common. Because topography across the Central Hardwoods and Appalachians is diverse, we contend that applying fire on positions best suited for burning is an effective approach to increase regional landscape heterogeneity and biological diversity. Herein, we offer prescriptive concepts for burning for various wildlife species and guilds in the Central Hardwoods and Appalachians.

probables a menos que el área quemada sea relativamente grande y las quemas sean utilizadas en la temporada temprana de crecimiento en forma continua. Nosotros no hemos encontrado evidencias de que el fuego esté conduciendo a la declinación de la población de cualquiera de las especies, incluyendo las listadas en la Ley de Especies Amenazadas (ESA) (por ej., el murciélago de Indiana [*Myotsis sodalis* Mill. Allen] o el murciélago orejudo [*M. septentrionalis* Touess.]). En cambio, los datos indican que el fuego puede favorecer el hábitat de los murciélagos al aumentar la capacidad de alimentarse y los sitios de percheo diurnos. En forma similar, una preocupación sobre las quemas y el desplazamiento de la salamandra de los arbustales (Plethodontidae), otro de los taxones de alto interés de conservación, se alivia cuando el fuego se prescribe a lo largo de orientaciones y gradientes de pendiente apropiados ecológicamente y no forzados a ambientes mésicos, donde los índices de presencia en el ambiente son altos y las salamandras son más comunes. Debido a que la topografía a través de los Bosques Centrales de Latifoliadas y de los Apalaches es diversa, nosotros bregamos para que la aplicación de fuego en las posiciones más apropiadas sea un acercamiento efectivo para aumentar la heterogeneidad regional del paisaje y la diversidad biológica. Al respecto, nosotros ofrecemos conceptos de prescripción para las quemas de varias especies de la fauna silvestre y especies asociadas en los Bosques Centrales de Latifoliadas y los Apalaches.

Keywords: fire frequency, fire intensity, fire prescriptions, hardwoods, prescribed fire, season of burning, southern Appalachians, wildlife

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INTRODUCTION

Fire has increasingly been recommended and used over the past two decades to manage hardwood and mixed hardwood-pine (*Pinus* spp. L.) systems of the Central Hardwoods and Central and Southern Appalachian (hereafter Appalachian) regions, USA (Figure 1; Yaussy 2000, Brose *et al*. 2001, Brose *et al.* 2014). The primary reasons for use of fire in hard-

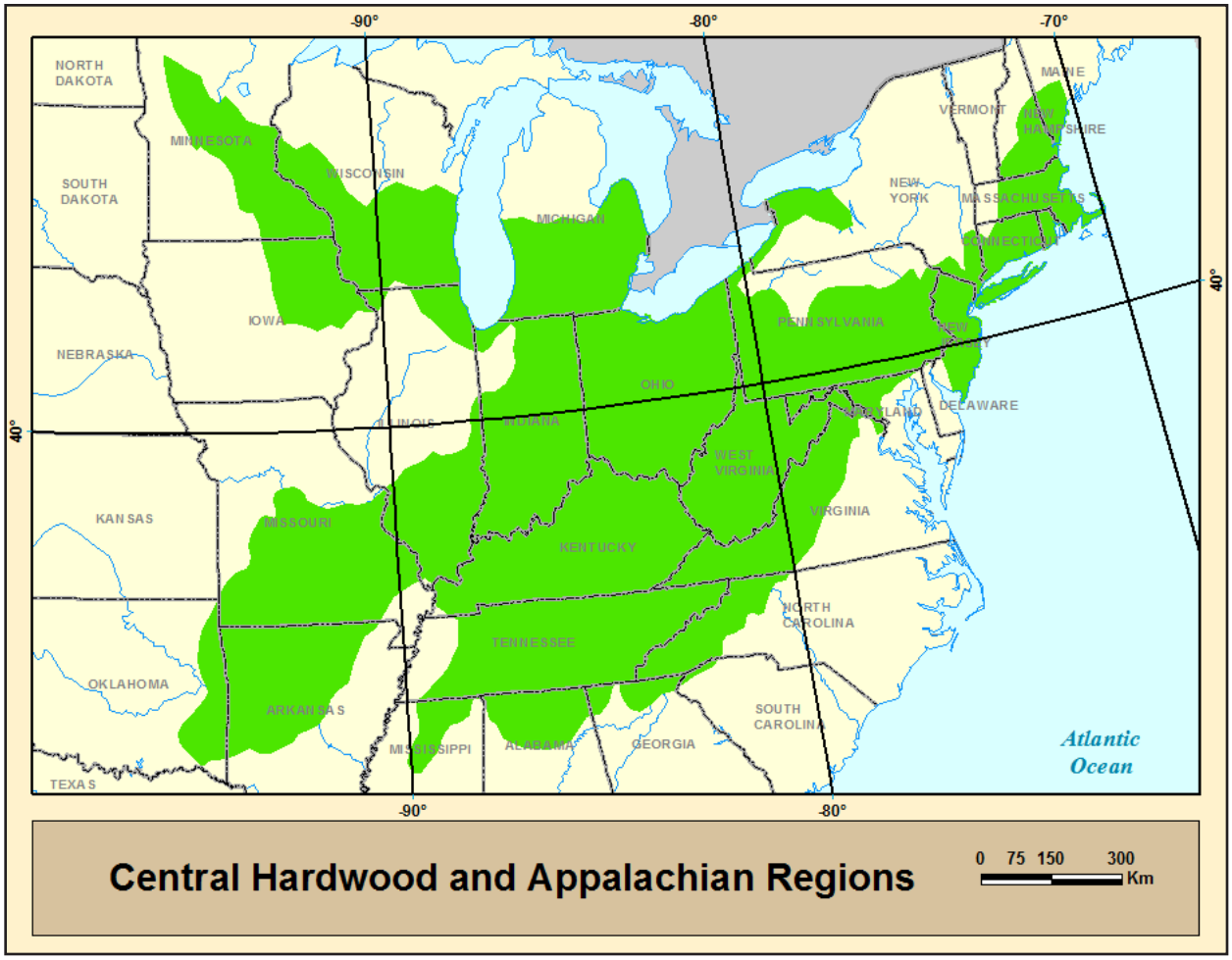

Figure 1. The Central Hardwoods and Appalachian forest types include a broad mixture of hardwood forests with a significant component of oak over diverse topography and physical settings that provides tremendous opportunity for managing multiple wildlife species and communities. Map adapted from Dyer (2006).

wood systems relate to the multiple benefits for ecosystem restoration (e.g., oak-pine woodlands or savanna), oak (*Quercus* spp. L.) regeneration, fuels reduction, and wildlife habitat management (McShea and Healy 2003, Burton *et al.* 2010, USDA Forest Service 2015). However, research investigating fire effects in eastern US deciduous forests is in its infancy compared to other regions and many questions remain unanswered (Stambaugh *et al*. 2015), particularly as related to wildlife. Because of the diverse requirements of the multiple taxa that occur in the region, fire effects and prescriptions vary greatly by location and with respect to different wildlife species (Smith 2000), with no single prescription optimal for all wildlife species.

Fire is a critical tool for managing habitat for various wildlife species in southern pine ecosystems (Johnson and Hale 2002, Van Lear *et al*. 2005, Masters 2006). Although the role of fire in restoration and maintenance of hardwood systems is less studied, empirical data regarding prevalence of fire and its use in hardwood systems shows that fire is important for maintaining and enhancing habitat for many wildlife species. Various fire prescriptions have been developed for pine ecosystems, such as frequent early growing-season fire in the longleaf pine (*Pinus palustris* Mill.)

ecosystem (Frost 1998, Johnson and Hale 2002, Van Lear *et al*. 2005). However, the effects of fire on the vegetation and wildlife community often are considerably different in hardwood systems than in pine systems. In particular, the fuels and vegetation characteristics that facilitate the spread of fire, fire intensity, and the tolerance of overstory trees to fire intensity are quite disparate. Ongoing research and management continue to build understanding of how fire affects hardwood systems and associated wildlife. However, we believe sufficient information exists to guide management efforts, whether for a specific wildlife species, for a guild, or for ecosystem restoration. Our goal for this paper is to summarize current research of fire effects on wildlife in the Central Hardwoods and Appalachians, provide recommendations for fire prescriptions with regard to various wildlife species and species guilds given the latest information, and present suggestions for future research related to fire effects on wildlife.

WHY ARE YOU BURNING?

When land managers are asked why they burn, common answers are, "For wildlife," and, "Because burning is good." However, "wildlife" is an ambiguous term (Hunter and Schmiegelow 2011), and burning is not necessarily "good." Indeed, prescribed fire at some application and frequency may promote or enhance habitat for diverse taxa, such as reptiles (Russell *et al*. 1999, Greenberg 2000, Keyser *et al*. 2004), wild turkey (*Meleagris gallopavo* L.; McCord *et al.* 2014), and white-tailed deer (*Odocoileus virginianus* Zimmerman; Lashley *et al*. 2011), but its occurrence can be negative for these and other species, such as ovenbird (*Seiurus aurocapilla* L.; Rush *et al*. 2012) or eastern box turtle (*Terrapene carolina* L.; Howey and Roosenburg 2013), depending on when and how the burn is conducted. We contend that a major limitation in accomplishing land management goals related to fire use is failure to articulate precise management objectives or outcome assessment to determine their success. Often, it is unclear whether practitioners are burning for a focal species or group of species (e.g., shrubland songbirds), or whether it is for a target condition or ecosystem function (e.g., table mountain pine [*Pinus pungens* Lamb.] restoration in montane systems or an oak woodland). Confusion abounds as to whether burning should closely mimic what is regarded as the historic fire regime (Flatley *et al*. 2013, Hermann *et al*. 2015), or if fire should be used in a manner to create optimum habitat conditions for a particular wildlife species or group of species. There is a large dichotomy between managing an area so that it will support a certain species versus managing an area for maximum production of that species. This distinction is important, especially for public-lands managers when iconic game species or at-risk species occur, or when conditions desired for other stewardship considerations exist.

Understanding how different fire regimes affect various wildlife species as well as the vegetation community is critical (Rush *et al*. 2012). Commonly, when "wildlife" is the objective, multiple species with vastly different habitat requirements are listed as focal species, such as northern bobwhite (*Colinus virginianus* L.) and ruffed grouse (*Bonasa umbellus* L.). There is no published information distinguishing fire prescriptions for most wildlife species in the Central Hardwoods and Appalachians. Even for species that use similar vegetation types and successional stages, such as white-tailed deer and wild turkey, or northern bobwhite and eastern cottontail (*Sylvilagus floridanus* Allen), the fire prescription should differ (e.g., timing or frequency) if the objective is to optimize conditions for a focal species. Often, the fire prescription is not congruent with the biology and life history of the focal species. More consideration should be given to precise prescriptions that fit the biology of focal species as well as the ecology

of an ecosystem. It should be recognized that, when multiple focal species exist, the appropriate fire regime for one species may conflict with another. In these situations, managers should first prioritize their objectives (decide which species is most important) and, if a conflict still exists, follow recommendations for fire frequency over those for fire intensity or seasonality.

WHAT ARE FIRE EFFECTS ON WILDLIFE?

Fire affects wildlife indirectly by impacting cover and food resources, and directly by causing injury or death (Smith 2000). The purpose of using fire is to set back or maintain a particular seral stage and influence plant composition, structure, and the subsequent successional trajectory. Therefore, by default, food and cover resources for various wildlife species are affected, positively for some species, neutrally for some species, and negatively for other species. Changes in food and cover also may influence core home range size (Rowan *et al*. 2005, Lashley *et al*. 2015), resource selection (Boyles and Aubrey 2006, Johnson *et al*. 2009, Kilburg *et al*. 2014), and movement of some species (Johnson *et al*. 2012). Indirect effects can be influenced greatly by area burned, pattern of burning, frequency and season of burning, and fire intensity (Lashley *et al*. 2015; Figure 2). Direct effects of fire on wildlife are much less common and poorly documented. In fact, observable direct mortality of most taxa by prescribed fire in hardwood systems is rare (Ford *et al*. 1999, Carter *et al*. 2002, Moseley *et al*. 2003, Howey and Roosenburg 2013). However, timing of burning and firing technique should be considered to reduce the likelihood of wildlife mortality or injury, as discussed below.

FIRE AND SILVICULTURE

Some discussion of fire and silviculture in hardwoods systems is warranted before describing fire effects and prescriptions for wildlife. Within a given size class, most hardwood species are more vulnerable to fire than yellow pines common in the southern US (e.g., longleaf, shortleaf [*Pinus echinata* Mill.], and loblolly [*P. taeda* L.] pines; Hare 1965, Harmon 1984). Therefore, if retention of a hardwood overstory is desired, relatively low-intensity fire must be used or injury and mortality of overstory trees are more likely (Wendell and Smith 1988, Marschall *et al*. 2014). However, without manipulation of the light environment, understory response following low-intensity fire can be negligible (Shaw *et al*. 2010, but see Schuler *et al*. 2013). Lashley *et al*. (2011) reported that forage availability for white-tailed deer was doubled by implementing

Figure 2. The biggest effects of fire on wildlife are indirect. Fire influences the structure and composition of vegetation, which changes availability of cover and food for wildlife. Indirect effects can influence presence, density, reproduction, survival, movements, and home range of wildlife in a particular area.

low-intensity, early growing season fire under closed-canopy hardwoods, but coupling fire with canopy disturbance resulted in eight times as much deer forage as compared to unthinned and unburned areas. Through time, continued low-intensity fire will remove the midstory, but some level of canopy removal is necessary to allow sufficient sunlight (at least 20% full sunlight) to the forest floor to stimulate extensive groundcover (Royo *et al*. 2010, Schuler *et al*. 2010, McCord *et al*. 2014, Knapp *et al*. 2015).

Many silvicultural practices can be used with prescribed fire in hardwood systems to create, maintain, or enhance food and cover resources for wildlife. Regeneration harvests (e.g., shelterwood and group selection), various types of thinnings, and midstory removal via herbicide applications may be used in combination with fire to manage habitat for wildlife (Brose and Van Lear 1998, Johnson *et al*. 2009, Lashley *et al*. 2011, Bakermans *et al*. 2012, McCord *et al*. 2014, Kendrick *et al*. 2015, Silvis *et al*. 2016). The amount of canopy removal and resultant increased sunlight directly influences plant composition and structure, as well as habitat for different wildlife species. Increased canopy removal stimulates increased woody stem density, which may be suitable for species such as brown thrasher (*Toxostoma rufum* L.), chestnut-sided warbler (*Dendroica pensylvanica* L.), ruffed grouse, or black bear (*Ursus americanus* Pall.) (Brody and Stone 1987, van Manen and Pelton 1997, Whitaker *et al.* 2006, Matthews *et al*. 2010), but could be temporarily negative for others, such as Acadian flycatcher (*Empidonax virescens* Vieill.; Kendrick *et al*. 2015) and some terrestrial salamanders (Plethodontidae), which may be adversely affected by increased temperatures on the forest floor (Swift *et al*. 1993, Semlitsch *et al*. 2009, Ford *et al*. 2010, Matthews *et al*. 2010, O'Donnell *et al*. 2015).

Efforts to restore and create oak woodlands and savannas have increased in recent years, not only for habitat for various wildlife species (Brawn 2006, Barrioz *et al*. 2013, Holoubek and Jensen 2015), but also for ecosystem services (Pickens and Root 2008). Tree removal via mechanical disturbance or herbicide application often is used to expedite woodland and savanna restoration prior to use of prescribed fire for maintenance and to influence plant composition and structure. Without tree removal, creation of oak woodland or savanna may require many years, perhaps decades, of frequent and more intensive fire to achieve proper stand structure and understory composition (Knapp *et al*. 2015). Moderate- to high-intensity fire would be required to sufficiently thin trees, which likely would damage residual boles. However, if wildlife is the primary objective, trees killed with moderate-intensity fire will benefit many wildlife species, retain biomass and nutrients on the site, and add to biological diversity (Hunter and Schmiegelow 2011). Tree removal allows use of less-intensive fire to influence groundcover composition and structure while minimizing damage to residual trees, thereby providing greater potential income if trees are later harvested (Kabrick *et al*. 2014, Dey and Schweitzer 2015).

FIRE PRESCRIPTIONS AND EFFECTS ON WILDLIFE

There are four primary factors regarding fire that affect wildlife directly and indirectly: 1) fire frequency, 2) fire intensity, 3) season (or timing) of burning, and 4) burn area and pattern of burning. We contend that fire effects on wildlife cannot be separated from fire effects on the vegetation community. Thus, both must be considered and understood before fire prescriptions can be recommended.

Fire Frequency and Intensity

Fire frequency is generally regarded as the most influential factor related to fire effects at local and landscape scales (Frost 1998, Nowacki and Abrams 2008). However, effects of fire frequency are so closely related to fire

intensity that it is difficult to discuss one without considering the other. For example, low-intensity fire implemented frequently in a mature hardwood forest may have less of an effect on the vegetation and wildlife community than less-frequent high-intensity fire that kills overstory trees. Nonetheless, within a given range of intensity, fire frequency is a requisite consideration for maintaining an early seral stage in the eastern US where precipitation exceeds 75 cm yr^{-1}. This is a critical factor for wildlife species that require early successional communities (Harper 2007, Gruchy and Harper 2014).

Low-intensity fire under closed-canopy conditions tends to have no or only transitory effects on wildlife, including terrestrial salamanders (Ford *et al.* 1999, Greenberg and Waldrop 2008, Matthews *et al*. 2010, Raybuck *et al*. 2015). If fire intensity is great enough to kill midstory stems, understory response will increase slowly over time with repeated burning as scattered overstory trees eventually die. However, after 60 years of annual burning with low-intensity fire in an oak-hickory (-*Carya* spp. Nutt.) forest in Missouri, USA, percent coverage of understory vegetation still did not exceed 40% (Knapp *et al.* 2015).

Silvicultural treatment can be used to increase light penetration and increase the influence of low-intensity fire on vegetation composition and structure. McCord *et al*. (2014) reported that low-intensity fire alone in Appalachian mixed hardwoods did not impact overstory basal area over a nine-year span with four fires. However, following improvement cutting or shelterwood harvest that allowed at least 20% to 30% sunlight into the stand, a fire-return interval within 6 yr to 7 yr maintained forest understory structure suitable for various forest birds, such as hooded warbler (*Wilsonia citrina* Bodd.), Kentucky warbler (*Oporornis formosus* Wilson), and worm-eating warbler (*Helmitheros vermivorum* Gmelin), that require a relatively dense understory of woody sprouts for nesting and foraging (Greenberg *et al*. 2007, Bakermans *et al*. 2012, McCord *et al.* 2014). Use of burned area by songbirds that require leaf litter (e.g., worm-eating warbler, black-and-white warbler [*Mniotilta varia* L.], and ovenbird), as well as terrestrial salamanders and some shrew (Soricidae) species, may be delayed for at least one growing season after burning until sufficient leaf litter accumulates and vegetation regrowth occurs (Artman *et al*. 2001, Greenberg *et al*. 2007, Matthews *et al*. 2009, Ford *et al*. 2010). A 3 yr to 5 yr fire-return interval was recommended to maintain structure suitable for nesting and brood-rearing wild turkey (McCord *et al*. 2014), as well as forage and soft mast for white-tailed deer following an improvement cut (Lashley *et al*. 2011). In old-field communities succeeding into dense, young trees, a 4 yr to 6 yr fire-return is necessary to maintain habitat for shrubland birds (e.g., yellow-breasted chat [*Icteria virens* L.], blue-winged warbler [*Vermivora pinus* L.], and white-eyed vireo [*Vireo griseus* Bodd.]), whereas a 2 yr to 4 yr fire-return interval generally is needed in such environments to maintain structure required for species such as indigo bunting (*Passerina cyanea* L.), field sparrow (*Spizella pusilla* Wilson), northern bobwhite, loggerhead shrike (*Lanius ludovicianus* L.), and eastern cottontail (Wilson *et al*. 1995, Hunter *et al*. 2001; Figure 3). Moderate-intensity fire will injure or kill overstory hardwood trees, depending on the size and species. However, injury and mortality of trees benefits many wildlife species. Additional sunlight from canopy reduction stimulates understory growth and benefits shrub-nesting birds (Greenberg *et al*. 2007, 2013). Furthermore, injured and dead trees are used by many species, especially woodpeckers (Picidae), followed by secondary cavity users, including birds, bats, and tree squirrels (Greenberg *et al*. 2007, Hunter and Schmiegelow 2011, Greenberg *et al*. 2013). Trees injured by fire often are invaded by fungi, which may cause heart rot (Silvis *et al*. 2015*b*). Trees that die from the inside out, as opposed to from the outside in (e.g., when a tree is killed via girdling and herbicide injec-

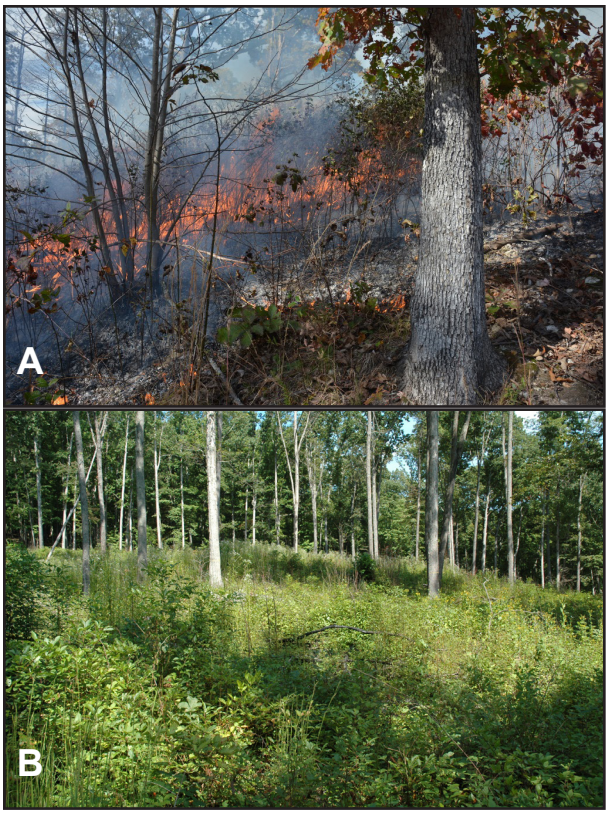

Figure 3. Silvicultural treatment, such as two-aged shelterwood in this mixed oak stand in the Ridge and Valley physiographic province of eastern Tennessee, USA, allows sunlight to enter the stand and stimulate groundcover response. Frequent, low-intensity prescribed fire (A, in October) is required to keep the understory from developing into a midstory and maintain the desired structure for various wildlife species (B, in September following fire).

tion), have softer interiors favored by cavity excavators and typically persist longer on the landscape (Hunter and Schmiegelow 2011). Following moderate-intensity fire, low-intensity fire can be used within a 6 yr to 7 yr fire-return interval to maintain a woodland structure that is necessary for several species of birds (e.g., great-crested flycatcher [*Myiarchus crinitus* L.], summer tanager [*Piranga rubra* L.], eastern wood-pewee [*Contopus virens* L.], and red-headed woodpecker [*Melanerpes erythrocephalus* L.]). Several bat species (e.g., the endangered Indiana bat, eastern red bat [*Lasiurus borealis* Müller], and evening bat [*Nycticus humeralis* Rafinesque]) also benefit from canopy gaps and decreased structural clutter, which allows for greater foraging efficiency (Ford *et al*. 2006, Dickinson *et al*. 2009, Greenberg *et al*. 2013, Amelon *et al*. 2014, Starbuck *et al*. 2015).

Dead and dying trees are used by many species, including many rare, threatened, or endangered species. For example, Indiana bat and the newly listed (threatened) northern long-eared bat often day-roost during the summer maternity season under exfoliating bark and in cavities, respectively, of snags or trees in decline (Johnson *et al*. 2009, 2010; Silvis *et al*. 2015*a*). Data indicate that low-intensity fire can be used to maintain woodland structure without reducing available snags for these animals (Ford *et al.* 2015; Table 1). Further-

Table 1. Snag (>25 cm dbh) retention (per ha) following silvicultural treatment from 2001 to 2011 in the Chuck Swan State Forest, Union County, Tennessee, USA. (Data from study described in McCord *et al.* 2014.)

	2001 (density ha^{-1})	**2008 (density ha^{-1})**	**2011 (density ha^{-1})**
Control	29.7	8.4	18.6
Fire only[1]	32.9	15.1	16.6
Improvement cut	57.7	40.4	18.6
Improvement cut with fire[1]	41.3	37.2	20.6

[1] Low-intensity early growing-season prescribed fire was implemented in "fire only" and "improvement cut with fire" treatments in 2001, 2005, 2007, and 2009. "Improvement cut" treatment killed trees deemed undesirable for wildlife and allowed approximately 30% sunlight into those stands.

more, low-intensity fire is easily implemented when the duff layer is still relatively moist. Under such conditions, large down woody debris is not consumed, which is a critical consideration for terrestrial salamanders, reptiles, and shrews (Ford *et al*. 1999, 2010).

If tree density is reduced and the intention is to maintain woodland or savanna structure, more frequent fire is necessary (Peterson and Reich 2001, Barrioz *et al*. 2013), similar to the 1 yr to 3 yr fire-return interval necessary to maintain early successional communities and prevent young trees from dominating the site (Gruchy *et al*. 2009). However, frequent fire can have negative indirect effects on certain wildlife, such as suppression of soft mast production in the understory (Lashley *et al*. 2015*b*). Low- to moderate-intensity fire may be used in woodlands or savannas to influence plant composition without killing overstory trees. Moderate-intensity fire may be needed to help set back prolific hardwood sprouting after tree removal, especially if stems are larger than 8 cm dbh. However, practitioners must use the proper firing technique (e.g., backing fire, flanking fire, or strip-heading fire) to avoid injuring or killing overstory trees, and season of burning should be considered.

Season (or Timing) of Burning

Season of burning has implications for both wildlife and plant communities, and there may be less understanding of this factor than any other. Knapp *et al*. (2009) provided an excellent review of the literature pertaining to season of burning across broad regions of the US. However, relatively little data exist with regard to the effects of fire seasonality on wildlife and vegetation in the Central Hardwoods and Appalachians. Vegetation response to season of burning must be considered because of its explicit indirect effects on wildlife.

Effects on vegetation. Studies conducted in pine systems of the American South indicate that growing-season fire provides better control of encroaching hardwoods than dormant-season fire (Waldrop *et al*. 1992, Glitzenstein *et al*. 1995*b*, Drewa *et al*. 2002, Robertson and Hmielowski 2014, Hermann *et al*. 2015). As a result, growing-season fire is promoted widely, especially in the longleaf pine ecosystem, because it enhances habitat for the red-cockaded woodpecker (*Picoides borealis* Vieill.) and other wildlife, more closely mimics the historical fire regime that resulted from lightning ignition, and provides additional opportunity for burning days to accomplish desired stewardship management goals (Cox and Widener 2008). Timing of the growing-season fires in these studies varied, but most were conducted in May and June. It is important to remember, when considering vegetation effects and season of burning, that bud break in the Deep South occurs three to eight weeks earlier than in various areas of the more northerly Central Hardwoods and Appalachians. Therefore, with regard to plant phenology, burning during June in north Florida may be analogous to burning during July or August in the mountains of North Carolina or West Virginia.

Confusion exists as many managers erroneously equate woody stem "control" with elimination. Burning during the early portion of the growing season usually only top-kills young trees and shrubs, similar to dormant-season burning (McCord *et al*. 2014, Glitzenstein *et al*. 2015). Density of sprouts often increases following dormant-season fire, whereas woody stem density may increase less or remain unchanged following early growing-season fire (Robertson and Hmielowski 2014, Sparks *et al*. 1999, Drewa *et al*. 2002). Burning during the early growing season (April and early May) on a 2 yr fire-return interval for 9 yr did not reduce woody stem density or coverage in the understory of Appalachian mixed upland hardwoods (McCord *et al*. 2014). Trees and shrubs were top-killed, but continued to resprout and dominate understory plant composition. Several studies have noted

or speculated that it may require ≥10 yr of frequent burning to realize an effect of seasonal burning on woody plant composition (Waldrop *et al*. 1992, Drewa *et al*. 2002, Robertson and Hmielowski 2014, Glitzenstein *et al*. 2015; Figure 4).

Limited data suggest that burning later in the growing season may reduce woody stem density more completely than burning during the dormant or early growing season. Lewis *et al*. (1964) reported that March burning in the Ozark Mountains increased hardwood sprouts, whereas burning in April, June, and August decreased hardwood sprouts, with slightly better control in June and August than in April. In the upper Gulf Coastal Plain, Gruchy *et al*. (2009) reported that burning in September reduced encroachment of red maple (*Acer rubrum* L.), green ash (*Fraxinus pennsylvanica* Marsh.), and sweetgum (*Liquidambar styraciflua* L.) in an old-field community just as well as did applications of imazapyr and triclopyr, and much better than burning in March. However, different species are more resilient to burning and continue to resprout better than others, and at least some woody sprouting will occur regardless of burn timing. Sparks *et al*. (1999) reported that density of woody stems <1 m tall was similar 3 yr and 4 yr after a single dormant- or late growing-season fire in shortleaf pine-hardwood stands managed for red-cockaded woodpecker in the Ouachita Mountains. Dormant-season fire controlled larger woody stems (>3 m tall) better than late growing-season fire, but that was because the late growing-season fire was not nearly as intense as the dormant-season fire and left unburned patches (Sparks *et al*. 1999). Small stems are easily top-killed with low-intensity fire as long as the cambium tissue is heated to 60 °C to 70 °C (140 °F to 160 °F) for a few minutes (Wright and Bailey 1982). Drewa *et al*. (2002) documented that burn timing, not intensity, was more influential on woody sprout regrowth as long as the fire was hot enough to kill the cambium. Continued burning is necessary to reduce woody stem density. However, it is possible that the fire-return interval may not have to be as frequent to control woody stem density when using late growing-season fire as compared to dormant- or early growing-season fire, within a similar range of fire intensity.

Figure 4. Early growing-season fire in mixed oak stands with a broken canopy will top-kill small woody stems, but the stems sprout back quickly, resulting in little compositional change in the understory (A; the growing season following second fire). However, for forest songbirds that nest and forage in a well-developed understory, as well as wild turkey and white-tailed deer, this type of structure provides good cover (B; second growing season following fourth fire).

It has been speculated that continued frequent burning may deplete carbohydrate reserves and eventually render a plant unable to continue resprouting (Drewa *et al*. 2002, Robertson and Hmielowski 2014). Carbohydrate reserves of most woody plants typically decline with spring growth to a minimum in early summer, then build up again through the

growing season (Wenger 1953, Landhausser and Lieffers 2002). Concentrations of starches in root systems decline after burning during the growing season as plants use reserves to regrow. Bowen and Pate (1993) reported that Australian shrubs required six months longer to restore starches depleted following summer burning (24 months) than spring burning (18 months). It is clear that frequent fire is necessary to deplete carbohydrate reserves as they are restored in many species relatively quickly (Waldrop *et al*. 1992, Schutz *et al*. 2009). However, the relationship between fire frequency, timing, and carbohydrate reserves on hardwood resprouting and the resulting plant community in the Central Hardwoods and Appalachian regions has not been investigated and is not well understood (Figure 5).

Timing of burning also may affect coverage and composition of herbaceous plants. Change in plant community composition is an important consideration for wildlife when determining fire prescriptions. There is little information available from the Central Hardwoods and Appalachian regions with regard to herbaceous response to seasonality of fire. Sparks *et al*. (1998) reported relatively little difference in herbaceous response between late dormant-season and late growing-season fire when burning in open shortleaf pine stands in the Ouachita Mountains. Gruchy *et al*. (2009) reported that coverage of native legumes in an old-field community in the upper Gulf Coastal Plain increased from less than 10% in control to 25% after burning in March, and to 55% after burning in September. Lewis *et al*. (1964) reported greater forb production following burns in August than following burns in March or June in the Ozarks. Howe (2011) reported greater forb richness following burning in July than in May in the Great Lake states. Growing-season fire likely promotes increased coverage of herbaceous species as a result of reduced competition with woody species (Knapp *et al*. 2009). Burning during the dormant season tends to increase coverage of native warm-season (C_4) grasses, but no season of burning has reduced coverage of these grasses (Lewis *et al*. 1964, Holcomb *et al*. 2014). Burning different areas of a property during the late growing season as well as at other times of the year not only provides increased heterogeneity of cover, but also expands periods of high-quality forages for species such as white-tailed deer and elk (*Cervus canadensis* L.; Cook *et al*. 2013, Towne and Craine 2014, Lashley *et al*. 2015*b*).

Figure 5. Fire intensity does not have to be great to top-kill small trees. These small trees were top-killed by a low-intensity prescribed fire in early October on the Cumberland Plateau in Tennessee in an effort to encourage more herbaceous groundcover in a developing oak savanna.

Dendrochronological evidence indicates that dormant-season fire was much more frequent than growing-season fire historically in the Central Hardwoods and Appalachians, suggesting that native Americans were equally as responsible as lightning for spread of fire in this region, if not more so (Shumway *et al*. 2001, Flatley *et al*. 2013). The majority of lightning-caused fires in the region occurred from April through August (Ruffner and Abrams 1998, Cohen *et al*. 2007), but fires later in the growing season (August to October) may lead to increased fire spread because of drier conditions (Peterson and Drewa 2006). Fire prescriptions in hardwood systems of the Central Hardwoods and Appalachians largely have involved dormant-season fire (Van Lear

and Waldrop 1989, Wade *et al*. 2000, Brose *et al*. 2001). Burning during the growing season is much more difficult in hardwood systems than in pine systems because of the shade effect and increased litter moisture in hardwoods, and the abundance and flammability of hardwood leaf litter is less than pine leaf litter (Varner *et al*. 2015). Often, burning May through mid-August is not possible in hardwood stands with considerable canopy coverage (Figure 6) except during exceptionally dry summers and, during those periods, it is common for state forestry agencies to implement burn bans. For much of the region, burning during the late growing season (August through October) historically occurred during extended dry periods when lower precipitation and less humidity resulted in drier fuels (Knapp *et al*. 2009). Following canopy-reduction treatment that allows additional sunlight into the stand, drying is expedited, better facilitating burning during these months. In open areas (e.g., old fields, forest openings, and savannas), conditions may allow burning during any month of the summer. Increased moisture and decreased flammability of fuels in hardwood systems during the growing season leads to relatively less-intensive fires than during the dormant season, which differs from pine systems in which increased fine fuels and sunlight may allow intensive fires any month during the growing season (Glitzenstein *et al*. 1995*a*).

Figure 6. Burning hardwood stands in the Central Hardwoods and Appalachians from May to August is usually difficult because of shade effect and moisture retained in the leaf litter.

Considerations for wildlife. Season of burning (along with fire intensity and firing technique) can influence the risk of direct mortality of wildlife. Animals are most vulnerable to mortality or injury from fire during nesting, brood-rearing, or fawning seasons, and soon after emerging from hibernacula (i.e., some herpetofauna). For most species, relatively few individuals in a population are affected by any given burn unless the area burned is relatively large and intense (Brennan *et al.* 1998). However, for a few species (e.g., timber rattlesnake [*Crotalus horridus* L.] soon after emergence from hibernacula, and eastern box turtle), a significant portion of the local population can be affected by a single fire (Beaupre and Douglas 2012, Howey and Roosenburg 2013). Data from the longleaf pine ecosystem have indicated that habitat improvement using fire can offset population losses or declines by improving habitat conditions in subsequent years (Engstrom *et al*. 2005, Cox and Widener 2008), especially for various birds, such as red-cockaded woodpecker (Walters 1997), Henslow's sparrow (*Ammodramus henslowii* Audubon; Thatcher *et al*. 2006), and Bachman's sparrow (*Aimophila aestivalis* Lich.; Tucker *et al*. 2004, Cox and Jones 2007).

Research on wildlife population response and season of fire in the Central Hardwoods and Appalachians also is limited. Concern has been expressed over potential effects of growing-season fire on herpetofauna (Russell *et al*. 1999, Renken 2006). Beaupre and Douglas (2012) reported that a local population of timber rattlesnakes declined dramatically following an early growing-season fire (April) that occurred soon after the snakes emerged from a den complex. The subpopulation slowly recovered over the following 11 years. It was assumed that the animals were destroyed by the fire, but studies that measure survival, not just occupancy, are needed to quantify direct

effects. Mortality by fire should not be assumed just because surveys suggest fewer animals are present following fire. At another site, Beaupre and Douglas (2012) documented that dormant-season burning (March) and stand thinning led to increased prey and enhanced growth and body condition of timber rattlesnakes. Burning during the dormant season has had no overall negative effect on herpetofauna (Ford *et al*. 1999, Floyd *et al*. 2002, Keyser *et al*. 2004, Greenberg and Waldrop 2008, Raybuck *et al*. 2015). Moreover, American toad (*Anaxyrus americanus* Holbrook; Kirkland *et al*. 1996) and lizards (i.e., eastern fence lizard [*Sceloporus undulates* Bosc. Daudin], ground skink [*Scincella lateralis* J.], and southeastern five-lined skink [*Eumeces inexpectatus* Taylor]) increased in relative abundance on burned sites (Keyser *et al*. 2004, Greenberg and Waldrop 2008, Matthews *et al*. 2010). Dormant-season fire (December) led to decreased surface activity of southern redbacked salamanders (*Plethodon serratus* Grob.) for one growing season following burning in mixed oak-hickory forest, but rebounded by the second growing season (O'Donnell *et al*. 2015). Even for cryptic species (e.g., Ambystomatid salamanders), their life history traits suggest that direct effects are not likely given their nocturnal movements from winter hibernacula to breeding ponds during periods of wet weather in February and March (Briggler 2014).

Concern also has been expressed over possible effects of growing-season fire on bats, especially the Indiana bat. However, Dickinson (2010) reported that, according to standard toxicology models, carbon dioxide levels would have no deleterious effect on bats unless they were directly above the fireline of a very intense fire. A larger concern emanates from heat effects. However, models suggest that heat would not be a factor unless flame lengths exceeded 9 m. Therefore, low- to moderate-intensity fire should have no direct effect on Indiana bats, the species of most concern relative to burning in the eastern US (Carter *et al.* 2002, Johnson *et al.* 2010). Moreover, myotid bats appear to readily vacate day-roosts when fire approaches (Rodrigue *et al.* 2001). Concern also seems unwarranted for maternal colonies given the near total lack of fire in hardwood forests of the Central Hardwoods and Appalachian region from May through early August, the period for maternity colony formation to juvenile volancy and weaning. Indiana bats in the Ozarks selected areas of mature upland oak-hickory forest that had been burned with low-intensity fire in April (Womack *et al*. 2013). Home ranges of northern bats on the Appalachian Plateau were closer to stands that had been burned with low-intensity fire in April (Lacki *et al*. 2009). Insects that are consumed by bats increased in abundance following fire, and more bats roosted in burned areas than in unburned areas (Lacki *et al*. 2009). Bat activity was greater in stands that had been regenerated via shelterwood harvest and later burned than in unharvested and unburned Appalachian hardwoods in Ohio (Silvis *et al*. 2016). The propensity of Indiana bats to forage in canopy gaps, within woodland structure, and along stream corridors in the Ohio River Valley (Kniowski and Gehrt 2014), supports allowing fire to feather into drainages, which is more likely with dormant- and late growing-season fire. Litter-roosting bats (e.g., eastern red bat) have been recorded flushing from the litter in front of the fireline during dormant-season fires (Saugay *et al*. 1998, Moorman *et al*. 1999), but no study has quantified direct effects of dormant-season fire on red bats. Most dormant-season burning (Figure 7) is conducted when ambient temperatures are above 5 °C, which allows for faster arousal from torpor (Perry 2012).

There is no published research that suggests that fire during a specific season is requisite for any wildlife species in the Central Hardwoods and Appalachians. Regardless of burn timing (similar to fire frequency), some

Figure 7. Prescribed fire can increase habitat suitability for several species of bats by creating snags and reducing clutter in the midstory.

species will benefit more than others, and some may be harmed more than others, which makes stating explicit objectives for the burn so important. Until research is completed on population response of various wildlife species to season of burning in the Central Hardwoods and Appalachians, recommendations for season of burning must be based on habitat conditions, fire effects on vegetation (for wildlife and ecosystem restoration), and the biology of focal species. Dormant-season fire has been used most commonly in the Central Hardwoods and Appalachians. However, growing-season fire (especially late in the growing season) must be used in many situations in order to accomplish management goals. Of course, other factors such as fire frequency and size of burn area must be considered with season of burn.

Pattern of Burning and Burn Size

Topography is diverse across the Central Hardwoods and Appalachians. Landform strongly influences soil type and moisture and the vegetation community, which influences fire-return interval, fire intensity, and season of burning. South- and west-facing slopes burn more frequently and with greater intensity than north- and east-facing slopes (Thomas-Van Gundy *et al.* 2007). Landform also strongly influences the wildlife community. For example, woodland salamanders (Plethodontidae) are most abundant on moist aspects and along lower slope positions (Harper and Guynn 1998, Ford *et al*. 2002). Concern for any negative effect of fire on these salamanders is alleviated when burning is concentrated on drier sites where fire is more common and salamanders are less numerous (Ford *et al.* 1999, Moorman *et al*. 2011).

We contend that only fire can provide landscape-level heterogeneity in some landscapes, such as the Appalachians, that otherwise largely would be an unbroken static-aged forest, particularly at present when forest management (i.e., timber harvest) now constitutes a very small proportion of any given area in the region's national forests (Sandeno 2015). Prescribed fire should be concentrated on drier sites that would burn more frequently naturally, depending on specific management objectives. However, fire should be allowed to feather into more moist environments where fuel consumption will be less complete and thus provide a mosaic of conditions and increase site heterogeneity. Relatively moist sites (e.g., southeast- and northwest-facing slopes) may be burned occasionally, according to land management objectives, but fire frequency and intensity generally should be less on those sites to provide a mosaic across time and space (from south-facing slopes around to

north-facing slopes) and increase landscape heterogeneity and wildlife diversity.

A major consideration when managing large tracts of land is size of burn. Landscape heterogeneity, land and wildlife management objectives, public perception, and limited manpower and funds are integral factors that influence size of burns. Often, burning in the region occurs at a small scale (<15 ha), which can have positive effects locally, but cannot elicit landscape-level change or help perpetuate fire-dependent ecosystems (e.g., oak woodland or savanna) unless small-scale fires are well distributed throughout the landscape considered. Larger burn areas, such as those being conducted now on many national forests in the central and southern Appalachians within US Forest Service Region 8, will be necessary to affect the landscape. We are not suggesting that every fire should be >100 ha, but there is an economy of scale whereby relatively small burns can take as much time planning and implementing as larger burns. Therefore, to have a landscape effect with limited manpower and funds, larger burns may be more effective in achieving desired effects. Variable fire intensity is commonplace when implementing larger burns, and is especially important for site heterogeneity. Larger burns also may be necessary to ameliorate impacts from deer herbivory. Over much of the Central Appalachians, white-tailed deer densities are at levels unprecedented over the past two centuries (McShea *et al*. 1997). Accordingly, failure to account for the effect of herbivory following burning and failing to burn in conjunction with harvesting may prevent restoration of native flora and may negatively affect wildlife dependent on understory structure. Burning at small scales may require localized population reduction (Miller *et al*. 2010) or exclusion measures (Kochenderfer and Ford 2008, Royo *et al*. 2010) to prevent herbivory effects or, alternatively, disturbance must exceed 10% of the surrounding landscape to compensate for herbivory effects (Miller *et al*. 2009).

RECOMMENDATIONS AND CONSIDERATIONS WHEN BURNING FOR VARIOUS WILDLIFE SPECIES IN THE CENTRAL HARDWOODS AND APPALACHIANS

We offer the following recommendations for burning when individual species or species guilds are the focus of management (Appendix 1). Our recommendations are based on published research and personal experience. We consider fire effects on vegetation as habitat for focal species, possible direct fire effects on focal species, and the biology (life history) of focal species. We acknowledge that data are lacking with respect to various burning regimes and population-level effects for many wildlife species in the Central Hardwoods and Appalachians. Also, based on our experience and review of the literature, we contend that burning during any season and within a relatively wide range of fire intensity is better than not burning at all for species that require fire to maintain or enhance their habitat. Certainly, a lack of fire in the Central Hardwoods and Appalachians is a much larger limiting factor for species that benefit from burning than an inexact fire frequency, intensity, or timing. That said, it should be clear that, when local populations and abundance of a species is of particular interest, burning prescriptions should be congruent with the life history of the focal species in order to benefit that species as much as possible (Appendix 2). Although we do not specifically address burn size for various species, it should be recognized and accepted that where fire is used, applications separated across time and space and less rigid prescriptions with regard to timing and frequency can provide a mosaic of habitat conditions to support the biological requirements of the focal species.

Songbirds

Habitat for various forest songbirds (e.g., black-and-white warbler, worm-eating war-

bler, Kentucky warbler, hooded warbler, and eastern towhee) that require a developed understory for nesting and foraging can be maintained with low-intensity fire on a 5 yr to 7 yr return interval. Burning outside late April to July will not disturb nesting, which should not limit burning hardwood systems in the Central Hardwoods and Appalachians because burn days during that time are relatively rare. Burning closed-canopy forests is unlikely to improve conditions for these birds unless the fire is intense enough to kill some overstory trees. Stands should have a broken canopy, allowing at least 20% sunlight to the forest floor or sufficient structure may not develop (McCord *et al*. 2014). Low-intensity fire can be used to maintain desirable structure without killing overstory trees. Low-intensity fire also does not consume small woody stems (Stribling and Barron 1995), leaving structure desirable for various winter migrants and residents (e.g., hermit thrush [*Catharus guttatus* Pall.] and Carolina wren [*Thryothorus ludovicianus* Latham]).

Birds that favor more open-canopy, woodland structure (e.g., yellow-billed cuckoo [*Coccyzus americanus* L.], red-headed woodpecker, eastern wood-pewee, least flycatcher [*Empidonax minimus* Baird Baird], great-crested flycatcher, eastern kingbird [*Tyrannus tyrannus* L.], pine warbler [*Dendroica pinus* L.], summer tanager, and orchard oriole [*Icterus spurius* L.]) benefit from both dormant- and growing-season fire. A fire-return interval within 6 yr to 7 yr will be necessary on most sites to retain desirable structure for these birds. All of these species nest either in cavities or at least 3 m to 6 m aboveground.

Burning openings with considerable shrub cover on a 6 yr to 7 yr return interval can be used to maintain habitat for songbirds that require such structure (e.g., white-eyed vireo, gray catbird [*Dumetella carolinensis* L.], brown thrasher, yellow warbler [*Dendroica petchia* L.], chestnut-sided warbler, common yellowthroat (*Geothlypis trichas* L.), and yellow-breasted chat). Late growing-season fire may be useful when some reduction in woody stem density is desired.

Early successional openings dominated with forbs, brambles, grasses, and scattered shrub cover can be maintained with late dormant-season fire on a 3 yr to 5 yr return interval to benefit species such as loggerhead shrike, eastern bluebird (*Sialia sialis* L.), blue-winged warbler, golden-winged warbler (*Vermivora chrysoptera* L.), prairie warbler (*Dendroica discolor* Vieill.), blue grosbeak (*Guiraca caerulea* L.), indigo bunting, field sparrow, and American goldfinch (*Carduelis tristis* L.). Burning just prior to spring green-up will maintain winter cover for various sparrows (American tree [*Spizella arborea* Wilson], chipping [*S. passerine* Bech.], field, savannah [*Passerculus sandwichensis* Gmelin], fox [*Passerella iliaca* Merrem], song [*Melospiza melodia* Wilson], white-throated [*Zonotrichia albicollis* Gmelin], and white-crowned [*Z. leucophrys* Forst.]) that overwinter in the region. Retaining winter cover is important for some species when burning is relatively widespread (Thatcher *et al*. 2006).

Grasslands within a grassland matrix, as well as reclaimed surface mine sites and large grassy balds, can be managed with dormant- or growing-season fire on a 1 yr to 3 yr return interval for grassland birds (e.g., dickcissel [*Spiza americana* Gmelin], savannah sparrow, grasshopper sparrow (*Ammodramus savannarum* Gmelin), Henslow's sparrow, and eastern meadowlark [*Sturnella magna* L.]). Size of the area burned may be relatively large (40 ha to 50 ha) when maintaining habitat for grassland obligate species, and although not all of the habitat should be burned in one year, it is important that some portion of the habitat is burned each year to provide a mosaic of burned and unburned area within the 1 yr to 3 yr fire-return interval (Hovick *et al.* 2012, 2015). Frequent dormant-season fire generally maintains a grassland community. However, when woody encroachment is problematic,

and especially when burn size is large, burning during the late growing season should be considered to avoid disrupting nesting. This is critical for grassland birds in this region because multiple successful nests may be necessary to maintain populations (Giocomo *et al*. 2008). A combination of both dormant- and late growing-season fire should provide increased diversity and increased grassland bird populations (Hovick *et al*. 2015).

Northern Bobwhite

Late dormant-season or early growing-season fire on a 2 yr to 4 yr return interval can be used to maintain early successional vegetation in openings and oak savannas. Peak nesting for bobwhite in the region occurs June to July (Roseberry and Klimstra 1984); therefore, early growing-season fire (April to May) poses relatively little direct effect on bobwhite. Moderate-intensity fire often is necessary to top-kill relatively large woody stems (7 cm dbh to 15 cm dbh). Late growing-season fire implemented in September and October (after peak nesting) may be used to help set back woody composition, but burn areas should be <12 ha (unless the fire is low-intensity and patchy) because burning at this time may reduce woody cover available in winter, which has been identified as a major limiting factor for bobwhite in the region (Brooke *et al*. 2015, Peters *et al*. 2015, Unger *et al*. 2015).

Wild Turkey

Low-intensity prescribed fire on a 3 yr to 5 yr return interval may be used to maintain suitable understory structure in broken-canopy hardwood forests and woodlands for nesting and brood-rearing wild turkey (McCord *et al*. 2014). Burning during the wild turkey nesting and brood-rearing season (April through early June) has been a concern of land managers. No negative population-level effects have been reported following early growing-season fire in longleaf pine systems (Kilburg *et al*. 2014). However, wild turkeys selectively nest in hardwood drainages dissecting longleaf stands that are burned frequently. Better cover for nesting exists in the drainages because they do not burn as often or as completely as the surrounding longleaf uplands and therefore fewer nests are exposed to burning (Kilburg *et al*. 2014). Wild turkey nest sites in upland hardwood forests are located more randomly and not concentrated in drainages (Wunz and Pack 1992). Although nesting wild turkey hens readily re-nest when disturbed during the laying period or early in incubation (Dickson 1992), it is possible that burning upland hardwoods during the nesting season could impact nest success more than burning in pine systems, especially if burned areas are relatively large. Burning outside the nesting season alleviates any concern for disrupting wild turkey nests in upland hardwoods. Wild turkeys are attracted for foraging to sites burned during the dormant season (Kilburg *et al*. 2015). Dormant-season burning also is more advantageous in providing brooding cover because burning during the early growing season does not allow sufficient regrowth to provide cover for broods by late May and June when most broods appear (Sisson and Speake 1994). Oldfields and other early successional areas, including oak savannas, that may be used for nesting or brood-rearing turkeys can be maintained with low- to moderate-intensity fire without damaging residual trees in a savanna. Burning during the late growing season expands opportunities for burning, provides foraging areas in early fall, and may provide better control of woody sprouting than dormant-season fire (Gruchy *et al*. 2009).

Ruffed Grouse

Low-intensity, dormant-season fire on a 6 yr to 8 yr return interval can be used in mature oak-hickory stands with a broken canopy (allowing 20% to 40% sunlight to enter the stand) to maintain desirable stem density and understory cover for ruffed grouse (Jones and

Harper 2007, Jones *et al*. 2008). Young forest stands without overstory trees can be managed explicitly for ruffed grouse cover with moderate-intensity, dormant-season fire on a 15 yr to 20 yr fire-return interval. We do not recommend early growing-season (mid-April through early June) burning where ruffed grouse is a focal species, especially if burn units are large. The re-nesting rate of ruffed grouse in oak-hickory forests of the central and southern Appalachians is extremely low (Devers *et al*. 2007, Jones *et al*. 2015), and fecundity is a limiting factor for ruffed grouse in the southern Appalachians (Jones *et al*. 2015).

White-Tailed Deer

Low-intensity dormant- or growing-season fire on a 3 yr to 5 yr return interval may be used in mature stands with a broken canopy to stimulate forage for white-tailed deer (Lashley *et al*. 2011). Using low-intensity fire in closed-canopy stands may provide some increase in forage availability, but the increase may be negligible (Shaw *et al*. 2010, Lashley *et al*. 2011). Early successional openings can be burned with low- to moderate-intensity fire to maintain forage availability and cover for fawning. Burning for white-tailed deer should be conducted outside the fawning season (May through July), given the reliance of females on associated cover at that time (Lashley *et al*. 2015*a*).

Bats

Moderate- to high-intensity dormant-season fire may be used to create snags and increase day-roost sites for species such as Indiana bat and northern long-eared bat in mature hardwoods (Johnson *et al*. 2009, Johnson *et al*. 2010, Ford *et al.* 2015). Low-intensity fire can be used during the dormant or early growing season on a 5 yr to 7 yr return interval to reduce the midstory and improve foraging conditions for most bat species in stands with a broken canopy structure. Forest openings can be burned on a 2 yr to 5 yr interval to maintain open areas for foraging bats (Loeb and O'Keefe 2011).

Reptiles and Amphibians

Dormant-season burning in open forest, woodland, or savanna encourages vegetation structure, cover, and microclimate beneficial for several reptiles, such as eastern fence lizard and timber rattlesnake, without posing any negative direct effect (Moseley *et al*. 2003, Keyser *et al*. 2004, Greenberg and Waldrop 2008, Matthews *et al*. 2010). Litter removal and greater ground temperatures following fires likely create thermoregulatory conditions favorable for lizards (Moseley *et al*. 2003). Overstory mortality following intense fires also generates down wood that may be used as basking sites by lizards and large-bodied snakes (Matthews *et al*. 2010). Low-intensity fire does not consume pre-existing large, coarse woody debris that is important as cover for many herpetofauna. Some snakes (e.g., timber rattlesnakes) are most vulnerable to fire soon after they emerge from winter hibernacula. Early growing-season fire poses a risk to these animals, especially when burning near known hibernacula and when burning relatively large areas (Figure 8).

Dormant-season burning avoids direct risk to terrestrial salamanders that are more active during the early growing season. Drier site conditions following burns, especially when in combination with overstory reduction through fire-induced tree mortality or timber harvest, may lead to reduced abundance or reduced aboveground activity of salamanders for at least one year post burning (Matthews *et al*. 2010, O'Donnell *et al*. 2015). However, burning sites that are more predisposed to fire (e.g., south- and west-facing slopes) can lead to increased assemblages of plant and wildlife species across the landscape without threatening salamander populations on more moist micro-

Figure 8. If hibernacula occur on the site, burning during the early growing season is more likely to have a direct effect on several snake species than burning during the dormant season before they emerge. However, burning during the early growing season does not necessarily mean snakes are going to die. This timber rattlesnake was observed immediately post burning in early April.

sites where they occur most readily (Moorman *et al*. 2011).

CONCLUSIONS AND SUGGESTIONS FOR FUTURE RESEARCH

We still have much to learn about the ecology of fire in hardwood forests in the Central Hardwoods and Appalachian regions. Historical evidence shows that fire once was prevalent on various sites throughout these regions. It is important for natural resource managers to recognize how fire is a fundamental ecological process in any fire-prone plant community and that it often is the primary driver in ecosystem function. Findings from recent research and management efforts show much promise for ecosystem restoration and enhanced wildlife management using prescribed fire. However, success of such efforts may be evasive and the effects may not be clear or realized if objectives for burning are not thoroughly considered and clearly articulated, and the fire not properly implemented.

Fire causes change, which, under any circumstance, is good for some wildlife species and not good for others. We must recognize the utility of fire to change specific sites and landscapes in a manner that will accomplish specific management objectives that should be planned and monitored for success. We view a lack of fire in these regions as a limiting factor for increased landscape heterogeneity and biological diversity, as well as a limitation to increased abundance of many wildlife species.

Information is lacking on population response of many wildlife species to fire, which is obviously important, especially for declining species. Relatively basic questions on how plant communities and various wildlife species respond to fire frequency and season of burning need additional research. Also, the conservation community would benefit from a better understanding of landscape-level wildlife response to small-scale burning, as well as landscape-level wildlife response to large-scale application of prescribed fire. Of course, long-term data are needed to answer most questions. Although we recognize that relatively frequent and sometimes intensive fire may be necessary to elicit compositional change in the plant community, we note that the suitable prescription to maintain the resulting plant community may be quite different. We have gained information from dendrochronological data to guide initial attempts, but we are just beginning to put this information into practice in hardwood ecosystems. The wildlife response to this management is yet to be realized.

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Appendix 1. Recommendations and considerations when burning for various wildlife species or taxonomic groups in the Central Hardwoods and Appalachian Forest regions.

Species or taxonomic group	Recommended fire prescription	Considerations or concerns	Key citations related to habitat requirements and wildlife response
Understory-nesting songbirds	Low-intensity fire on 5 yr to 7 yr return interval in mature hardwoods	Avoid burning large, contiguous areas during nesting from April through July	Stribling and Barron 1995; Greenberg *et al*. 2007; McCord *et al*. 2014
Open-canopy songbirds	Low- to moderate-intensity fire within a 6 yr to 7 yr return interval to maintain habitat in existing woodlands	Moderate- to high-intensity fire required to develop habitat where closed canopy conditions exist and silvicultural treatment is not implemented	Wilson *et al*. 1995; Blake 2004; Bakermans *et al*. 2012; Barrioz *et al*. 2013
Shrubland songbirds	Late dormant-season fire on a 3 yr to 5 yr return interval in areas with considerable shrub cover	Avoid burning large, contiguous areas during nesting from April through July; burning just prior to green-up maintains cover for wintering sparrows	Wilson *et al*. 1995; Hunter *et al*. 2001; Thatcher *et al*. 2006
Grassland songbirds	Dormant- or late growing-season fire on a 1 yr to 3 yr return interval in grasslands that meet area constraints of grassland birds	Avoid burning large, contiguous areas during nesting from April through July; burning just prior to green-up maintains cover for wintering sparrows; late growing-season fire may help reduce woody encroachment	Hovick *et al*. 2015; Giocomo *et al*. 2008
Northern bobwhite	Late dormant-season or early growing-season fire on a 2 yr to 4 yr return interval in early successional communities and oak-pine savannas	Most nesting occurs after April; maintaining shrub cover in close proximity in a relatively open landscape is critical	Roseberry and Klimstra 1984; Brooke *et al*. 2015
Wild turkey	Low- to moderate-intensity fire on a 3 yr to 5 yr return interval	Avoid burning large, contiguous units during nesting and brood-rearing (April to June)	McCord *et al*. 2014
Ruffed grouse	Low-intensity dormant-season fire on a 6 yr to 8 yr return interval in mature oak-hickory; moderate-intensity dormant-season fire on 15 yr to 20 yr return interval in young forest stands	Avoid burning large, contiguous units during nesting and brood-rearing (April through June)	Jones and Harper 2007; Jones *et al*. 2008
White-tailed deer	Low- to moderate intensity dormant- or late growing-season fire on 3- to 5-yr return interval	Avoid burning during fawning season (May to June); fire effects will be minimal under closed canopy conditions unless fire intensity is great enough to kill some trees and allow light into the stand	Lashley *et al*. 2011
Bats	Low-intensity dormant- or late growing-season fire on 5 yr to 7 yr return interval	Higher-intensity fires may create snags used as roosting sites; lower-intensity fires reduce clutter for foraging bats	Boyles and Aubrey 2006; Johnson *et al*. 2009; Johnson *et al*. 2010; Perry 2012; Ford *et al*. 2015; Silvis *et al*. 2016
Reptiles	Dormant-season fire in early successional communities, savannas, and woodlands	Avoid early growing-season burning near known snake hibernacula when snakes are emerging	Moseley *et al*. 2003; Keyser *et al*. 2004; Greenberg and Waldrop 2008; Matthews *et al.* 2010
Amphibians	Dormant-season fire	Canopy reduction from fire-induced tree mortality and leaf-litter removal reduces habitat quality for salamanders for at least 1 yr post fire; canopy reduction at woodland vernal pools increases Anuran diversity	Renken 2006; Ford *et al.* 2010; Matthews *et al.* 2010; O'Donnell *et al*. 2015

Appendix 2. Periods of the year when burning could be problematic for various species and species groups in the Central Hardwoods and Appalachians[1].

Species or taxonomic group	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
White-tailed deer (primary fawning season)					X	X						
Eastern cottontail (primary nesting in early successional areas)			X	X								
Bats (maternal colonies in woodlands and forests)					X	X	X	X				
Wild turkey (nesting and brooding)				X	X	X						
Northern bobwhite (primary nesting in early successional areas)						X	X	X				
Ruffed grouse (nesting and brooding in forests)				X	X	X						
Forest songbirds associated with understory (nesting)					X	X						
Grassland songbirds (nesting)					X	X						
Shrubland songbirds (nesting)					X	X						
Reptiles (clustered at hibernacula)				X						X		
Woodland salamanders (most active aboveground)					X	X	X					

[1] This table is not meant to imply that burning should not be conducted at particular times of the year, but to illustrate periods in the year when various species and species guilds are most vulnerable to fire. Burning relatively small areas and on relatively long intervals during any time of year should not have population-level effects. However, land managers with a particular interest in various species or species groups may use this information to help ensure that they are burning during times of the year that are least likely to adversely affect those species.