Forestry Matters: Decline of Oaks Will Impact Wildlife in Hardwood Forests

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ABSTRACT Acorn production by oaks (*Quercus* spp.) is an important food resource for wildlife in many deciduous forests. Its role as a hard mast crop that can be either stored or used to build fat reserves for winter survival cannot be replaced by most other potential foods. Changes in forest management, introduced pests and pathogens, and increased deer populations have resulted in significant changes in the demography of oaks in eastern North America, as evident in Forest Inventory and Analysis data. Specifically, maples (*Acer* spp.) are replacing oaks in many forests through dominance of the younger age classes. These changes are not yet obvious in mast production but will take decades to reverse. Effective forest management for mast production is arguably one of the more important tasks facing wildlife professionals, yet receives scant attention by both public and private land managers. Public forests need to explicitly include mast production in their forest planning and reduce adversarial relationships over forest management. Market forces are driving commercial forests toward forest certification. Private forests compose 80% of our oak forests and are the hardest group to influence. States have not been able to effectively market forest plans and we recommend joining with advocacy groups more adept at motivating the public. Increased communication between wildlife and forestry professionals is needed through agency restructuring and joint meetings of professional agencies at the state level. Professional wildlife and forest managers are encouraged to make increased use of monitoring data and form a multiagency cooperative using a joint venture model, which has been successful for other organizations. (JOURNAL OF WILDLIFE MANAGEMENT 71(5):1717–1728; 2007)

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There is an impending crisis in the decline of important tree species and the accompanying loss of wildlife habitat and ecosystem function in hardwood forests of North America. Specifically, we are concerned about the declining abundance of oaks (*Quercus* spp.), because acorns are arguably the most important food resource for birds and mammals during the dormant season in hardwood ecosystems (Martin et al. 1961). Ninety-six species of birds and mammals are known to consume acorns, with many of these species relying heavily on acorns during the fall and winter (Martin et al. 1961). Oaks comprise a foundation genus; they control population and community dynamics and modulate ecosystem processes (Ellison et al. 2005). A significant reduction in the abundance of oak will have profound effects on wildlife communities and a solution to this problem will take decades to bear fruit.

Tree seed crops (mast) are the most valuable and energy-rich plant food available for wildlife in eastern forests during the dormant season. At the time of European settlement, the most abundant and widespread mast-producing tree genera were oaks, beech (*Fagus*), hickory (*Carya*), and chestnut (*Castanea*; Braun 1950). Chestnut apparently was the most prolific nut-producing tree (Brewer 1995) and beech the most widely distributed in the eastern forest (Braun 1950). The annual mast crop from these forests supported the passenger pigeon (*Ectopistes migratorius*), formerly one of the world's most abundant birds (Bucher 1992). Today, American chestnut (*Castanea dentata*) has been virtually eliminated and American beech (*Fagus grandifolia*) has been greatly reduced in abundance, primarily by introduced pathogens (Healy et al. 1997). Consequently, oaks have substantially increased in importance for eastern wildlife during the past century. Hickories remain abundant, but hickory nuts are protected by a hard shell and are available primarily to rodents (Martin et al. 1961). No other current tree species fills the functional role of oaks for wildlife in eastern forests (Healy et al. 1997, McShea and Healy 2002).

Oak forests have a long history of importance in North America (Abrams 2002), but their abundance and distribution have changed in recent history, with decline evident since the early 20th century due to a combination of fire suppression, increased deer herds, and introduced diseases and pathogens (Whitney 1994, Abrams 2003). Even within the genus there have been changes in relative abundance, with white oak (*Q. alba*), the once dominant species, being replaced by red (*Q. rubra*) and chestnut oak (*Q. prinus*) due to changes in climate, land use, and disturbance severity

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Figure 1. Percentage of eastern United States forest land in select upland oak forest types and densities (stems/ha) of dominant and codominant oak species estimated from the 2000 Forest Inventory and Analysis inventory cycle. Forest types included chestnut oak, white oak–red oak–hickory, white oak, northern red oak, yellow poplar–white oak–northern red oak, scarlet oak, and chestnut oak–black oak–scarlet oak (Miles et al. 2001). Available data excludes Mississippi.

(Abrams 2003). The increased dominance of red oak within oak forest types has ramifications; for example, red oaks are more susceptible than white oaks to an emerging pathogen, sudden oak death (caused by *Phytophothora ramorum*).

Oaks have direct and indirect impacts on a variety of wildlife species throughout the eastern forests. Direct impacts are largely mediated through the production of acorns and can influence behavior, habitat use, physiology, and abundance. In autumn, white-tailed deer (*Odocoileus virginianus*) in Virginia, USA, spent 40% of their time feeding in forest stands dominated by oaks during years of above-average acorn production compared to <5% of their time during years of below average acorn production (McShea and Schwede 1993). In southwest Virginia, white-footed mice (*Peromyscus leucopus*) typically do not breed during winter, but long-term monitoring documented breeding in winters following heavy acorn production (Ostfeld et al. 1996). In years of below average acorn production, ruffed grouse (*Bonasa umbellus*) annual home ranges in the southern and central Appalachian Mountains increased 2.5-fold (Whitaker et al. 2005); male home ranges increased from 7.3 ha to 22.3 ha, and female home ranges increased from 19.7 ha to 51.6 ha. Female ruffed grouse collected in the southern and central Appalachian Mountains with acorns in their crop in late March and early April had greater percent fat (20%) than females collected without acorns in the crop (11.7%; Long and Edwards 2004). In western Massachusetts, the percentage of fat in black bear (*Ursus americanus*) milk, postdenning, was greater (26.7%) in years following abundant acorn production (396 kg/ha) than in years with low acorn production (0.9 kg/ha; McDonald et al. 2005). In New York, USA, the density of white-footed mice increased 15-fold in July following above average mast production the previous autumn (Jones et al. 1998). These researchers also manipulated experimental plots by adding ≥811,000 acorns (at densities of 60/m^2 of oak canopy) and documented densities 3–7 times greater than on control plots (Jones et al. 1998).

One example of the indirect link between acorn production and wildlife is how acorn production influences predation rates on nestling songbirds. The influence of acorn production on songbird productivity is mediated through nest predators, specifically white-footed mice and eastern chipmunks (*Tamias striatus*; McShea 2000). In the Hudson Valley region of New York, wood thrush (*Hylocichla mustelina*) nest mortality rate increased from 33% in years of low rodent density to 65% in years of high rodent density (Schmidt and Ostfeld 2003). Rodent density was positively related to acorn production the previous year (Schmidt and Ostfeld 2003). Using empirical data and a simulation model, researchers demonstrated rodent populations may have large impacts on veery (*Catharus fuscescens*) productivity in New York (Schmidt 2003). In years following heavy mast production, veery populations declined between 12% and 29%. In contrast, following low mast production veery populations increased between 3% and 27%.

We have reviewed the importance of oaks for wildlife and, for the sake of brevity, confined our comments to acorn production and not the structural properties of oak forests. Our aim for this paper is to examine the current distribution of oaks, the evidence of declining abundance, and possible reasons for the decline. We suggest practical ways to maintain oak and sustain the diversity and productivity of hardwood forests.

STUDY AREA

Oaks occurred throughout much of the United States and extended into the southern portions of central and eastern Canada (McWilliams et al. 2002). Although oaks' decline was evident throughout the United States, we focused on oak forests east of the Great Plains, because 1) oaks were most abundant in this region, 2) sufficient data existed to infer temporal changes in oak forests and effects of mast production on wildlife populations and, 3) other dominant mast-producing species have already been eliminated or reduced in abundance. In the east, oaks were prevalent in all of the major forest type groups with the exception of the spruce-fir and aspen–birch forests common in the northern states (McWilliams et al. 2002).

METHODS

We used United States Forest Service (USFS) Forest Inventory and Analysis (FIA) data to estimate the current distribution and abundance of select oak forest types and oak species within the red and white oak subgenera in 29 eastern states (Fig. 1), and to examine trends in the distribution and

Table 1. Definitions for the crown class codes assigned to individual trees in the Forest Inventory and Analysis database.[a]

Crown class code	Definition
Dominant	Well-developed crown extending above general level of canopy, receiving full light from above and partly from the sides; larger than average tree in stand
Codominant	Crown forming part of the general level of the crown cover and receiving full light from above but little from the sides
Intermediate	Trees shorter than those of preceding 2 classes receiving little light from above, with crowns either below or extending into the canopy formed by the dominant–codominant trees
Overtopped	Crown entirely below the general canopy level and receiving no direct light from above or the sides.

[a] Miles et al. (2001).

abundance of the species and oak forest types over the past decade. The USFS initiated the FIA national program to collect, analyze, and report information on the status and trends of America's forests (Miles et al. 2001). Historically, FIA inventory cycles have occurred at approximate 10-year intervals, with 6–8 years to complete an inventory cycle for the entire country (U.S. Forest Service 1992), and we acquired data from the 1989 (±4 yr) and 2000 (±3 yr) inventories from the online FIA database (http://www.fia.fs.fed.us/tools-data/data/) to calculate our estimates. We considered 7 oak forest types derived by the FIA program: chestnut oak, white oak–red oak–hickory, white oak, northern red oak, yellow-poplar–white oak–northern red oak, scarlet oak, and chestnut oak–black oak–scarlet oak (see Miles et al. 2001). We also considered structural composition of the oak forest stands, using 4 tree crown classes: dominant, codominant, intermediate, and overtopped (Table 1).

RESULTS

The amount of forest land in oak forests ranged from 1.6% in Vermont and Maine, USA to 60.9% in Kentucky, USA (Fig. 1). Within these oak forests, the average (±SE) density of dominant–codominant trees was 804 ± 116 stems/ha, with the white oak species group more dominant than the red oak group (375.1 ± 64.6 stems/ha and 241.9 ± 35.9 stems/ha, respectively). With few exceptions, both the greatest proportions of oak forests and highest densities of dominant–codominant oak trees were located in the central and southern Appalachian states west into Arkansas and Missouri, USA (Fig. 1). Over the past decade, the average proportion of forest land in oak forest types has remained similar (net increase of 2.6%), but their distribution has changed (Fig. 2). Indiana, Kentucky, Rhode Island, and Ohio, USA have seen large increases in oak forest area ranging from 19% to 36%, whereas Alabama, Iowa, and Tennessee, USA have seen decreases ranging from 11% to 25%.

Although the overall proportion of oak forests has changed little, the structure of these forests has changed, with oaks declining in dominance. During the 1989 inventory cycle, the intermediate crown class (those stems that will replace the codominant and dominant trees in the

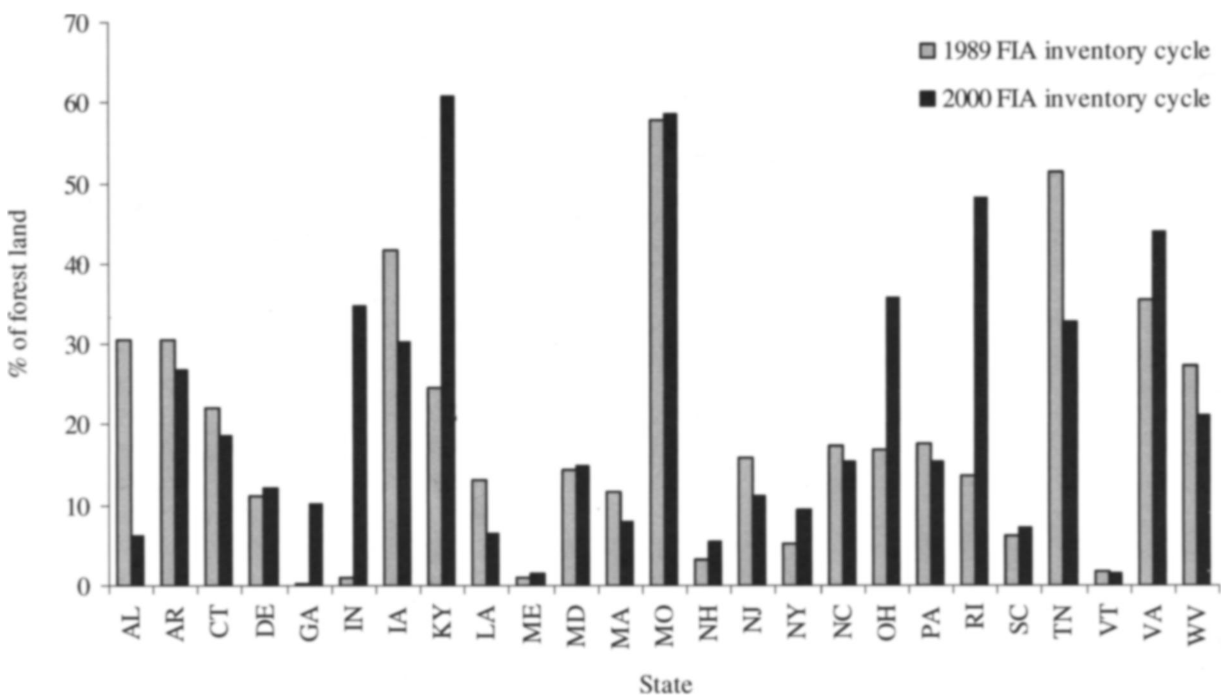

Figure 2. Proportion of forest land in select oak forest types by state estimated from the 1989 and 2000 Forest Inventory and Analysis (FIA) inventory cycles. Illinois, Michigan, Minnesota, and Wisconsin, USA omitted because detailed forest type classifications were not available for the 1989 cycle.

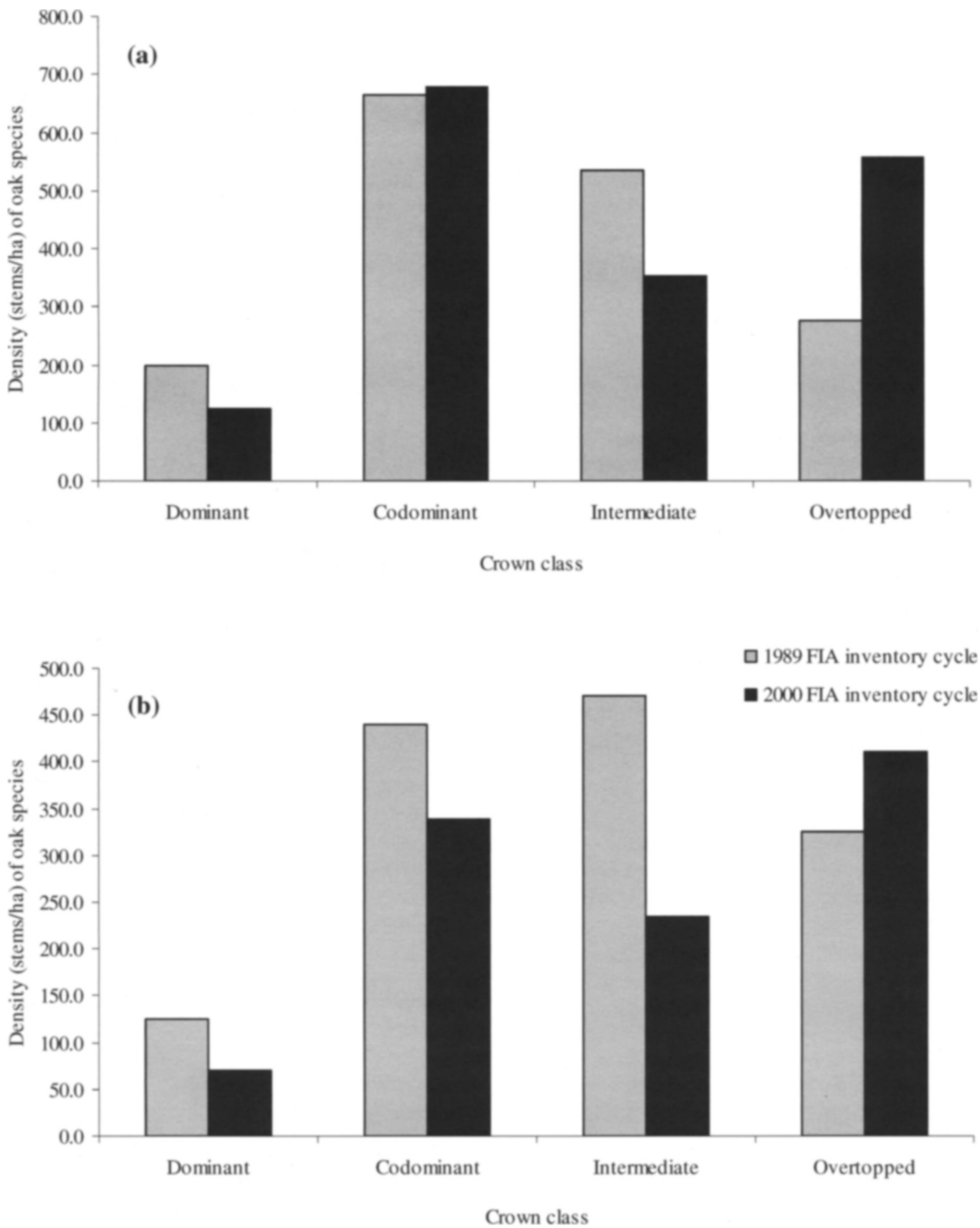

Figure 3. Average density of oak species by crown class code on oak forest land (a) and all forest land (b) in the eastern United States during the 1989 and 2000 Forest Inventory and Analysis (FIA) inventory cycles.

overstory), represented 32% of the average total oak stems in oak forest land while the dominant and codominant classes collectively represented 52% (Fig. 3a). These numbers declined to 21% and 47%, respectively, during the 2000 cycle (Fig. 3a). This trend also was apparent when considering the density of oaks in all forest land, where the proportion of intermediate class trees decreased from 35% to 22% and the proportion of dominant–codominant trees decreased from 42% to 39% (Fig. 3b). In both cases, the proportion of stems in the dominant class decreased between cycles, whereas those in the codominant class remained relatively constant in oak forests but decreased across all forest land (Fig. 3a, b). These figures illustrate that 1) during both cycles, the proportion of stems in the

intermediate class appears insufficient to adequately replace stems in the dominant and codominant classes; 2) the gap between these classes increased between cycles; 3) dominant trees were not being fully replaced by codominant trees; and 4) the proportion of stems in these 3 categories decreased relative to the total. In other words, oaks are losing their dominance in the overstory and have an inadequate number of intermediate stems present in the midstory available to replace them.

Changes in the composition of the overtopped canopy class parallel those in the dominant, codominant, and intermediate classes and also suggest that oaks will be less abundant in future stands. The average number of oak stems in the overtopped category increased between the 1989 and 2000 cycles on both oak forest land and all forest land (Fig. 3a, b). However, the relative abundance of oak stems in the overtopped class decreased due to an increase in the density of competing tree species during the same period (Fig. 4a, b). Between the 1989 and 2000 FIA inventories, the average total density of maples (*Acer* spp.) in oak forests nearly doubled (660 ± 201 stems/ha to 1303 ± 246 stems/ha), with the largest increase occurring within the overtopped crown class (Fig. 4a). In contrast, the average total density of maples in all forests declined 4% (1,196 ± 260 stems/ha to 1,147 ± 208 stems/ha; Figs. 4a, b). Some of the greatest increases in maple density within oak forests occurred in states that also have the greatest proportion of oak forests or highest oak stem densities, including Kentucky, Arkansas, Ohio, and Pennsylvania, USA (Fig. 5).

DISCUSSION

These data expose 2 trends detrimental to the long-term conservation and persistence of oak forests in the east. First, oaks are declining in prevalence within the stands in which they tend to be the most dominant, and there appears to be a poor reserve of intermediate stems available to replace them. Second, the density of maple stems is increasing rapidly, especially within the understory. These increasingly dense understories interfere with the establishment of oak seedlings (Lorimer et al. 1994, Abrams 1998). Further, maples and other understory competitors are either more shade tolerant or faster growing than oaks, and thus capable of out-competing oaks following canopy disturbance (Burns and Honkala 1990).

The loss of dominant oak stems will impact both wildlife and oak regeneration as these stems are the primary mast production trees (Sharp 1958). Greenberg and Parresol (2002) found basal area and crown size were the best indicators of mast production in southern Appalachian oaks. Maintaining large dominant and codominant trees is the best way to ensure mast production. A large-scale reduction in the prevalence of these trees equates to a corresponding reduction in mast availability for wildlife, as well as a seed source for continued oak regeneration. The shift in stand composition, and decline of oak stands, should be reflected in forest acorn production. This is a difficult measure to obtain, as most statewide estimates involve observing sample trees, and counting the number of acorns on a predetermined number of limbs or for a fixed-time interval. When survey trees die they are replaced to maintain sample sizes. Therefore, this protocol yields a per tree index of mast production but does not reflect changes in tree density, or stand area. Changes in oak forest composition should alter acorn production, but the regional datasets are not available to test this hypothesis.

The Problems

Oaks were self-perpetuating and dominant over much of eastern North America for the past 6,000–9,000 years, but today oaks are declining in dominance and being replaced by other species throughout much of their range. The reasons for this change are complex. All of the factors that have been associated with the lack of oak regeneration interact with each other. Fragmentation and parcelization of remaining forests result in biological changes and make the application of sustainable forest management difficult. The ecosystem processes that sustained oaks have been interrupted by introduced pathogens and insects, altered fire regimes, loss of keystone predators and increased herbivory, and the timber harvest practices characterized as high grading (i.e., selective harvest of largest or most productive trees). Below we provide details on each of these processes and how they have increased in recent decades.

Land use: fragmentation and parcelization.—Forest fragmentation is the division of continuous forest into smaller patches. Fragmentation includes the reduction in size of forested patches due to land use changes at their edges, as well as perforation, in which nonforested areas are opened within previously continuous forest, creating edge effects deep within interior forest (Riitters and Coulston 2005). Although forested land covers >50% of the eastern United States, most states in the region have experienced a net loss of forests in recent decades, primarily from fragmentation due to urbanization (Riitters et al. 2002, Riitters and Coulston 2005). Between 1982 and 1997, the United States experienced a 34% increase in developed land (Alig et al. 2004). Roughly 40,000 km^2 of privately owned forest was converted to urban land during this time period, primarily along the Atlantic seaboard (Riitters and Coulston 2005). The forests of the southern United States are facing particular pressure from suburban sprawl as people migrate to the region's cities (Alig et al. 2004, Dwyer and Childs 2004). Forest fragmentation disrupts habitat connectivity, historical disturbance regimes, and nutrient fluxes (Saunders et al. 1991) and during the last few decades has been especially detrimental for oak-dominated forest systems: fragmentation—especially perforation—has been concentrated in the eastern broadleaf forests, where oaks are a major component, as well as the oak–hickory and oak–pine forests of the southern Piedmont and Coastal Plain (Coulston and Riitters 2003, Riitters and Coulston 2005).

Parcelization, the subdivision of large forest ownerships into multiple smaller ownerships, affects forest pattern differently than fragmentation; even when parceled areas remain forested, the subdivision of ownership impedes silvicultural management targeting oaks or other tree species

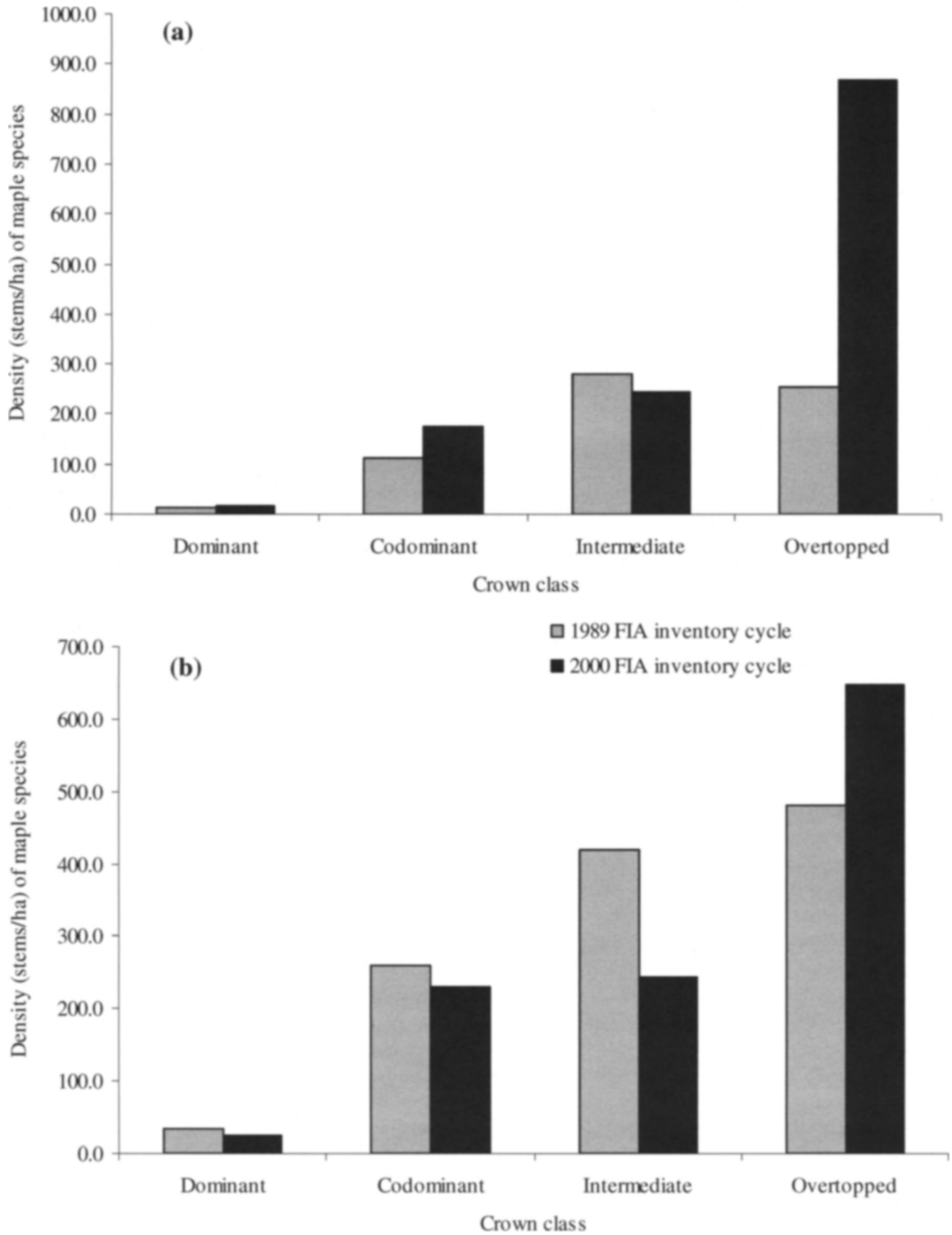

Figure 4. Average density of maple species by crown class code on oak forest land (a) and all forest land (b) in the eastern United States during the 1989 and 2000 Forest Inventory and Analysis (FIA) inventory cycles.

of interest (Brooks 2003). For instance, in the northeastern United States, the total loss of private forest during the last 50 years has been relatively small, but parcelization has been widespread, such that numerous small, disconnected parcels have been converted with negative impacts on adjacent forested land (Brooks 2003). In the southern United States, the number of private forest landowners increased by one-third (1.1 million new ownerships) between 1978 and 1994, with the vast majority of these ownerships containing less than 4 ha (Zhang and Zhang 2004). Furthermore, the advancing age of current landowners means significant turnover in United States private forest ownership is probable during the next few decades, likely leading to increased absentee ownership and less sustainable forest

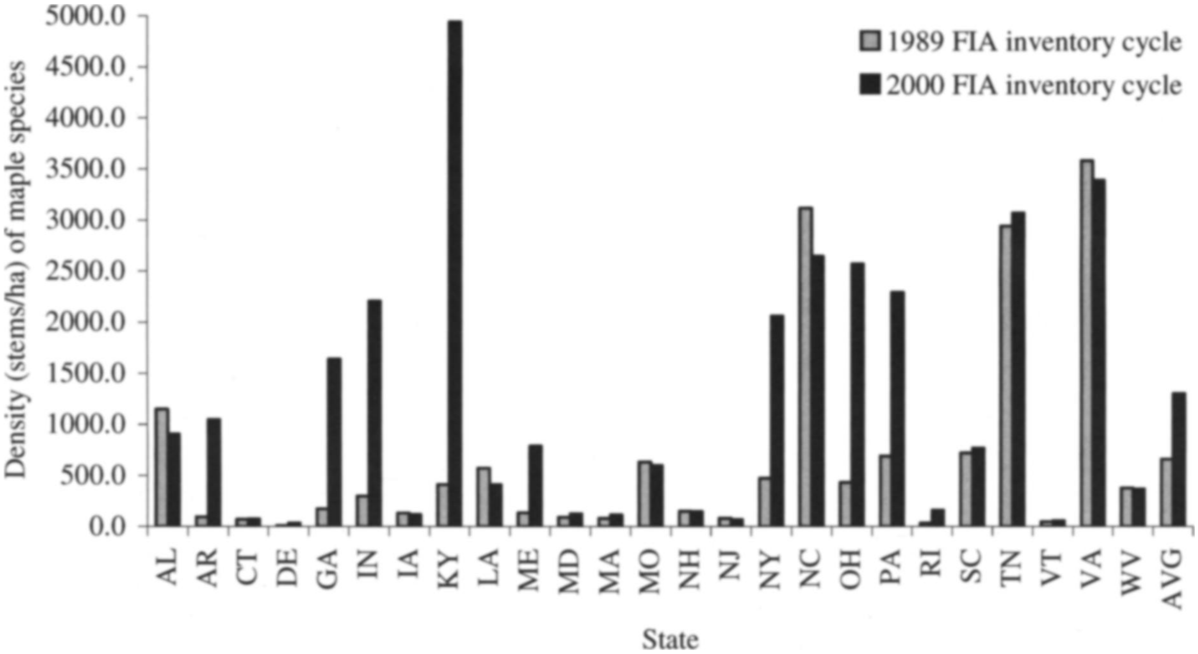

Figure 5. Density of maples on oak forest land in the eastern United States during the 1989 and 2000 Forest Inventory and Analysis (FIA) inventory cycles.

management (Conway et al. 2003, Butler and Leatherberry 2004). Notably, both forest fragmentation and parcelization exacerbate the ongoing conflict between deer and forestry, as they often improve food resources for deer while restricting the effectiveness of public hunting.

Insects and diseases.—Introduced insects and diseases have dramatically altered eastern forests. In particular, these pests have functionally removed or caused precipitous declines in foundation tree species such as the American chestnut and eastern hemlock (*Tsuga canadensis*; Ellison et al. 2005). The loss of these species has increased the importance of oaks for stabilizing ecosystem processes (Ellison et al. 2005), but oaks also face potentially severe reduction by a suite of pests. In particular, the European gypsy moth (*Lymantria dispar*) has developed into one of the most destructive forest defoliators throughout the northeastern United States, particularly on oaks, and continues to expand its range (Sharov and Liebhold 1998, Sharov et al. 2002). Severe defoliations may shift forest stand composition away from oaks, either directly through overstory mortality or indirectly through seed failures or seedling mortality (Gottschalk 1990). Oak wilt (caused by the fungus *Ceratocystis fagacearum*) has resulted in significant mortality in Texas and upper Midwest (Rexrode and Brown 1983). Although it has not yet substantially affected the eastern seaboard, it can be found in pockets from Pennsylvania to South Carolina. There is some risk that the fungus, having adapted to the Texas environment, may spread across the southern distribution of oaks (Ward and Mistretta 2002). Similarly, the sudden oak death pathogen has infected oaks in coastal forests of California and Oregon, with mortality >40% (Garbelotto et al. 2001, Rizzo and Garbelotto 2003). Appalachian forests face an extremely high infection risk because of three coinciding factors: the dominance of red oaks, the near-ubiquitous presence of suitable understory shrub hosts, and appropriately cool, moist conditions. Furthermore, additional pests are likely to arrive in coming decades due to escalating global trade (Levine and D'Antonio 2003, Work et al. 2005).

Fire and silviculture.—Fire played a critical role in the development of oak forests in eastern North America during the Holocene (Abrams 2002). The failure of oak to regenerate coincides with the onset of forest fire prevention in the 20th century (Abrams 2002). Fire favored oak because of its thick bark and strong sprouting ability, while reducing the abundance of fire-sensitive species. Periodic burning encouraged the regeneration of oak over competing shade-tolerant, late successional species and shade-intolerant pioneer species by reducing tree density and creating intermediate light levels and drier conditions (Van Lear and Brose 2002). Effective suppression has eliminated fire as an ecological factor in eastern forests and leaves small-scale disturbances as the primary means of succession in mature forests (Runkle 1982).

Silvicultural systems are available to regenerate and sustain oak forests (Dey 2002, Johnson et al. 2002). There is, however, no simple, single treatment that is effective over the range of sites occupied by oaks. Oak silviculture is inherently complex because regeneration must be established before mature trees are harvested. Even-age management systems have been more successful than uneven-age systems at regenerating oak. The most promising regeneration methods include shelterwood cutting and the combination of shelterwood harvest followed by prescribed fire (Brose et al. 1999). Sustainable management of oak forests requires long-term planning, careful monitoring, and flexibility in the timing and choice of silvicultural treatments. Management is essential. Both indiscriminant logging and complete

protection from disturbance lead to the replacement of oaks by other tree species (Fralish et al. 1991, Lorimer 1993).

Deer management.—White-tailed deer influence forest ecosystem dynamics in many ways (see Côté et al. [2004] and Latham et al. [2005] for comprehensive reviews). At the extreme, browsing by deer can prevent hardwood stands from regenerating after either timber harvest or natural disturbance (Tilghman 1989), and heavy browsing can interrupt understory development in mature oak stands thus preventing them from progressing to an old-growth condition (Healy 1997). For many states, current deer populations are at densities beyond those recorded in the last 100 years (Knox 1997) and multiple authors have determined the sustainable management of eastern hardwood forests requires the regulation of white-tailed deer populations below current densities (Waller and Alverson 1997, McShea and Healy 2002, Rodewald 2003, Côté et al. 2004, McShea 2005).

The Solutions

We feel strongly that the risk of losing large components of the eastern oak forest is real, and the potential consequences to the timber industry and wildlife populations will be dire. The Wildlife Society has recently issued a position statement encouraging wildlife needs to be considered in forest management (The Wildlife Society 2005). This call can be made more specific; there is a need to consider mast production when managing all deciduous forests. We still have time to conserve eastern oak forests while there are still large acreages if we can establish a long view of forest management and establish the infrastructure which facilitates communication among stakeholders. We recognize 3 major groups of forest managers (i.e., public, commercial, and private) and the prescription for each forest type has a slightly different emphasis.

Public forests.—Public forests compose 11% of the oak forests in the eastern United States (McWilliams et al. 2002). There is an essential role of forest management and the application of silviculture for maintaining biodiversity in eastern hardwood forests on public lands, which include National Parks. Protection status, by itself, is unlikely to maintain the diversity of oak forests. Whether discussing National Parks, or designated wilderness areas within National Forests, attention must be given to the regulation of deer numbers, maintenance of appropriate fire regimes, and control of alien pests. We have identified mast production as a critical element for deciduous forests and we must work to maintain the strong mast component in these forests.

National Forests create wildlife management plans as part of their forest planning documents. The wildlife plans frequently focus on individual species, either game or indicator species. We recommend including mast production as a component of wildlife plans, but it is not possible to set a single target that would be appropriate for all forests. Traditional mast targets were to maintain half the management unit in mast-producing stands, which included oak types >40 years old, sawtimber-size hardwood types with 50% of the basal area in oak, and any cover type with >30 square feet of basal area per acre in oak sawtimber (Dellinger 1973). One problem is that basal area is used as a surrogate for direct measurements of mast production, but there are >40 species of oak in the eastern United States and each has specific mast production potentials. For example, the same basal area of red oak can produce 3 times the mass of acorns produced by black oak (*Q. velutina*; Greenberg and Parresol 2002). A second problem is these targets were based primarily on the needs of a few game species and were derived prior to the concept of ecosystem management (Healy 2002). We know competition between small mammals and deer for acorns is more obvious when mast production is <200 kg/ha (McShea 2000), which translates into a target of 12 m^2 basal area/ha for *Q. rubra*, but we don't know the dynamics of all trophic levels dependent on mast production. The best we can say now is basal area targets should be based on species composition of each forest stand, and that these targets reflect potential mast production and should recognize annual variation in actual mast production.

Setting mast targets within forest plans is only part of the solution. Everyone familiar with the forest planning system is aware of the time, effort, and litigation of the current process. Some solutions to the problems of sustaining oak forests on National Forest lands lie in the realm of politics. The primary mission of the USFS and other federal land management agencies, has evolved through interacting laws and interpretations by the federal courts into the preservation of biodiversity (Thomas 2004). That change in mission was unintended and has not been officially recognized, but clarifying the agency mission requires action by the administration or congress. In addition, management on Forest Service land has been gridlocked by a planning system that gives individuals or small minorities the power to block decisions at any time through administrative or judicial challenges (Rauscher 1999). Clearcuts or controlled burns may be indicated in the forest plan to enhance mast production, but implementation could be delayed or curtailed by judicial challenges. Changing the planning process would require legislation that would exempt actions approved in the forest plan from further appeal; an unlikely occurrence in the current political climate.

The adversarial relationship between public forest managers and forest user groups over management plans has led several forest managers to find an alternative way. The Forest Stewardship Council's (FSC) has created principles and criteria of sustainable forest management (http://www.fsc.org) that meet the objectives of this paper. The certification process requires a comprehensive third-party review of the forest operation; consideration of social, economic, and environmental issues; detailed planning; and comprehensive inventories of forest resources. Just over 100 forests in the United States currently have certification, including 63 eastern forests. Several public land management agencies, particularly state forests in Pennsylvania, Massachusetts, North Carolina, and Minnesota, USA, have

sought certification to improve their management programs, educate their staff and the public, and build support for their programs. For example, the Pennsylvania Bureau of Forestry has developed a detailed plan (http://www.dcnr.state.pa.us/forestry/sfrmp/index.htm) that recognizes most of the critical issues brought forth in this paper; the critical need for adaptive silvicultural management, control of deer overbrowsing, regularly updated ecological and forest inventory data, and scientific research to support long-term oak regeneration in state forests. Certification of forest management operations does not guarantee the perpetuation of oak forests but is a step in the right direction and bypasses much of the distrust that currently exists between public land managers and environmental groups. With only 11% of the resource, public forests should set a positive example for other landowners, and we urge public forest managers to set mast production targets and seek FSC certification.

Commercial forests.—Commercial oak forests are almost as abundant as public oak forests (9% of eastern oak forest is commercial; McWilliams et al. 2002) but do not always have the wildlife management plans of public forests. Market forces may be the best means for influencing this group of landowners. Forest industries do seek certification of their operations and products for many reasons, including the economic advantages of greater consumer acceptance of their products. Certification systems for industrial forests are relatively new and proliferating (Rickenbach et al. 2000). The American Forest and Paper Association, an industry trade group, developed the Sustainable Forestry Initiative (SFI) as an alternative to FSC certification. Initially, SFI relied on landowners to design their own environmental standards and management systems but now provides the option of third-party review and verification. The FSC standards may converge with those of SFI in the future, but now we recommend FSC certification.

Private forestland.—The stewardship of private forestland represents the greatest challenge to the maintenance of oak forests and forest diversity in general. A diverse group of individuals, collectively referred to as nonindustrial private forest owners, own 80% of oak forests in the eastern United States (McWilliams et al. 2002). Conservation on these lands is inherently difficult because ownership objectives vary widely, land tenure is generally short, and land parcels are small.

Abundant technical advice and support is available to private landowners interested in forest stewardship through both public agencies and private organizations. Public support is generally delivered through a network that involves the university extension service, the state forestry agency, and the United States Department of Agriculture (USDA). The USDA administers incentive programs through the Farm Service Agency, Natural Resources Conservation Service, and Forest Service. State district foresters administer two important federal incentive programs: the Forest Stewardship Program and the Forest Land Enhancement Program. Together these programs assist landowners in developing forest management plans that meet their objectives, and furnish partial funding to implement practices recommended in their stewardship plans.

Private forest owners can also obtain services from private forestry consultants and nonprofit organizations. Two national nonprofit organizations are dedicated to promoting stewardship on small private forestlands: the American Forest Foundation and the National Woodland Owners Association. The American Forest Foundation standards are similar to those developed by the FSC, but designed for properties that are usually <1,000 acres. Many other nonprofit conservation organizations, such as Ducks Unlimited, National Wild Turkey Federation, Ruffed Grouse Society, and Trout Unlimited, also promote wildlife habitat management and provide services to landowners, but the membership of these organizations is not limited to landowners.

The majority of private forest landowners do not participate in stewardship programs despite the diversity of services and economic incentives available. For example, the American Tree Farm System includes 51,000 family forest owners and 33 million acres, but this is only 10% of private forest land in the United States. In West Virginia, USA, Forest Stewardship Program management plans cover over 600,000 acres of private forestland, but this represents only 3,500 of 260,000 private landowners (Jennings and McGill 2005).

We have 2 recommendations to rectify this obvious gap between available knowledge and its use by private forest landowners:

1) Public service providers, especially district foresters, Farm Service Agency, and Natural Resources Conservation Service, need a marketing plan. The Forest Stewardship Program participants tend to have large properties, higher incomes, and more education than the average forest landowner (Jennings and McGill 2005). Older rural landowners, with low incomes, little technical education, and no access to the Internet are a difficult audience to reach, yet these owners would benefit most from professional help. We know of no state forest plan that effectively results in action on the part of private citizens, but this skill is obvious among many advocacy groups. State agencies should consider forming partnerships with organizations such as National Wildlife Federation (http://www.nwf.org), Izaak Walton League (http://www.iwla.org), or The National Wild Turkey Federation (http://www.nwtf.org), which would combine knowledge with advocacy to motivate private forest owners to action. At a regional level, the multiagency cooperative outlined below can work to network individual states with national advocacy groups.

2) All wildlife and forestry professionals in the East need to broaden their job description. Most private forest owners come in contact with a forestry professional far more often then a wildlife professional because many states require forest plans prior to timber harvest. One way to reach the private sector is through the professional forester. Forester certification happens through the cooperative extension

agencies at each land grant university. Wildlife professionals assuming a larger role in the certification, or recertification, process would broaden the knowledge base of foresters. Few professionals are members of both The Wildlife Society and the Society of American Foresters, mostly because of the professional requirements of Society of American Foresters. Given the dovetailed missions of the 2 groups, these organizations should host joint annual meetings at the state level to reacquaint members what is happening in each field. Wildlife biologists imbedded within primarily forest agencies have a unique advocate role that is not exercised enough. States can better integrate forestry and wildlife programs by administrating both programs through a single bureau, so that foresters and wildlife biologists who share regions also share office space. We cannot expect the public to understand habitat management for wildlife if professionals rarely cross the professional boundaries.

We recommend 2 activities that cut across the types of forest ownership and professional boundaries: we need to monitor our forest resources better and we need to form a cooperative network of stakeholder groups.

Forest monitoring framework.—Useful tools exist for monitoring both long- and short-term patterns of forest composition and wildlife habitat quality. For instance, although many wildlife professionals do not use them, FIA data provide information on the best indicators of long-term mast production: density and basal area of dominant and codominant oaks within forest types (Greenberg and Parresol 2002) and the total area of oak forests. State-level inventory data sets may be freely downloaded from the FIA Program's web site. Previously, these inventories were conducted on 10-year cycles, but the 1998 Farm Bill mandated a pseudo-annual survey cycle, with data collected annually on 20% of the inventory plots within each state (Gillespie 1999). Although the FIA data can be used to assess historic trends, recent FIA initiatives have focused on the collection of tree seedling and understory vegetation data, which may be used to predict future forest composition (e.g., McWilliams et al. 1995). With an average sampling intensity of 6 plots per county, the FIA data may not reflect conditions in individual forest stands. Nevertheless, they can provide forest and wildlife managers with benchmarks for evaluating the long-term prospects for oak regeneration in individual stands.

Mast surveys are used to predict game harvests and forecast hunting conditions, and mast indices are often used as covariates in wildlife analyses (e.g., Steffen et al. 2002, Whitaker et al. 2005). Currently, most wildlife agencies in the eastern states conduct annual mast surveys, and efforts are underway to develop standard regional mast survey protocols. We encourage state forest and wildlife management agencies to collaborate on these surveys, because there is the potential to couple annual (i.e., short-term) mast production indices with long-term FIA data, and create a monitoring system with a broad-scale view of the quantity and quality of oak forest, from both timber and wildlife habitat perspectives.

The FIA is a great monitoring tool for the resource, but there is no equivalent measure for introduced threats. Minimizing the threats posed to eastern oak forests by pest species and other agents requires a multifaceted approach with a prominent monitoring component. For example, monitoring of pest species (which may include deer) can be made more cost-efficient by focusing initially on the highest risk areas, which are typically at the forest–urban interface. Spatially explicit risk assessments by the USFS or other agencies are a starting point for developing pest survey protocols, with the national Sudden Oak Death Survey as an example (Oak 2006). To improve such risk assessments, data on potential threat pathways (e.g., urban forests) should be developed or enhanced.

Multiagency cooperative effort.—Raising awareness among the professional community, the public, and political decision-makers is imperative. Any effective strategy will require a cooperative, multiagency group whose focus is to coordinate and prioritize strategies and management plans. The authors are part of the Cooperative Eastern Oak Initiative (CEOI) modeled after the Joint Ventures that evolved from North American Waterfowl Management Plan and the recently organized National Fish Habitat Initiative. The CEOI is an interdisciplinary working group created to address these oak issues proactively, with an overall mission of ensuring the sustainability of oak forest ecosystems. The CEOI currently consists of representatives from the Conservation Management Institute at Virginia Polytechnic Institute and State University, The Smithsonian Institute, Wildlife Conservation Society, the Northeastern and Southern Research Stations of the USFS, the USFS Health Monitoring Program, the Virginia Department of Game and Inland Fisheries, North Carolina Wildlife Resources, the Virginia Department of Forestry, Pennsylvania State University, Virginia Polytechnic Institute and State University, and MeadWestvaco Cooperation. The immediate goal of this group is to encourage participation from all interested parties (i.e., agencies, conservation organizations, corporations, and individuals) and formalize the structure, mission, goals, and objectives of the initiative. Ongoing activities include maintaining a web page to coordinate and disseminate information related to oak forest and wildlife management (http://www.cmiweb.org/ceoi), hosting symposia at applicable natural resource meetings and conferences, and pursuing seed money to support initial organizational and coordination meetings. The group has the goal of helping each state set mast production goals and develop effective forest plans and communication networks focused on mast production.

MANAGEMENT IMPLICATIONS

In conclusion, oak is the foundation species for many of the eastern forests that support wildlife. Its decline is evident in the present age structure of many forests. Long-term forest plans that utilize disturbance regimes, either natural or man-made, are part of the solution. Communicating proper forest management to public, commercial, and private forest owners is the main challenge. A good place to start is

better practices in public forests and better communication among forest and wildlife professionals. We know what to do to maintain healthy oak forests, but we need a better awareness among professionals and a communication system to landowners to change the current situation.

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