Chapter 3
The Value of Old Forests: Lessons from the Reynolds Research Natural Area

Don C. Bragg and Michael G. Shelton

Abstract In 1934, the Crossett Experimental Forest (CEF) opened to develop good forestry practices for the poorly stocked pine-hardwood stands that arose following the high-grading of the virgin forest. One CEF demonstration area has had no active silviculture other than fire protection since 1937; this 32.4-ha stand is now the Russell R. Reynolds Research Natural Area (Reynolds RNA). Periodic inventories of this tract provide a unique account of long-term stand development under minimal anthropogenic disturbance. For instance, successional change has been characterized by the slow conversion from pines to hardwoods. Gradually, as the dominant pines die, they are replaced by increasingly shade-tolerant hardwoods, resulting in a dense understory and midstory. Without concurrent fire to help prepare the seedbed, even a relatively severe bark beetle infestation in 1993–1994 failed to sufficiently disturb the site and permit the establishment of a new pine cohort. In addition to lessons learned on succession in this cover type, research associated with the Reynolds RNA has also helped develop old-growth restoration strategies, the ecological role of large dead wood in southern pine forests, the deleterious effect of dense midstory hardwoods on red-cockaded woodpecker habitat, the value of old forests in modeling tree allometry and carbon sequestration, and the unexpected benefits of preserving unique landscape features for future study. Clearly, the Reynolds RNA has demonstrated that there are opportunities to learn from passive stand management.

Keywords Crossett Experimental Forest · Disturbance · Red-cockaded woodpeckers · Southern pines · Succession

3.1 Background

Toward the end of the nineteenth century, timber supplies were nearly exhausted in the northern USA, and many companies began moving their logging operations to the south—a land of seemingly endless pine forests (Baker and Bishop 1986).

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The early harvesting strategy was almost universally one of high-grading the virgin timber, in which only the best trees were taken (Della-Bianca 1983) and only the choicest parts of these trees were utilized, leaving huge quantities of usable timber in the woods to either burn or rot (Chapman 1913). The abundant supply of cheap, high-quality timber provided virtually no incentives to curb this reckless behavior. Large-scale removal of old-growth pine began in the 1890s in southern Arkansas, and was almost complete by 1930 (Reynolds 1980; Smith 1986). The Crossett Lumber Company, as well as numerous other operations, thoroughly cut the piney woods of Arkansas, Louisiana, and Texas, producing billions of cubic meters of valuable lumber and leaving behind logging slash, stumps, and scattered unmerchantable trees. Most of these companies then followed a "cut-out and get-out" strategy—they would either move their operations to the next area of virgin timber or close their business. By the late 1920s, though, the end was in sight for this free-for-all, and a few lumber companies such as Crossett resolved themselves to making sustainable, science-based forestry work on their cutover lands—they just needed help learning how to do it (Reynolds 1980; Darling and Bragg 2008).

At this time, ideas on the nature and value of the virgin forest had changed considerably, but were still far from the conservation of today. The science of forestry had yet to catch up with its practice, and the efficacy of these new techniques needed to be documented and demonstrated if the profession was to succeed. Indeed, the whole forest products industry required a revamp, and soon—the fast-growing second-growth timber that appeared after the "big cut" was thought to be substandard for lumber (Reynolds 1980) and the industry and local economy faced collapse. Experimental forests were vital to this learning process, and a number of them were established to provide proof of concept. In late 1933, Russell R. Reynolds of the USDA Forest Service scoured the lands of the Crossett Lumber Company for a suitable location for such an experimental forest and research center (Reynolds 1980).

And he found it! Opened in 1934, the Crossett Experimental Forest (CEF) is located on the Upper West Gulf Coastal Plain in Ashley County, Arkansas, 11 km south of the city of Crossett (Fig. 3.1). Over the decades, considerable research has been conducted on this experimental forest. Though the 680-ha CEF is renowned for its role in the development of uneven-aged silviculture, a small tract of unmanaged old timber, the Russell R. Reynolds Research Natural Area (Reynolds RNA), has also proven highly illustrative regarding ecosystem patterns and processes. The evolving role of the Reynolds RNA, first established as a control of active silviculture in pine-hardwood stands, now allows for the consideration of many contemporary resource issues and continues to provide new lessons for the future.
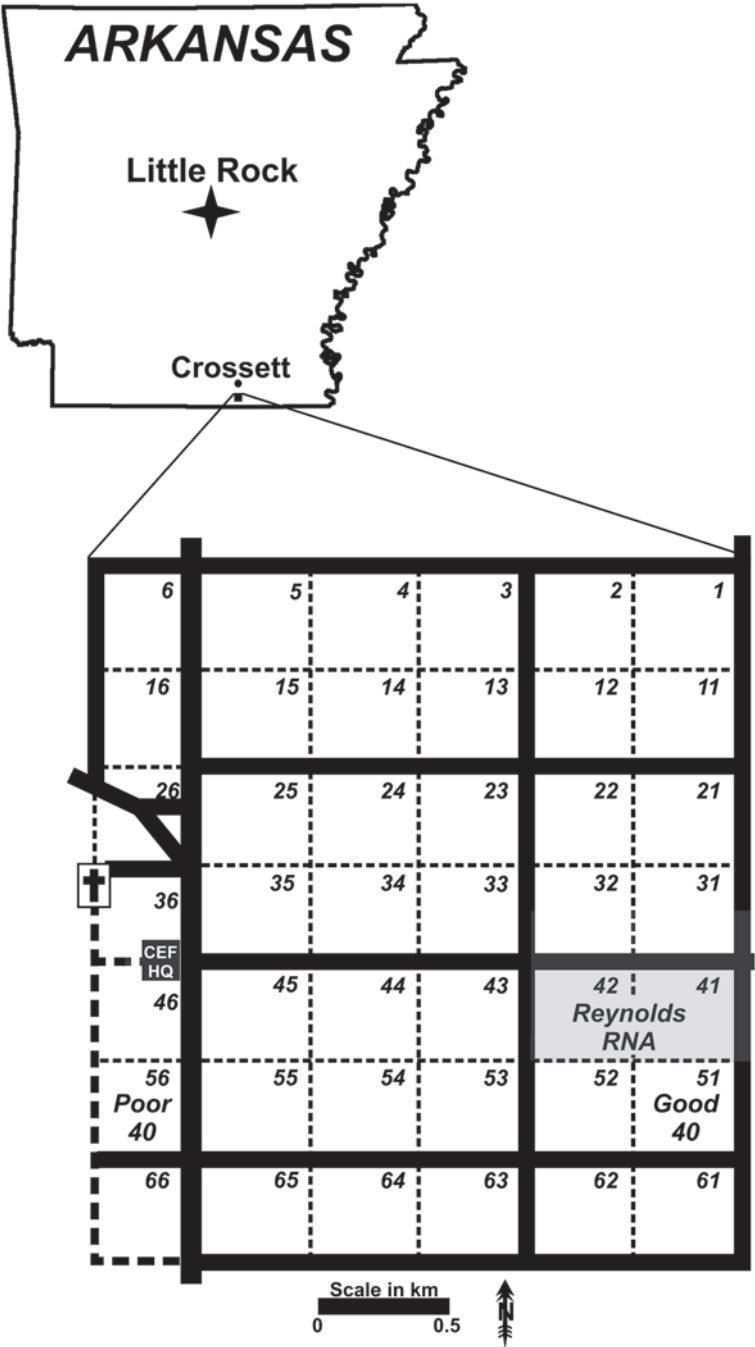
Fig. 3.1 Map of the location and layout of the CEF in Arkansas, including the Reynolds RNA

3.2   Reynolds RNA Description

3.2.1   Establishment History

Since hardwoods had little value during the original logging period, most were left among the surviving submerchantable pines. These legacy trees often grew at impressive rates once released and also provided a seed source for future stands. Periodic fires were common in the virgin forest; some fires were very intense and widespread, particularly in the heavy slash left after cutting (Reynolds 1980). Although these fires destroyed considerable quantities of trees, some fast growing individuals were able to reach fire-tolerant sizes between burns, and certain species—such as shortleaf pine (*Pinus echinata* Mill.) and most of the hardwoods—could resprout after being top-killed (Cain and Shelton 2000). These historic fires also prevented the buildup of litter on the forest floor and killed herbaceous vegetation, creating a receptive substrate for the small, wind-disseminated pine seeds. However, many areas burned too frequently and intensely to adequately reforest, resulting in poorly stocked, second- growth stands with a wide range of tree size classes—conditions viewed as too challenging for the practice of forestry (Anonymous 1981). Reynolds even credited local "woods burners" for helping to locate of the CEF—the Crossett Lumber Company was eager to have the Forest Service share responsibility in this arson-plagued portion of Ashley County (Reynolds 1980).

Most of the first year's activity on the CEF focused on building a modest headquarters, constructing 22 km of roads, establishing a system of 16.2-ha compartments, and inventorying the existing stands. By the summer of 1935, it was time to formulate a research strategy for the CEF, as Reynolds (1980, p. 12) recalled:

> …[we] had a final meeting to agree on the assignment of research study areas on the Experimental Forest. The result was that 80 acres [32.4 ha] was to be left untouched as a 'Natural Area'…[another] 80 acres [32.4 ha] was for farm forestry studies.

This planning session established the three hallmark demonstration areas that have been maintained to this day—the compartments that would become the Reynolds RNA and the "Good" and "Poor" Farm Forestry Forties. The remaining area was allocated to an arboretum (planted in 1935), small plot research, large compartment studies, and administrative purposes.

The role of the natural area changed dramatically over the years. Initially, it served only as an unmanaged control to highlight the enhanced productivity of the Good and Poor Forties. However, this eventually changed. Following a rapid expansion and product diversification during the 1930s and 1940s, forest industry sought to intensify their timber management to ensure a large quantity of inexpensive raw materials (Heyward 1958). The rapid growth of naturally regenerated stands was not able to meet this increased demand. Furthermore, the implementation of effective fire control and the large-scale abandonment of marginal croplands spurred work on pine plantation management. Silvicultural research in southern pines had developed in tandem with the forest products industry, and had proven the efficacy of plantations of genetically superior seedlings, competition control, density

control, and thinning to increase fiber production. During this period, the expansion of the southern pulp and paper industry also increased demand for fast-growing young pines (lower pitch content), which could be cut in mid-rotation thinnings of natural or planted stands (Heyward 1958).

By the 1960s, the industry was shifting from naturally regenerated southern pine stands to genetically improved pine plantations. To some, the selective timber management research at the CEF seemed dated and inadequate for a future silvicultural universe of artificially regenerated commercial forests (e.g., Wakeley 1964). Even after his retirement, Russ Reynolds maintained a spirited defense of this system (e.g., Reynolds 1974), but the growing interest in plantation silviculture was clearly one of several factors that led to the closing of the CEFin 1974. The CEF was re-opened in 1979 after the Forest Service recognized that many landowners remained interested in silvicultural options other than intensive plantation culture. Hence, the focus of the CEF shifted toward low-cost management alternatives designed to appeal to small private landowners, as well as public agencies and large private owners interested in other uses of their timberlands. During this revisioning, the low productivity of the unmanaged natural area was still used to contrast the enhanced production of adjacent managed stands, but the non-timber attributes of what had become a mature, mixed pine-hardwood stand were also touted, especially aesthetic properties, wildlife benefits, and recreational potential (Baker and Bishop 1986). Also in the 1980s (about 70 years since the virgin forest was cut), the Reynolds RNA achieved a status of its own—it had become old and thus unique.

In 2005, this unmanaged parcel was officially designated as the Russell R. Reynolds RNA (USDA Forest Service 2005). The Forest Service developed their RNA program to preserve, as reference areas, examples of natural features and processes in ecosystems that can be contrasted with more human-influenced environments (Northern Research Station 2010). RNAs are considered to be natural laboratories and outdoor classrooms of historical and biological significance (Fountain and Sweeney 1987). Though some were established to protect small areas of old growth on national forest lands (Devall and Ramp 1992), many (such as the Reynolds RNA) were located in previously cutover stands and thus offered the opportunity to understand long-term vegetation dynamics and forest succession (Hemond et al. 1983).

3.2.2 Woody Vegetation, Past and Present

Prior to the early 1900s, records of the composition of virgin pine forests in the South are spotty at best (Eldredge 1952). Most accounts refer to pine and a handful of other commercial species, and are largely silent on the minor taxa that were present. However, the virgin forests are now known to be considerably more dynamic, complex, and robust than the ecological deserts they were once considered. A recent literature review of the region prior to lumbering found a wide range of pine dominance, with shortleaf being the most common pine on many upland sites, probably due to fire (Bragg 2008a). In southern Arkansas, the upland virgin forest was dominated by loblolly (*Pinus taeda* L.) and shortleaf pine in a roughly equal mixture,

often with a significant hardwood component (Reynolds 1980; White 1984; Bragg 2004a; 2008a). The second-growth forests that appeared after lumbering differed in key ways. Where Yale Professor Herman Haupt Chapman had inventoried open, multi-cohort stands of old-growth pine-dominated forests in the uplands of the Crossett area (Chapman 1912, 1913), just two decades later Reynolds inherited a mix of variably stocked young pines and hardwoods that emerged following logging, overtopped by legacy trees.

Originally, the unmanaged CEF natural area was tallied with a 100% inventory by 2.5-cm-diameter at breast height (DBH) classes with a minimum measurement threshold of 9-cm DBH; eight inventories were conducted in this manner from 1937 to 1993. Only broad species groups, such as pine, oaks, and other trees, were recorded in these inventories. However, it became apparent that these coarse inventories provided an incomplete picture of the net changes that were occurring, and were unsuitable for determining stand dynamics, including survivor growth, ingrowth, and mortality. Thus, in 1989, 12 permanent 0.1-ha plots were established in the natural area where individual trees ≥9.0-cm DBH were numbered, identified by species, measured, and their location mapped. Two years later, eight additional plots were established for a total of 20 plots representing 6% of the area (Shelton and Cain 1999), and all plots are now measured about once every 5–10 years. Also, subplots within the permanent plots were established to collect information on seedlings and saplings of woody species.

Today, the overstory of the Reynolds RNA is still dominated by loblolly pine, with noticeably lower amounts of shortleaf pine. Of the canopy hardwoods present, white oak (*Quercus alba* L.), southern red oak (*Quercus falcata* Michx.), post oak (*Quercus stellata* Wang.), water oak (*Quercus nigra* L.), cherrybark oak (*Quercus pagoda* Raf.), sweetgum (*Liquidambar styraciflua* L.), and black gum (*Nyssa sylvatica* Marsh.) prevail (Cain et al. n.d.; Shelton and Cain 1999). The midstory is dominated by increasingly shade-tolerant hardwood species, including eastern hop hornbeam (*Ostrya virginiana* (Mill.) Koch.), elms (*Ulmus* L.), American holly (*Ilex opaca* Ait.), red maple (*Acer rubrum* L.), and flowering dogwood (*Cornus florida* L.). The understory is composed of numerous tree seedlings, although pines larger than recent germinants are conspicuously absent in this layer. A variety of shrubs and woody vines, including American beautyberry (*Callicarpa americana* L.), deciduous holly (*Ilex decidua* Walt.), hawthorns (*Crataegus* L.), huckleberries (*Vaccinium* L.), poison ivy (*Toxicodendron radicans* (L.) Kuntze), greenbrier (*Smilax* L.), grape (*Vitis* L.), Chinese privet (*Ligustrum sinense* Lour.), and sweetleaf (*Symplocos tinctoria* (L.) L'Hér) are abundant (Cain and Shelton 1995).

3.3   Current Research and Synthesis on the Reynolds RNA

Throughout much of human history, old forests were thought to be unproductive, stagnant, and even sterile environments. Rather than considering the value of old growth for the protection of its dependent species, scientists often dismissed the

virgin forests as decadent timber stands with poor wildlife habitat scarcely fit for birds or rodents (e.g., Munger 1930). Over the past few decades, the role of old forests has been completely reevaluated. The following discussion focuses on two recent research outcomes from the Reynolds RNA that consider the value of old forests in contemporary landscapes, rather than its role as an unmanaged control for more conventional silvicultural research.

3.3.1 Structural and Functional Lessons

One of the first ecological lessons from the Reynolds RNA arose from the long-term dynamics of an unmanaged, relatively undisturbed second-growth pine-dominated stand. Stand developmental trajectories became of particular interest in the 1980s as ecological theories on forest succession matured, and the Reynolds RNA became the subject of publications describing the vegetative dynamics of its understory (Cain 1987) and overstory components (Guldin and Baker 1985). Their work was made possible by the long sheltered history of this stand, and has since been complemented by a number of follow-up studies that have further documented change to the structure and function of the Reynolds RNA (e.g., Cain and Shelton 1995, 1996; Shelton and Cain 1999; Bragg and Shelton 2011).

After the original logging of the area, most of the residual timber in the Reynolds RNA was loblolly and shortleaf pine, which destined the early stages of this development to be heavily pine-dominated for decades (Fig. 3.2). After lumbering, these legacy pines grew considerably larger than either the new crop of recently germinated pines or slower growing residual hardwoods, producing an irregular size distribution and multistoried pine canopy comparable to managed uneven-aged stands (Fig. 3.2, 1937 and 1942). This structure, however, was fleeting as the vigorous pine regeneration soon ascended into the overstory. Eventually, as the canopy closed, pine regeneration began to fail and a variety of hardwoods soon dominated the understory and midstory. The pine size distribution became broadly unimodal, with virtually all pines except the most suppressed individuals reaching the overstory (Fig. 3.2, 1952–1983). Over the past few decades, many of these pines died, interrupting what had largely been a continuous pine canopy across the Reynolds RNA (Fig. 3.2, 1993–2007). Mortality has claimed all of the overstory pines in some parts of this stand, leaving a pure hardwood overstory. In other areas, only a handful of super-canopy pines rise above a closed hardwood canopy. Pine density (stems > 8.9-cm DBH) declined from 320 stems/ha in 1937 to 66 stems/ha in 2007, while hardwood density increased from 100 stems/ha to 383 stems/ha over the same period. Individual pine growth has ameliorated the impact of the loss of stems on relative stand density—pines accounted for an average of 66 % of the total basal area in 1937 and 54 % in 2007.

Coarse woody debris (CWD) has also accumulated differently in the Reynolds RNA than in managed stands in the same region. Although the ecological role of dead wood has been recognized for years (e.g., Lemon 1945; McMinn and Crossley 1996; Braccia and Batzer 2001), very little work has been done in assessing CWD
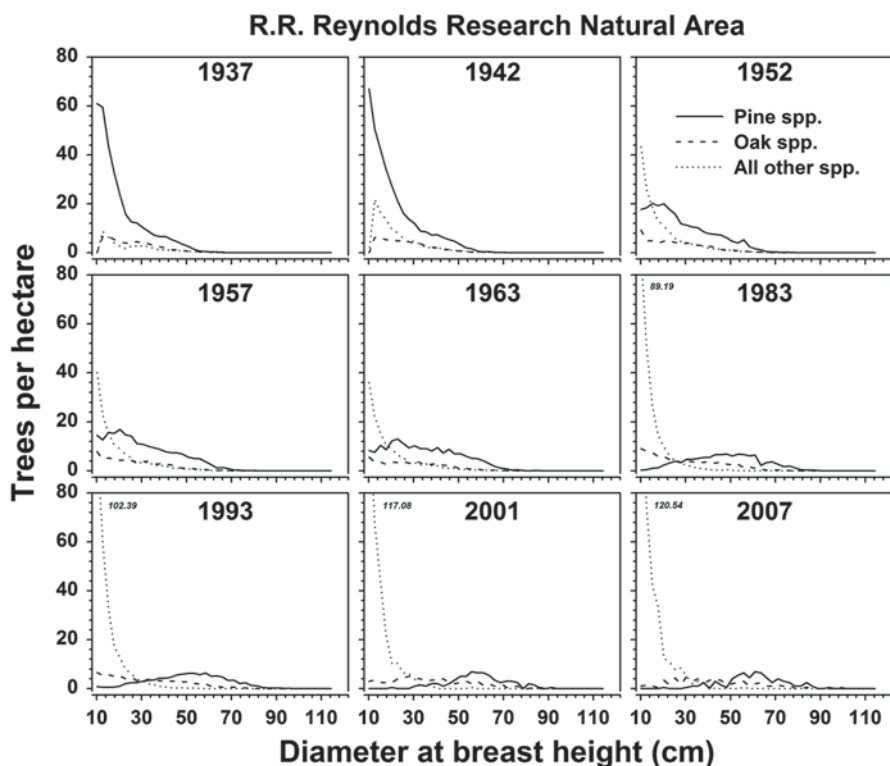
Fig. 3.2 Patterns in stem density (trees > 8.9-cm DBH) over the 70-year period of observation on the Reynolds RNA. Small italicized numbers in the upper left corners of the graphs from 1983 to 2007 are the number stems in the smallest size class truncated by the density scale

volumes in southern forests, especially for mature stands of natural origin. From a silvicultural standpoint, dead wood was traditionally considered an undesirable attribute of any forest type, and was typically ignored or treated as a forest health problem. However, in recent years CWD has recognized as an important ecosystem metric associated with habitat quality (e.g., Braccia and Batzer 2001; Fan et al. 2005), carbon storage (Radtke et al. 2009), and other ecological functions.

Research in the Reynolds RNA has shown that this stand has accumulated considerably more dead wood than nearby examples of managed timber (Zhang 2000; Bragg 2004a). Table 3.1 provides estimates of CWD volume from a number of mature, pine-dominated forests from the region. The 90 to >300 m³/ha totals in the Reynolds RNA are several times greater than mature managed second-growth stands, and comparable to that found in a nearby old-growth remnant that experiences periodic salvage (Bragg and Heitzman 2009). These accentuated CWD levels can be largely attributed to the senescence of many large pines due to windthrow, lightning strikes, and southern pine beetle (SPB) infestation (Cain and Shelton 1996; Zhang 2000). Intensively managed pine stands, such as the Good Forty

Table 3.1 Coarse woody debris volume in some mature pine-hardwood stands of southern Arkansas

Stand	Silvicultural regime	Volume (m³/ha)	Source
Good Forty[a]	Managed second-growth	35.5	Zhang (2000)
Reynolds RNA[a]	Unmanaged second-growth (with some old-growth remnants)	93.7–309.7	Zhang (2000)
POWCNA[b]	Unmanaged second-growth	28.9	Bragg and Heitzman (2009)
Levi Wilcoxon DF[b]	Old-growth (some salvage of dead pine)	191.0	Bragg (2004a)
Hyatt's Woods[b]	Remnant old-growth (some salvage of dead trees)	19.8	D.C. Bragg, unpublished data

[a] Located on the Crossett Experimental Forest (AshleyCounty, AR) of the USDA Forest Service
[b] The Prisoner of War Camp Natural Area (POWCNA) is owned by the University of Arkansas at Monticello (Drew County, AR), the Levi Wilcoxon Demonstration Forest (DF) is owned by Plum Creek Lumber Company (Ashley County, AR), and Hyatt's Woods is a privately owned parcel in the southern portion of Drew County, AR

Demonstration Area on the CEF, typically have much less dead wood because of salvage, lower large tree density, and the higher vigor of the managed stands, which make them less vulnerable to certain mortality events such as SPB (Thatcher et al. 1980). Two other nearby unmanaged old stands (the POWCNA and Hyatt's Woods) have much less CWD than the Reynolds RNA because they have yet to reach the stage of extensive pine overstory mortality (Bragg and Heitzman 2009).

3.3.2   Forest Succession and Natural Disturbance

The development of a substantial hardwood component during the undisturbed natural succession of pine-dominated southern forests is well documented (e.g., Wahlenberg 1960; Quarterman and Keever 1962; Switzer et al. 1979; Glitzenstein et al. 1986; Huston and Smith 1987). This progression reflects differences in the autecology of the associated species in the southern forest community, which affect their establishment, development, and survival over long periods of time. Loblolly and shortleaf pines are opportunistic, shade-intolerant species which can rapidly establish and capture the resources of an unoccupied site (Shelton and Cain 2000). Although much harder to generalize, hardwoods typically tend to be less opportunistic, more shade-tolerant, and slower growing—at least on the upland sites they share with the pines. Under these circumstances, additional external factors are needed to ensure the long-term perpetuation of unmanaged pine-dominated ecosystems.

Conventional wisdom now holds natural disturbances capable of this, although this perspective was not always the case. For example, during the transition from unsustainable lumbering to scientific forestry, fire was almost always seen as a destroyer of timber and a limitation to forest productivity. Virtually all early published

reports emphasized the losses that arose from uncontrolled fire (e.g., Barrett 1928; Forbes 1923; Bruner 1930; Garren 1941). At this time, most researchers were also confident that dominant pines would remain self-replacing without direct human intervention (e.g., Hall 1945; Eldredge 1952). Complete fire exclusion was thought to be the only reliable means to ensure adequate pine regeneration, especially in uneven-aged stands. Much of the early work at CEF consisted of fighting wildfires and trying to convince people not to burn their lands, even though this was a cherished local tradition (Bruner 1930; Shea 1940; Eldredge 1952). Of course, not everybody considered fire to be a problem. Reynolds and the Forest Service began a series of studies during the 1940s (Reynolds 1980, p. 38) in response to Herman Haupt Chapman's advocacy of the utility of certain types of controlled burning (e.g., Chapman 1916, 1932, 1942, 1952), work that demonstrated fire had both positive and negative silvicultural values.

Forest succession in the Reynolds RNA after the implementation of fire suppression was characterized by a 70+ year period relatively free of catastrophic disturbance. Rather, frequent, small-scale disturbances predominated, such as an individual tree or small groups of trees being killed by a lightning strike, severe winds, ice storms, insect infestations, or disease. Most of these minor disturbances went undetected by the early stand-level monitoring of the Reynolds RNA. Other than the broad umbrella of fire control, major anthropogenic disturbances have also been excluded from the Reynolds RNA area since its establishment. However, limited salvage was conducted to suppress a southern pine beetle (SPB) (*Dendroctonus frontalis* Zimm.) epidemic in southern Arkansas during the early 1970s (Ku et al. 1981). At that time, a 0.4-ha SPB "spot" was salvaged along the perimeter of the Reynolds RNA, and a cut-and-leave treatment was imposed on infested but isolated pines, affecting about 0.5 trees/ha.

Another SPB outbreak occurred in the 1990s when the Reynolds RNA was more closely monitored. Examination of this SPB infestation demonstrates how succession and disturbance interact to determine the composition of the forest community, and how multiple, small-intensity disturbances can have synergistic effects. The SPB infestations in 1993 followed an early spring windstorm that uprooted or damaged pines in a compartment immediately south of the Reynolds RNA. Although the pines were salvaged outside the perimeter, no suppression activity was conducted within the Reynolds RNA and the SPB remained active within the stand throughout the 1993 growing season. In February of 1994, the area was hit by an ice storm of historic proportions (Halverson and Guldin 1995). During 48 h, the accumulated ice broke tree limbs and even toppled a few old pines and hardwoods. Storm injuries further stressed the pines and exacerbated the SPB infestation, which intensified during the 1994 growing season. In 1995, however, the SPB activity stopped as abruptly as it started. Losses within the Reynolds RNA were not uniformly distributed. For example, one quarter of the permanent monitoring plots had pine mortality losses of about 50 %, while losses were negligible on the other plots (Table 3.2). Four of the plots with SPB high activity were located in an infestation of about 4-ha in size located in the eastern part of the Reynolds RNA, while the remaining plot was located in a relatively isolated infestation of about 1 ha located

Table 3.2 Mean basal area in the Reynolds Research Natural Area of living pines and hardwoods over a 10-year period on 20 permanent, 0.1-ha plots—5 plots with high levels of southern pine beetle activity in 1993 and 1994 and 15 plots with low activity. (Adapted from, Shelton 2007)

Year[a]	Pines		Hardwoods	
	High activity	Low activity	High activity	Low activity
	m²/ha		m²/ha	
1990	24.5	22.1	12.2	15.0
1993	18.7	22.7	12.8	15.5
1994[b]	18.5	22.3	12.8	15.5
1994	9.0	22.0	10.6	14.6
1995	9.0	21.8	–[c]	–
1996	9.1	21.9	–	–
2000	9.2	22.1	13.0	16.0

[a] Inventoried (1990, 1993, and 2000) or visually inspected (1993–1996) for mortality after the growing season of the specified year. Survivor growth between inventories was interpolated
[b] Measurement after the February 1994 ice storm, but before the 1994 end of growing season inventory
[c] Not evaluated

in the western part of the Reynolds RNA. Although mortality losses were severe, even the locations with high activity still had live pine basal area averaging 9 m²/ha after the infestation (Table 3.2).

A number of factors contributed to the patterns observed in this outbreak. On coastal plain sites in the South, overstocked stands of loblolly pine on good sites with reduced radial growth are most often attacked by SPB (Hicks 1980). In an assessment of SPB infestations in southern Arkansas, Ku et al. (1981) reported that high levels of pine basal area (>22 m²/ha) increased the susceptibility of loblolly and shortleaf pines to attack. In addition, older pines are particularly susceptible to SPB infestations (USDA Forest Service 1993). Old, low-vigor pines in the Reynolds RNA provided the focal points for initial SPB attack, while the additional stress associated with the ice storm contributed to its expansion.

The primary effect of this SPB activity was to accelerate the successional transition of this stand to hardwoods (Fig. 3.3). This is especially apparent in the areas hardest hit by SPB, which amounted to about one sixth of Reynolds RNA's area. In these areas, pines currently make up less than 50 % of the basal area (Table 3.2). As the dominant pines continue to die due to natural events, they are not being replaced by the next generation of pines because none currently exist (Fig. 3.2). The fairly intensive disturbance from the 1993–1994 SPB infestation was insufficient to permit a new cohort of pines to establish and recruit to the overstory. Furthermore, large dead pines tend to remain erect and gradually deteriorate as snags over many years rather than collapse and create gaps by knocking down nearby living trees (Jones et al. 1981). Such was the case following this SPB infestation—the canopy below dead and dying old-growth pines remained closed during the 1994 growing season because of the combined effects from understory, midstory, and overstory hardwoods. This was confirmed by measuring photosynthetically active radiation (PAR) at a height of 1.37 m. PAR averaged 7.9, 5.4, and 7.2 % of full sunlight for

Fig. 3.3 View of the
Reynolds RNA in 1959,
showing how its original
second-growth stands
contained a prominent
hardwood component, with
pine regeneration occurring
almost exclusively along the
margins of the stand. (Photo
from the USDA FS archives
at the CEF)

areas where pine mortality was complete, partial, and none, respectively, and PAR
was not significantly related ($P=0.34$) to the intensity of the SPB activity (Cain and
Shelton 1995). Thus, little direct sunlight penetrated to the forest floor under these
closed canopy conditions.

Further evidence of the ineffectiveness of scattered SPB mortality on sustaining
pine regeneration can be seen in the paucity of pine reproduction eight growing
seasons after the onset of the SPB activity compared to the abundance of hardwood
reproduction and shrubs (Table 3.3). Pines killed by SPB rarely disturb the ground
surface enough to provide an adequate substrate for pine seedlings to germinate on,
and existing hardwood and shrub competition is almost never reduced enough to
provide pine seedling release opportunities. The handful of pine seedlings that were
found were in the shortest (<15-cm tall) height class recognized in the inventory
procedure. According to Shelton and Cain (2000), an adequate stocking of pine re-
generation to sustain a strongly pine-dominated overstory should exceed 500 stems/
ha that are free to grow above competing non-pine vegetation and growing at least
15 cm in height per year.

Thus, the existing stand structure and long-term trends suggest that a pine-
dominated overstory will not be sustained in the Reynolds RNA in the absence
of some unforeseen large-scale disturbance or silvicultural intervention. In the
past, fire, coupled with the high fuel loads associated with SPB activity, may have

Table 3.3 Mean density of seedlings (<1.3-cm DBH) and saplings (1.3–8.9-cm DBH) in the Reynolds RNA during the fall of 2000 (eight growing seasons after the onset of a southern pine beetle infestation) on 5 plots with high activity and 15 plots with low activity (there were five 8-m^2 subplots per plot)

Species group	High activity	Low activity
	Seedlings—stems/ha	
Pines	543	181
Oaks	5,286	4,907
Other canopy species	1,186	659
Midcanopy species	4,150	3,376
Shrubs	7,656	4,594
Total	18,822	13,717
	Saplings—stems/ha	
Pines	0	0
Oaks	99	16
Other canopy species	445	148
Midcanopy species	1,334	823
Shrubs	99	82
Total	1,977[a]	1,069[a]

[a] The difference between the high and low activity levels was significant at $P \leq 0.05$

created enough of a favorable environment for pine establishment and development (Waldron et al. 2007). Although it is tempting to apply silvicultural manipulations within the Reynolds RNA, the long history of "passive" management in this stand will be continued so that rates and direction of successional change can be determined. If nothing else, this approach will provide a certain environmental condition with specific ecological values. While this stay-the-course strategy leaves unanswered questions, two supplemental research studies (Bragg 2004b; Guldin 2005) have been implemented on other compartments in the CEF to evaluate the effectiveness of more intensive silvicultural treatments to produce old-growth-like characteristics in managed pine stands. These studies involve the use of fire either alone or in combination with herbicides, mowing, and selective harvesting to create an environment favorable to the development of new pine germinants into dominant overstory trees.

3.4 Future Research Opportunities

There are numerous research prospects in old forests, primarily because there are very few old, relatively undisturbed upland forests remaining in the southeastern USA, and the continuing intensification of silviculture across the region has further diminished their abundance. The uniqueness of these old stands gives them a particular value in the development and evaluation of certain concepts, especially those focusing on ecosystem goods and services as well as mensurational or modeling efforts. The following provide examples of some of these research opportunities.

Fig. 3.4 Unlike most managed forests, the Reynolds RNA still contains a number of examples of very large trees that can be very useful in the extension of tree allometric models. This specimen, a now-deceased loblolly pine, was 118 cm in diameter and 39.6 m tall when this photograph was taken in 1968. (Photo by James Burton, from the USDA FS archives at the CEF)

3.4.1   Carbon Sequestration in Old Forests

Carbon (C) sequestration has become an increasingly relevant aspect of forest management nationwide, and is of particular interest in southern forests, as this region has many timberland owners willing to consider alternative management opportunities. Currently, C credits are concentrated in the afforestation of non-timbered lands rather than the continued accumulation of C in existing stands (e.g., extended rotation silviculture). However, there is a good chance that other sequestration opportunities may arise if research can demonstrate that certain management practices can sustain C storage above and beyond that possible in business-as-usual silvicultural treatments. The well-documented stand history of the Reynolds RNA, coupled with other long-term research and demonstration projects on the CEF, lends itself to the description of C accumulation in mature pine-dominated forests, including what to expect following the transition from a pine- to hardwood-dominated overstory.

An under appreciated aspect of C sequestration linked to the study of old forests relates to the modeling of trees at the upper end of their physical dimensions (Fig. 3.4). Currently, most allometric relationships are developed using the typically small trees of managed landscapes—few specimens of considerable size are

incorporated in these regressions. This in turn can have significant implications on the predictive models developed, which can be highly sensitive to the data used to derive them. For example, loblolly pines from the Reynolds RNA and a nearby privately owned old-growth remnant were used to predict height as a function of diameter (Bragg 2008b). If this model was fitted to the same data but with the upper diameters truncated, a different set of equations arose (Fig. 3.5). These new models had reasonably large sample sizes and were well fit (pseudo-$R^2 > 95\%$), with virtually no noticeable difference between them up to at least 40-cm DBH. However, removal of all pines >70-cm DBH produced a height model that underestimated large tree heights, while removing pines >40-cm DBH yielded a model that drastically overestimated height (Fig. 3.5b–d). It is clear that the addition of the big pines considerably improved large tree predictions while having virtually no impact on those for smaller diameter stems. Individually, the difference of a few percent of total tree height on a 40-m tall loblolly pine may not seem much, but the cumulative volume extrapolated over landscapes or regions is considerable, and could prove especially problematic if the model leads to inappropriate estimates of C storage.

3.4.2   Managing For Old-Growth-Like Attributes

Although left untreated for decades, compartments 41 and 42 (the lands eventually designated the Reynolds RNA) were not originally intended to protect old forests. Given their history, these compartments are not old growth, even though there were some trees in the stand that escaped the original lumbering period (Shelton and Cain 1999). The north–south fire break between compartments 41 and 42 intersects an east-west rail tram line built 90+ years ago to haul logs from this tract, which has long since been returned to forest (today, a number of large loblolly pines grow on the remains of tram line). Yet our modern-day sensibilities tell us that the towering trees and accumulation of dead wood in the Reynolds RNA differ from the most pine-dominated forests in the region. This suggests that we can learn from the Reynolds RNA to help frame management options in old, naturally regenerated, pine-dominated forests of the region. Even with our best science, we cannot recreate the virgin forest—the environment that now encompasses the region has changed too much for this to be practicable. However, it should be possible to encourage certain conditions in contemporary pine-dominated forests to satisfy the habitat requirements of at least some of the most threatened elements of these landscapes.

Managing for old-growth-like attributes in southern pine forests means different things to different people. Under some circumstances, simply retaining a number of larger-than-typical pines sufficiently improves desired habitat qualities. This could entail, for example, the permanent retention of seed trees to provide biological and structural legacies. Though not a seed tree system, the Reynolds RNA had a considerable number of pines left after the original high-grading. Most of these have since died, but during their lifespan they provided the mature tree structure that would have otherwise been absent in the developing stand. In death, these large pines have
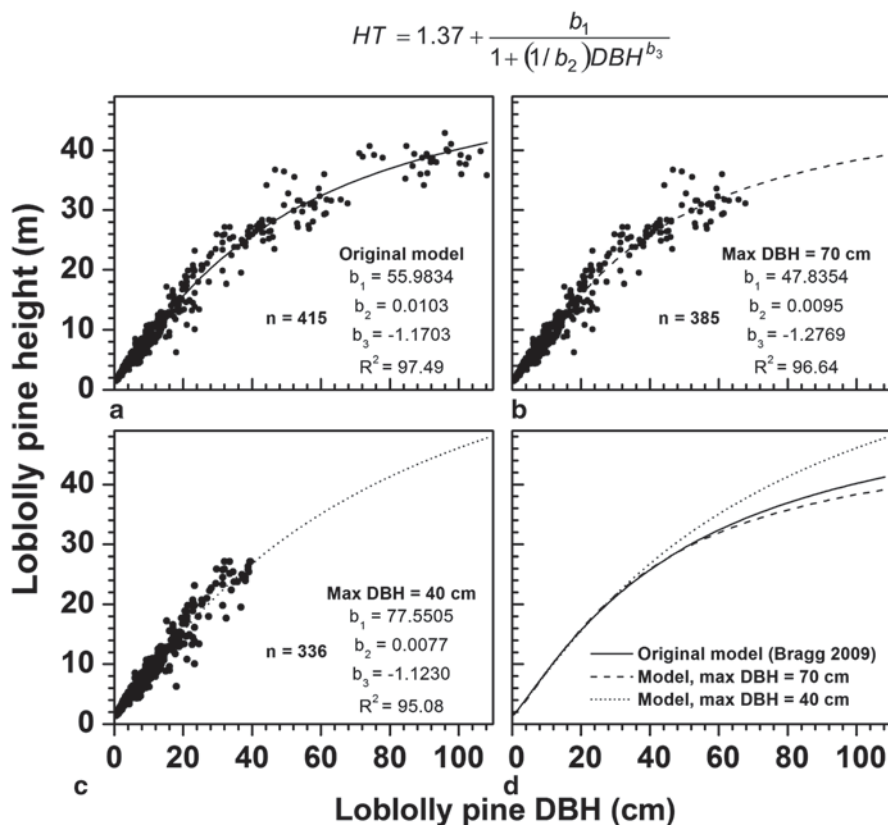
$$HT = 1.37 + \frac{b_1}{1 + (1/b_2)DBH^{b_3}}$$

Fig. 3.5 Differences in total tree height models using truncated versions of the same data set. The original (**a**) modified logistic model is from Bragg (2008b), and included very large loblolly pine from the Reynolds RNA and a nearby privately owned old-growth stand. The next two graphs, (**b**) and (**c**), show the fit when this original data set was reduced to pines less than 70-cm DBH and 40-cm DBH, respectively. When compared, these models fit large pines poorly (**d**), suggesting that regression models based on limited data may substantially influence aggregated measures like total C sequestration in mature to old stands

contributed a considerable quantity of dead wood (see Table 3.1) that can act as stratum for a number of species.

Another objective may be to increase the proportion of certain taxa in an otherwise conventionally managed pine sawtimber stand—treatments can be developed to favor shortleaf pine over loblolly pine or hardwoods (Bragg 2004b; Bragg et al. 2008). Others may want to more closely emulate the open, grassy, large pine-dominated stand condition in which frequent fire and episodic pine recruitment drive the dynamics. The Reynolds RNA and numerous other protected areas have shown that without active intervention, conditions can quickly turn unfavorable for the red-cockaded woodpecker (RCW, *Picoides borealis* Vieillot; Saenz et al. 2001, Bragg et al. 2008). If the specific objective of this strategy is to improve upon RCW

habitat, then removing the midstory and retaining live pines with heart rot (as opposed to culling them for more vigorous individuals) or preparing clusters for nest box inserts should prove more useful than hoping these conditions arise by chance (Saenz et al. 2001). Not surprisingly, the need to more intensively manage lands for non-timber attributes to ensure the persistence of certain elements (e.g., RCWs) has implications for public policy.

3.4.3   Ecological Implications of Public Land Management

Land management efforts have significant implications on the ecological response of the forests being treated. Over the years, the focus of management of public forestlands has shifted from timber production to a broader range of environmental services. This necessitates that a different perspective be taken on what constitutes appropriate and acceptable outcomes. For example, the success of a silvicultural approach that incorporates old-growth-like conditions depends on both intensive and extensive treatments to ensure that certain natural elements are retained. If burning is to be used to maintain stand conditions for fire-dependent species, is this treatment possible in a highly fragmented modern landscape, with its complicated mixture of public and private lands? What productivity, risk, and liability issues constrain this option?

For all of those interested in the active management of stands, there are others interested in the opposite—functionally, from a land management standpoint these people desire a version of the "set-aside" or "passive" management approach. From this perspective, no human intervention is acceptable, regardless of the intent, with the possible exception of fire protection to preserve a remnant condition. However, if an increasing fraction of the public ownership is removed from active management, a cascading series of responses will arise from both the biotic and socioeconomic communities associated with those lands. Although it is not of the appropriate scale to consider many impacts, the Reynolds RNA offers an excellent opportunity to evaluate the long-term outcome of such a passive strategy on a fine scale. Few examples highlight this issue more tellingly than rare woodpeckers in the South.

The most prominent woodpecker species to vanish from the forests of eastern USA was the ivory-billed woodpecker (*Campephilus principalis* L.), which relied upon large old-growth bottomland hardwood tracts. The ivory-bill was thought to have gone extinct when one of the last large remnants of virgin bottomland hardwoods in northeastern Louisiana was logged during World War II (Tanner 1942; Fitzpatrick et al. 2005). The apparent loss of this hallmark species helped galvanize portions of the environmental community to action in order to avoid such catastrophes in the future. During the next few decades, organizations dedicated to the acquisition and preservation of suitable habitats arose and federal, state, and local agencies began adapting to further protect species and habitats, culminating in the 1973 passage of the Endangered Species Act. Even most lumber companies and

many private citizens changed at least some of their land management practices. In many places, preserves were established to protect the special conditions (e.g., old trees) needed for habitat for threatened species.

This transformation almost came too late for a different woodpecker. By the 1960s, bird-watchers and scientists across the southeastern USA began noticing a precipitous decline in the abundance of the RCW, a small and unassuming bird that once frequented the piney woodlands that had dominated this area. RCW's peculiar nesting requirements—a mature, live pine with extensive red heart (*Phellinus pini* (Thore) Fr.) disease growing in an open stand—coupled with changing forest structure and demographics resulted in the rapid collapse of RCW populations across the species range (Conner and O'Halloran 1987; Saenz et al. 2001). Forest management practices can be blamed for much of the decline suffered by the RCW. Even though the loss of the virgin pine forest, with its abundance of large, red heart-infected pines, was a devastating blow to the RCW, large areas of the region remained in mature, open second-growth stands—acceptable if not ideal habitat. During much of the mid-twentieth century, conventional silvicultural practices in naturally regenerated loblolly and shortleaf pine also helped to nurture RCW habitat, as both uneven-aged management and seed tree/shelter wood techniques of the time retained enough large, old, live individual pines to support the species.

However, pines with obvious signs of red heart were considered cull trees, treated as a loss, and often removed from stands to permit healthier trees more growing space. In addition, short-rotation (<35 years) intensively managed plantations proved more economical than naturally regenerated stands, and thus a large-scale conversion of southern upland forests to planted loblolly pine occurred (Schultz 1999; Conner and Hartsell 2002; Fox et al. 2004; Allen et al. 2005; Rousseau et al. 2005). While it is possible to grow pines of adequate diameter during this rotation length, RCW cavity trees are usually significantly older and slower growing, reflecting the gradual development of extensive red heart disease in the bole (Conner and O'Halloran 1987; Conner et al. 2004a, b).

The Reynolds RNA has a large number of old loblolly and shortleaf pine full of red heart disease, and would represent a good block of suitable RCW habitat if large, decaying live pines were all that mattered. However, there is not a single RCW nest cavity to be found on this tract, nor is there any evidence of a colony abandoned in the recent past. Pine age and overstory structure are only one part of the recent decline in RCW—the rest has to do with overall habitat quality in areas reserved for the perpetuation of this woodpecker. In Louisiana, Oklahoma, and Texas, Saenz et al. (2001) noted that unmanaged pine stands experienced severe RCW population declines relative to those in managed stands and attributed much of this drop to hardwood encroachment. The absence of periodic fire in the Reynolds RNA has permitted this stand to grow too dense, with too many hardwoods to provide suitable RCW nesting habitat. This was an unintended consequence of the passive management strategy employed on the RNA, and indicative of what has happened across much of the remaining RCW habitat in the South.

Another policy-related challenge lies in the determination of what to restore where, as this will help dictate priorities. For example, habitat conditions favorable

for a particular rare species (e.g., RCW) may not be suitable for other taxa facing similar pressures. Aquilani (2006) noted that certain forest-obligate bird species (e.g., worm-eating warblers; *Helmitheros vermivorus* Gmelin) required interior areas with high amounts of shrubby understory coverage, a condition compatible with the modern-day structure of the Reynolds RNA but unsuitable if the stand is managed for more open conditions. This suggests that areas of older forest managed for ecosystem services other than fiber production be kept in a range of stand conditions—tree size or age are but some of the many components that affect habitat suitability.

3.4.4 Evidence of Climate Change

The relatively undisturbed soils of the Reynolds RNA also provide a good opportunity to study past climates. Recent research has suggested that the "pimple" or "prairie" mounds that dot the landscapes of the Midsouth may actually be "nebkha" or "coppice" dunes from much drier periods in the late Holocene (Seifert et al. 2009). These natural mounds are rapidly being destroyed by land leveling or the ripping and bedding practices that commonly precede pine plantation establishment. Hence, the mounds found in the Reynolds RNA and a few other protected old pine stands may be increasingly important records of prehistoric megadroughts.

Today, increasing atmospheric CO_2 threatens southern forests with global climate change, which is a possible catalyst for a number of other environmental concerns, including species migration, exotic species invasion, and the alteration of natural disturbance regimes. Researchers have begun to project species migration under a number of different climate scenarios using inferences from forest growth and yield plots located across the eastern USA (e.g., Iverson et al. 2004; Woodall et al. 2009). Long-term observations on a fixed location such as the Reynolds RNA can be used to directly observe the appearance or disappearance of trees as a function of climate change, the spread of exotic and endemic pests and pathogens, and natural successional tendencies. None of these purposes would have been anticipated in the 1930s when the Reynolds RNA was initially established, yet they are examples of important benefits of undisturbed natural areas in experimental forests.

3.5 Conclusions

Old forests offer opportunities to better understand the impacts of our management on the environment across a range of scales. Unfortunately, we have so few remaining examples of these stand conditions that it is increasingly difficult to study an ecosystem in the detail necessary to be able to predict outcomes under a variety of different scenarios. Natural areas, such as those found on experimental forests, offer a unique opportunity to observe the development of a particular stand over a long

time period without worrying about how shifts in ownership or management strategy may affect the results. In the case of the Reynolds RNA, we have 70+ years of documentation on stand development under a fixed management regime—a record hardly equaled elsewhere in southern forests.

As can be seen in the climate change study opportunities, the lessons we can learn from long-term studies are not necessarily limited to those in place when the natural area was originally designated, nor do they need to be. Adaptive research policies that allow for refocusing of the analysis (if not the treatment) can supplement or extend contemporary investigations into problems not previously anticipated. For example, the study of C sequestration in southern forests would not be complete without the knowledge of how old forests such as the Reynolds RNA are organized and how they may respond to changes in atmospheric chemistry, precipitation patterns, or temperature regimes. Too many differences exist between the composition, structure, function, and genetics of 25-year-old pine plantations and old, natural origin pine-hardwood stands to extrapolate between these conditions. Furthermore, the ecological studies of the Reynolds RNA can document the impacts of disturbance exclusion over many years, thereby helping policymakers understand the consequences of certain decisions.

Long-term studies on experimental forests and ranges provide federal, academic, and even industrial research programs the flexibility and leverage they need to address future environmental issues in an efficient and predictable manner. It would be irresponsible to exclude unmanaged, protected old forests such as the Reynolds RNA from our toolbox, as we can sometimes learn as much from the unanticipated consequences of passive stand management as we do from direct treatments.

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