SURVIVAL AND GROWTH OF BOTTOMLAND HARDWOOD SEEDLINGS AND NATURAL WOODY INVADERS NEAR FOREST EDGES

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Abstract—Several oak species are frequently planted for reforestation projects in the Lower Mississippi Alluvial Valley (LMAV), but the success of these plantings has been variable. The survival and growth of planted seed or seedlings are affected by a variety of factors, including competition, herbivory, site preparation, precipitation, planting stock quality, and planting techniques. We surveyed reforested fields in the LMAV to examine survival and growth of planted oaks and the occurrence of natural invaders that became established in these fields. Oak (*Quercus* spp.) densities averaged 413 stems per ha within 150 m of forest edges, as compared with 484 stems per ha between 150 to 300 m from the forest edge. Also there were higher densities of natural woody invaders near forest edges (4,234 stems per ha at 0 - 150 m compared with 2,193 stems per ha at 150-300 m). These data show that seed and seedlings proximity to a nearby forest edge has an effect on survival and growth. Since planted trees in the 0 – 150 m forest edge zone encounter high densities of natural invaders, it may be prudent to reduce the number of planted trees. Naturally occurring invaders enhance diversity and also augment depleted oak plantings near the forest edge with no added expense or effort.

INTRODUCTION

The Lower Mississippi Alluvial Valley (LMAV), an area that extends nearly 1,000 km from the confluence of the Mississippi and Ohio Rivers to the Gulf of Mexico, once supported over 10.1 million ha of wetlands (Hefner and Brown 1985, Keeland and others 1995). Greater than 80 percent of the forested wetlands in the LMAV have been lost, mostly as a result of clearing for agriculture. The wetlands that remain are highly fragmented and degraded. Forested wetlands of the LMAV continue to be lost, but attempts to reforest some of the area have been made by several state and federal agencies (Haynes and others 1995, King and Keeland 1999, Schoenholtz and others 2001). In fact, reforestation of bottomland hardwoods in the LMAV is projected to increase from the 77,698 ha planted between 1986 and 1997 to 89,009 ha between 1997 and 2008 (King and Keeland 1999). Although some reforested tracts may be as old as 30 years, many were planted less than 15 years ago (Haynes and others 1995). These reforested tracts range in size from less than 100 ha to greater than 1,500 ha (McCoy and others 2000). Few fields have been monitored for success of reforestation (Allen 1990, Schweitzer and others 1997). Very few studies have addressed oak survival and growth in the LMAV, and even fewer have addressed natural invasion of woody species onto reforested sites (Allen 1990, Allen and others 1998). Most studies of planted oak survival and growth have examined the effects of soils, site (Groninger and others 2000), water, sunlight, and other factors, but little information on the spatial distribution patterns of survival, growth, and natural invasion within these reforested fields is available.

The purpose of this analysis was to examine spatial patterns of survival and growth for planted oaks and natural woody invaders in reforested stands of the LMAV. Specifically, our objectives were to examine the effects of direction and distance from the nearest forest stand (fragment) on survival, growth, and natural invasion.

METHODS

Study sites were established in 18 reforested fields selected from 7 U.S. Fish and Wildlife Service National Wildlife Refuges in Arkansas, Louisiana, and Mississippi, 2 Wildlife Management Areas of the Louisiana State Department of Wildlife and Fisheries, and one privately owned tract (fig. 1). All fields were planted with oak species within the last 7 to 15 years. Planting densities varied for each field (Lockhart and others 2003). Most fields were direct seeded, while three fields were planted with bare rootstock.

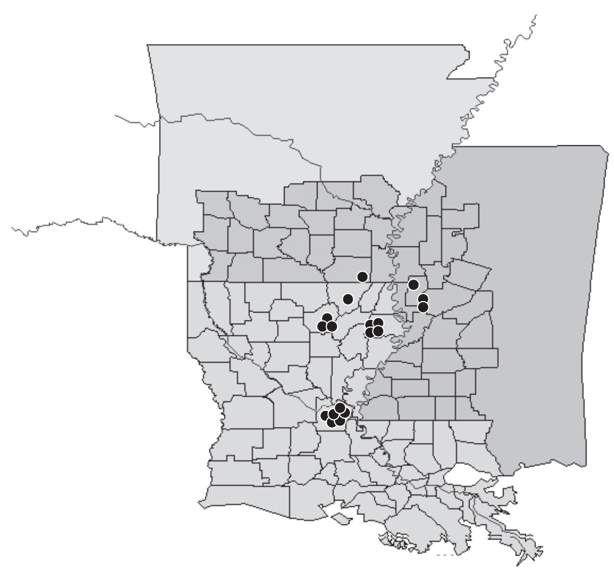

Figure 1—Map of Arkansas, Louisiana, and Mississippi showing general areas where the 18 study sites are located.

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The number of plots established within each field was determined by the size and shape of the field and the number of transects needed to adequately cover the area. About 1.3 percent of the total field area was sampled for this study. Transects were initiated at and oriented perpendicular to the field edge, which was often but not always contiguous with the forest edge. A variable distance, minimum of 75 m, was allowed between transects and between transects and field corners. Placement of transects generally depended on the direction and distance to the nearest forest fragment. We used this placement because one of our main goals was to examine natural woody invaders originating from these forest fragments. Field corners were avoided because they could be easily influenced by propagules originating from two directions.

Circular plots, each 200 m^2, were established along each transect, with the center of the first plot for each transect always established 8 m from the field edge. This insured that the plot was at the very edge of the field, yet completely within the field. Subsequent plots were spaced at 50 m intervals along the transect. The total number of plots along each transect depended on the size of the field. Plot distances referred to in this manuscript represent the midpoints of 50 m distance categories beginning at the nearest forest edge. These categories begin with 0 – 25 m because our first plot was placed at the field edge, which in many cases was immediately adjacent to the forest edge. In cases where the forest edge was at some distance from the field edge, the distance was measured and the plot placed into the appropriate distance category.

All tree or shrub stems encountered within the plots were recorded by species into four size classes: (1) 50 – 100 cm tall, (2) 100 – 140 cm tall, (3) greater than 140 cm tall but less than 2.5 cm diameter at breast height (d.b.h.), and (4) greater than 2.5 cm d.b.h. Seedlings less than 50 cm in height were not recorded. Two quadrates, each 1 m^2, located 2 m from plot center and perpendicular to the transect direction, were examined for vascular plant species and small woody seedlings. Herbaceous vegetation cover classes included, (1) 0 - 5 percent, (2) 5 - 25 percent, (3) 25 – 50 percent, (4) 50 – 75 percent, (5) 75 – 95 percent, and (6) 95 – 100 percent, for each species recorded. Woody seedlings less than 50 cm tall that were encountered in the herb subplots were counted by species.

To examine the effect of distance from forest edge on oak survival and growth and natural invasion rates, we concentrated on the zone where the majority of our plots were found. This area included the zone between 0 to 300 m from the nearest forest edge. Although a small number of our plots were as much as 1,000 m from the nearest forest edge, that data was not included in this analysis.

Differences in seedling densities between field areas less than the midpoint of the sampled distance (< 150 m) versus farther (150 - 300 m) from forest edges were tested for significance using *t*-tests under the one-way ANOVA procedure in JMP software (SAS Institute 1995). Correlation between field size to oak stem densities and proportion of the field perimeter consisting of forest to oak stem densities were also calculated using the one-way ANOVA procedure in JMP software.

RESULTS AND DISCUSSION

A total of 459 study plots were established along 67 transects at 18 sites (fields) in the LMAV. Within these plots, a total of 46 tree or shrub species, including the oaks, were recorded. The number of woody tree and shrub species per field ranged from 12 to 24 with an average of 19. Three plots did not have any woody trees or shrubs greater than 50 cm in height, while 35 plots did not contain any oak stems > 50 cm in height.

Thirty-five percent of the woody species encountered were recorded at all sites. The most common species were sweetgum (*Liquidambar styraciflua* L.), the elms (*Ulmus americana* L., *U. alata* Michx., and *U. crassifolia* Nutt.), red maple (*Acer rubrum* L.), persimmon (*Diospyros virginiana* L.), and sugarberry (*Celtis laevigata* Willd.). These species accounted for 80 percent of all naturally occurring woody stems. Additional species that were on more than 50 percent of the sites included ash (*Fraxinus* spp.), buttonbush (*Cephalanthus occidentalis* L.), mayhaw (*Crataegus spp.*), eastern baccharis (*Baccharis halimifolia* L.), locust (*Gleditsia aquatica* Marsh. and *G. triacanthos* L.), black willow (*Salix nigra* Marsh.), water oak (*Quercus nigra* L.), willow oak (*Q. phellos* L.), Nuttall oak (*Q. nuttallii* E.J. Palmer) and deciduous holly (*Ilex decidua* Walt.). All other species occurred in low numbers and had low relative frequencies for this study. The number of stems and species composition in our study was very similar to those found in a 1981 study of an 11-year-old hardwood stand on Sharkey clay soil in Mississippi (Krinard and Johnson 1981).

The most common oak species was Nuttall oak, planted on eight of the fields, with water oak and willow oak planted on four fields each. Minor amounts of overcup oak (*Q. lyrata* Walt.) and Shumard oak (*Q. shumardii* Buckl.) were also encountered. Overcup oak was planted at one site, but Shumard oak was not planted on any fields. The average density of oaks was 467 stems per ha, but the numbers were not distributed evenly among size classes. Fewer oaks were found in the smaller size classes (24 and 25 per ha for size classes 1 and 2) than in the larger size classes (150 and 268 per ha for size classes 3 and 4). The low density of the shorter oak stems was expected as these fields were planted a minimum of 7 years before our study. Although oaks have been shown in some cases to grow as little as 15 cm per year (Johnson 2002), under better conditions they can achieve as much as 137 cm in only 2 years (Burns and Honkala 1990). The largest oaks, in size class four, had measurable diameters that ranged from 2.5 cm (the smallest diameter we measured) to 9.8 cm.

The mean density of natural invaders was much higher than the density of oaks at 2,638 stems per ha. As seen with the oaks, there were relatively fewer short natural invaders with only 540 and 449 stems per ha in size classes 1 and 2. The majority of natural invaders (1,323 stems per ha) were greater than 140 cm tall but less than 2.5 cm in d.b.h.. Larger stems (> 2.5 cm d.b.h.) were less abundant, with only 326 stems per ha. These larger stems ranged from 2.5 to 6.6 cm d.b.h.

An important component of this study was the effect of distance from the nearest forest edge on the density of woody natural invader species. Within 150 m of the forest edge an average of 4,463 tree and shrub stems per ha, including oaks, was recorded. Between 150 to 300 m from the forest edge, the number of stems was much smaller, with 2,646 stems per ha. We noted a steady decrease in the number of natural invaders as distance from the forest edge increased (table 1, fig. 2), a fairly consistent pattern also reported by Allen and others (1998), McCoy and others (1998), and McCoy and others (2002). However, the pattern of decline varies greatly among species.

Near the forest edge a large number of light seeded species can become established. For example, adjacent to the forest edge we found an average of 1,581 sweetgum stems per ha, but this number declined dramatically with distance. Seed size and weight helps to determine the distance it may be disseminated into a field. Heavy seeded species such as oaks and hickories establish closest to the forest edge, while others such as hawthorn, dogwood, eastern red cedar, and baldcypress disseminate to greater distances. For several species, we noted the highest densities about 50 m away from, rather than immediately adjacent to, the forest edge. This group included hickory, dogwood,

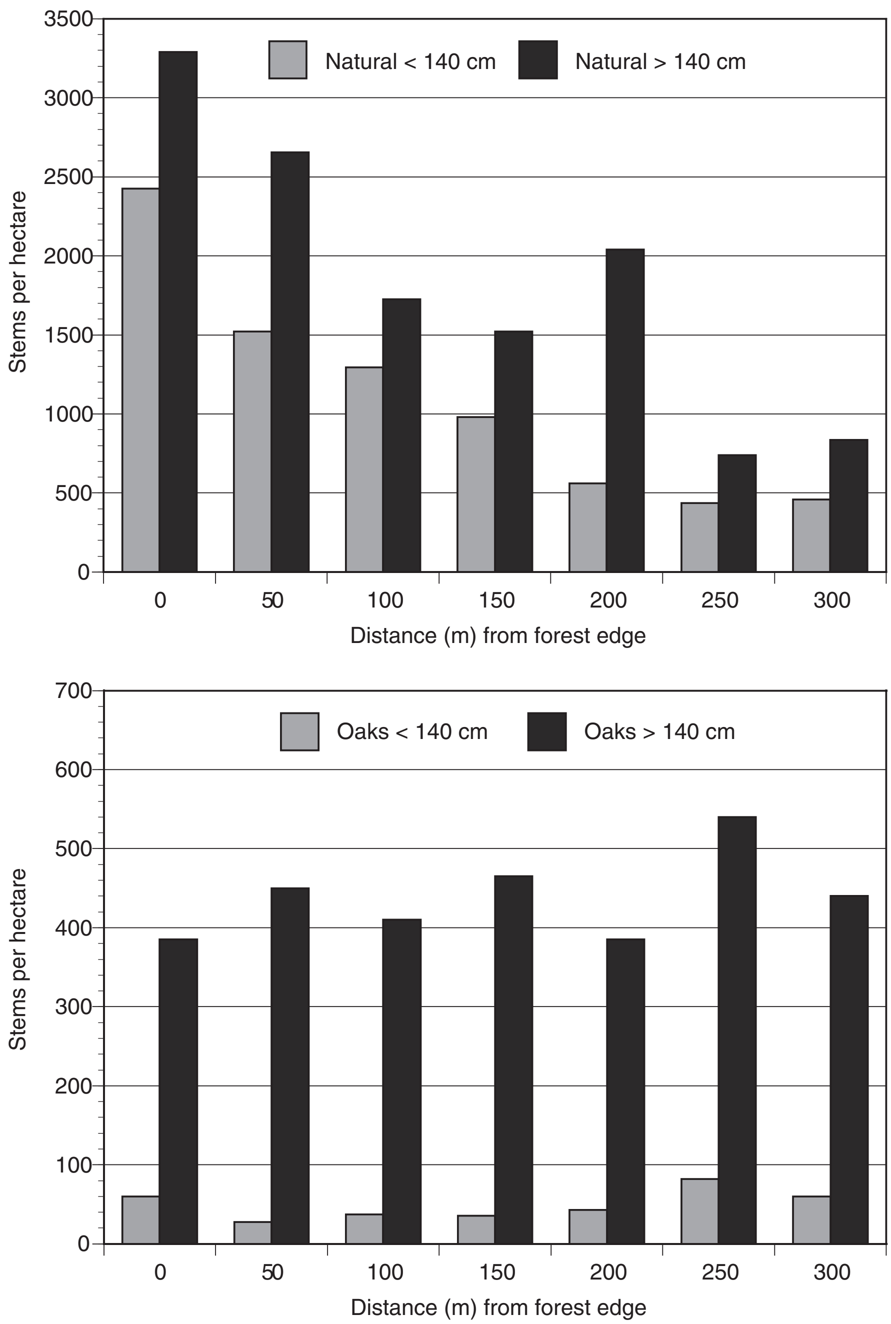

Figure 2—Stems per ha of oak and natural invader stems for < 140 cm (4.6 feet) and > 140 cm height classes.

Table 1—Density of stems/ha (> 50 cm in height) by species at the given distances from a forest edge

Species Common name	Scientific name	H or L	Distance class 0	50	100	150	200	250	300	Mean to 300	All dis
Box elder	*Acer negundo* L.	L	426	185	134	77	12	9	11	122	108
Red maple	*A. rubrum* L.	L	271	158	160	119	159	13	11	127	113
Lead plant	*Amorpha fruticosa* L.	H	176	68	96	189	71	32	175	115	88
Eastern baccharis	*Baccharis halimifolia* L.	L	363	294	308	134	709	58	174	291	254
Hickory	*Carya illinoinensis* (Wangenh.) K. Koch										
	C. aquatica (Michx. f) Nutt.	H	51	77	38	19	14	41	31	39	37
Sugarberry	*Celtis laevigata* Willd.	H	130	118	95	131	149	169	169	137	126
Buttonbush	*Cephalanthus occidentalis* L.	L	18	50	35	169	34	19	27	50	46
Dogwood	*Cornus stricta* Lam., *C. foemina* P. Mill.	H	66	131	113	22	33	21	8	56	66
Hawthorn	*Crataegus marshallii* Egglest.	H	172	196	149	77	46	51	47	105	95
Persimmon	*Diospyros virginiana* L.	H	436	171	173	199	127	208	92	201	182
Ash	*Fraxinus caroliniana* P. Mill.										
	F. profunda (Bush) Bush	L	768	1011	540	444	521	213	161	523	475
Honey locust	*Gleditsia tricanthos* L.										
	G. aquatica Marsh.	H	68	43	48	33	38	26	22	40	41
St. John's Wort	*Hypericum hypericoides* (L.) Crantz	H	7	14	10	2	2	0	2	5	7
Deciduous holly	*Ilex decidua* Walt.	H	198	193	160	123	93	68	97	133	114
Eastern red cedar	*Juniperus virginiana* L.	H	1	5	1	0	0	0	0	1	1
Sweetgum	*Liquidambar stryraciflua* L.	L	1,581	790	404	412	92	154	81	502	443
Loblolly pine	*Pinus taeda* L.	L	1	2	2	0	1	4	0	1	1
Water elm	*Planera aquatica* J.F. Gmel.	L	1	0	0	1	0	0	0	< 1	< 1
Sycamore	*Platanus occidentalis* L.	L	0	1	2	1	0	0	0	1	1
Cottonwood	*Populus heterophylla* L.	L	0	0	0	2	1	0	1	1	2
Mexican plum	*Prunus mexicana* S. Wats.	H	0	0	0	0	0	0	1	< 1	3
Oaks	*Quercus* spp.	H	381	420	406	455	413	622	453	450	466
Black locust	*Robinia pseudoacacia* L.	H	67	0	0	0	0	0	0	10	8
Palmetto	*Sabal minor* (Jacq.) Pers.	H	13	7	5	1	0	0	2	4	3
Black willow	*Salix nigra* Marsh.	L	14	48	12	28	36	15	48	29	27
Chinese tallow tree	*Triadica sebifera* (L.) Small	H	4	8	7	2	3	13	48	12	17
American snowbell	*Styrax americanus* Lam.	H	25	14	14	3	8	4	2	10	8
Baldcypress	*Taxodium distichum* (L.) L.C. Rich.	H	1	2	0	2	0	0	0	1	1
Elms	*Ulmus americana* L.										
	U. crassifolia Nutt.										
	U. alata Michx.	L	865	585	515	310	452	54	85	409	371
Hercule's club	*Zanthoxylum clava-herculis*	H	1	2	0	0	0	0	0	< 1	< 1
Total			6,105	4,593	3,427	2,955	3,014	1,794	1,748	3,377	3,106

H = heavy seeded; L = light seeded; Mean to 300 = the mean of 0 to 300 m; All dis = a mean for all distances and includes all distances in which a species was actually represented in our study including those outside of the 0 – 300 m range.

hawthorn, ash, and black willow. Although not tested in this study, it may be that these slightly smaller numbers immediately adjacent to the forest edge result from seed predation or herbivory of young seedlings by rabbit or deer. It may also be a result of animal behavior during or after feeding on these seed.

As distance from the forest edge increases, most wind dispersed species such as box elder, red maple, water elm, sycamore, and cottonwood decrease in density. A few wind-dispersed species, such as the elms, ash, buttonbush, and eastern baccharis, can be found in relatively high numbers at distances beyond 300 m. Anomalous patterns of density distribution, such as extremely high numbers of eastern baccharis at 200 m (table 1) can be caused by an individual field with environmental and biotic conditions that foster abnormally high numbers of a particular species.

Heavy seeded species, for the purpose of this study, are those typically dispersed by animals. Several species with seeds that are small, yet still classed as heavy seeded, such as sugarberry and Chinese tallow [*Triadica sebifera* (L.) Small], disperse to distances much greater than 300 m. Although these species are classed as heavy seeded, they are small enough for small birds to eat and disperse. We found several natural woody invaders, including persimmon, sugarberry, deciduous holly, swamp dogwood (*Cornus stricta* Lam.), locust (*Robinia pseudoacacia* L.), ash, red maple, and sweetgum, as far as 1,000 m from the nearest forest fragment. However, at these distances, stem densities averaged only 290 stems per ha.

The density of planted oak stems ranged from 0 to 2,900 stems per ha for each plot and varied significantly with distance (0 – 150 vs. 150 – 300 m) from the forest edge ($F = 18.76$, $P < 0.0001$). We counted an average of 413 oaks per ha between 0 and 150 m from the forest edge, whereas between 150 and 300 m, the count was 484 per ha (table 1). Although this difference is small, it seems to indicate a distance dependent relationship that warrants further consideration. A possible explanation for the lower density of oaks at 0 - 150 m could be herbivory of the planted oaks combined with suppression by the higher density of natural invaders establishing in this area, in a manner similar to that reported by Lorimer and others (1994). Several species of mammals, especially rabbits (*Sylvilagus floridanus*) and white-tailed deer (*Odocoileus virginianus*), use areas near the forest edge and are known to feed on oak seeds and seedlings (Castleberry and others 1999). Deer tended to stay within about 80 m of the forest edge for protective cover (Dugger and others, in press). After the competing woody species grow large enough, especially near the forest edge where densities can be quite high, the shading effect could reduce the palatability of oak leaves and perhaps reduce the herbivory pressure (Blair and others 1983).

Several additional factors could affect the spatial distribution of stem densities. First, the original planting density was variable among sites. This was probably because a combination of different oak species were planted in the various fields, local conditions may have prompted the land manager to seed the fields at higher or lower rates, and while most fields were direct seeded, a few were planted with bare-root seedlings. Within the fields, variations in soils, topography, hydrology, aspect, or spatial differences in competition or herbivory rates could also affect invasion and survival rates for natural invaders that in turn affect planted oaks (Bowers 1993).

Study fields varied in size from 7 to 150 ha. Fields were classified into (1) small (< 20 ha), (2) medium (20 – 40 ha), and (3) large (> 40 ha). The small- and medium-size fields had relatively uniform increases in oak densities as distance from the forest edge increased. Variation in topography and soils of small fields would be less than for larger ones. For large fields, the pattern of greater stem densities with distance from the forest was much more variable, possibly a result of the natural variation discussed above. However, the average oak stems per ha for small and medium sized fields was 393 stems per ha while large fields averaged 541 stems per ha. Although this difference is not significant, it does suggest larger fields may have higher densities of surviving oak stems. The opposite was true for natural invaders, with small, medium, and large fields having 5,904, 2,101, and 1,745 stems per ha, respectively. This effect was significant ($F = 5.7479$, $P < 0.0014$). As field size increased, the density of natural invader stems decreased, due to increasing distance from the nearest forest edge.

One other important factor in this study was the amount of the field perimeter made up of intact forest. The study fields were classified into three categories of contact with forest edges: (1) < 25 percent, (2) 25 – 50 percent, and (3) > 50 percent. Comparisons between these categories were not significant ($F = 1.4207$, $P > 0.2722$), but the number of oak stems per ha was, at 556, 410, and 267 in categories 1, 2, and 3, respectively. In general, smaller fields had more surrounding forest, and our results show 23 - 48 percent fewer oaks in fields with greater than 50 percent of the field perimeter in contact with forest. Conversely, natural woody invaders were more prevalent (21 – 102 percent more stems) in fields with greater amounts of forest edge. Larger numbers of invaders are expected in fields surrounded by more forest, as the trees provide a good seed source, but the reduction in survival of planted oaks with increased forest perimeter may be harder to explain. It is possible that a larger forest component provides habitat for larger populations of herbivores that feed on oak seedlings in the reforested field. A more formal evaluation of this possibility will have to wait for future studies.

The number of fields in this entire study was 18 and the total number of plots 459. Given the amount of variation in field topography, size of fields, planting techniques, preplanting preparation, seed source, and management personnel at the different locations there is a great deal of variability in the data. This variation between and within fields confounds the analysis and makes identification of significant relationships difficult. A larger sample size may have revealed more significant relationships.

CONCLUSIONS

Oaks planted in old fields are subject to a variety of factors that control their survival and growth (Allen and others 2001).

The intensity and importance of these factors, however, change through time. The herbaceous vegetation and woody vines that develop soon after field abandonment provide cover for seed and seedling predators such as rodents (*Sigmodon* spp., *Peromyscus* spp., *Oryzomys* spp.) and rabbits. Herbaceous plants can also influence the survival and growth of oak seedlings (Gordon and others 1989). However, this same cover also provides perch sites that attract birds, thus encouraging natural invasion by other woody species. Wind dispersed seeds of many woody species are blown into the fields to varying distances. As the woody seedlings grow, the habitat becomes more appealing to animals that browse on the planted oaks and the natural woody invaders. This browsing reduces survival of seedlings and slows the growth of others. With increased cover, other animals use the habitat and possibly disseminate additional heavy seeded tree species. Within about 4 years (McCoy and others 1998), the oaks and natural invaders begin to overtop the herbaceous vegetation. This is especially obvious at the forest edges where natural invader densities can be very high. In many cases, the oaks will be the tallest woody species in the field since they were planted before invaders had the opportunity to become established. In some areas, such as along the forest edge, natural invaders with higher growth rates and very high stem densities can overtop and possibly decrease growth rates of the oaks. Over the next decade, the density of oaks will probably remain about the same or decrease, while the density of natural invaders will increase, especially near forest edges. This is due to a low natural invasion rate of oaks. The number of oak stems will primarily be dependent upon the initial planting, while the natural invaders continue to establish, grow, and amass by wind or animal dispersal into the field. Variables such as field size and/or forest edge contact will affect the survival and growth of woody seedlings, whether they are planted or are natural invaders. Field size may be a factor in that larger fields often have greater variability in topography and soils.

The amount of field perimeter that is contiguous with intact forest will affect the survival of oaks and the invasion rates of other woody species. The management implication of this study is that although oak densities may be reduced near forest edges, natural invasion will more than make up for the loss of stem density. Natural invasion rates will decrease beyond about 150 m from a forest edge. Although many individuals of ash, persimmon, and sugarberry will disseminate to distances greater than 150 m, the overall stem densities will be lower and additional planting may be warranted. Because of different afforestation objectives of land managers, target densities of planted species should be decided before field preparation and planting begins. Previous studies (McCoy and others 1998) have shown that sites not disked prior to planting are more diverse and develop higher densities of natural invader trees and shrubs than those disked prior to oak planting. It may therefore be sensible to plant fewer oaks within 0 - 100 m of a forest edge. This will allow for natural invaders to develop without additional competition from planted trees. In addition, small fields may not need to be planted.

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