NOTE

Recovery of l-year-old loblolly pine seedlings from simulated browse damage

Michael G. Shelton and Michael D. Cain

Abstract: Loblolly pine (*Pinus taeda* L.) seedlings are frequently browsed by a wide variety of animals during the first few years of their development. Although anecdotal observations indicate that the potential for seedling recovery is good, there is little quantitative information on the factors affecting the recovery process. Thus, we conducted a study to evaluate the effects of the extent and season of simulated browse damage on the recovery of I-year-old loblolly pine seedlings under controlled conditions. Seedlings were clipped at five positions: at the midpoint between the root collar and cotyledons and so that 25. 50, 75, and 100% of the height between the cotyledons and the terminal remained after clipping. Clipping treatments were applied in two seasons: winter and spring. All seedlings clipped below the cotyledons died, confirming that dormant buds or lateral shoots are required for recovery. Survival of seedlings clipped above the cotyledons was 97% for winter clipping and 96% for spring clipping. Most of the seedling mortality (73%) was for seedlings with only 25% of their height remaining. Regression analysis revealed that second-year seedling size was positively affected by first-year size and percentage of remaining height after clipping and that seedlings clipped in winter were larger at 2 years than those clipped during spring. Logistic regression indicated a higher probability of multiple stems resulting from the more severe clipping treatments. Clipping season and severity also significantly affected the probability for tip moth (*Rhyacionia* spp.) damage, which occurred more frequently in the larger seedlings. Results suggest that planting seedlings deep, with the cotyledons just below ground level, may be an advantage in areas where browse damage is common.

Résumé : Les semis de pin à encens (*Pinus taeda* L.) sont souvent broutés par une large gamme d'animaux durant les premieres années de leur développement. Malgré les observations anecdotiques indiquant que le potentiel de recouvrement des semis est bon, il existe peu d'informations quantitatives sur les facteurs qui affectent le processus de recouvrement. Nous avons donc mené une etude pour évaluer les effets de l'ampleur des dommages dus à un broutement simulé et de la saison durant laquelle surviennent ces dommages sur le recouvrement de semis de pins à encens de 1 an, dans des conditions contrôlées. Les semis furent taillés à cinq positions au point median entre le collet racinaire et les cotyledons et de manière à laisser, après la taille, 20, 50, 75 et 100% de la hauteur entre les cotyledons et la pousse terminale. Lcs traitements furent appliques durant deux saisons : en hiver et au printemps. Tous les semis taillés plus has que les cotyledons sont morts, ce qui confirme que des bourgeons dormants ou des pousses latérales sont nécessaires pour le recouvrement. La survie des semis taillés plus haut que les cotyledons fut de 97% pour la taille hivernale et 96% pour la taille printanière. La majorité (73%) des semis qui sont morts avaient été taillés pour laisser settlement 25% de leur hauteur. Les analyses de regression révèlent que la hauteur des semis de deux ans est corrélée positivement à celle de l'année précédente et au pourcentage de la hauteur résiduelle après la taille; que les semis taillés en hiver sont plus grands à 2 ans que ceux taillés au printemps. La regression logistique indique une probabilité accrue que les semis developpent plusieurs têtes dans le cas des traitements les plus sévères. La saison et la sévérité de la taille influencent aussi la probabilité de dommages par des perceurs des pousses (*Rhyacionia* spp.), qui sont plus fréquents sur les plus grands semis. Les résultats indiquent aussi que le fait de planter les semis profondément, en laissant les cotyledons juste au-dessus du niveau du sol, peut procurer un avantage dans les regions où les dommages par broutement sont courants.

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M.G. Shelton' and M.D. Cain. USDA Forest Service, Southern Research Station, P.O. Box 3516 Monticello, AR 71656-3516, U.S.A. (e-mails: mshelton@fs.fed.us and mcain@fs.fed.us).

[1]Corresponding author.

Introduction

Loblolly pine (*Pinus taeda* L.) seedlings are at risk of being clipped from a variety of browsing animals during the first several years of their development. Animals that have been documented to damage young loblolly pine seedlings include: rabbits (*Sylvilagus* spp.), white-tailed deer (*Odocoileus virginianus* Zimmerman), pocket gophers (*Geomys* spp.), cotton rats (*Sigmodon hispidus hispidus*

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Say & Ord), and domestic livestock (Wakeley 1954; Wahlenberg 1960; Schultz 1997). Damage is usually greatest in late winter when browse from other more preferred species is at a minimum. Although damage to seedlings is usually light to moderate, regeneration failures have been observed because of heavy browsing (Wakeley 1954). Most of the information available on recovery from browse damage comes from plantations. However, natural seedlings may be at greater risk than planted seedlings, since they tend to be smaller and develop more slowly, remaining in vulnerable size classes for longer periods of time. Natural seedlings may be browsed the entire winter of their first year, whereas planted seedlings are at risk only after they are planted. In addition, the low-intensity site preparation conducted in natural stands may improve the habitat for certain browsing animals by making browse more plentiful.

Little quantitative information exists on the potential recovery of damaged loblolly pine seedlings. Schultz (1997) noted that seedling recovery was generally good if the browse damage occurred up to about 3 years of age. However, no mention is made of the relationship between recovery and the extent of damage or the effects of season. To address some of these questions, we conducted a study on the recovery of l-year-old loblolly pine seedlings to five degrees of damage and two seasons of simulated browse. Because our seedlings were established in place, they represent seedlings in naturally regenerated stands. Loblolly pine was chosen for study, because it is a widespread and commercially important species that is frequently regenerated by natural means. Simulated damage was applied in the winter, when animal damage usually occurs, and in the spring, when carbohydrate reserves are low because of reallocation to new growth (Kramer and Kozlowski 1979).

Methods

The study was located on forest lands of the School of Forest Resources, University of Arkansas at Monticello. The study site is in the West Gulf Coastal Plain at 91°46′W, 33°37′N. Elevation is 98 m with a rolling topography. The soil is a Sacul loam (clayey, mixed, thermic, Aquic Hapludult), which is a moderately well-drained upland soil with a site index of 24 m for loblolly pine at 50 years (Larance ct al. 1976). The growing season is about 240 days with seasonal extremes being wet winters and dry autumns. Annual precipitation averages 134 cm.

The study site was a 20 x 20 m cleared area at the edge of a IO-year-old, naturally regenerated loblolly pine stand. The area occasionally received shadows from adjacent trees during the winter months but was in full sunlight during the summer. Within the study area, eight 1.7 x 2.1 m beds were leveled using hand tools and framed with wooden boards.

Seeds for the study came from cones collected in mid-October 1998 from about 12 sawtimber-sized loblolly pines in a stand that was being clear-cut in southeastern Arkansas. After extraction, seeds were dewinged by hand, float tested, and stored at -18°C after drying. Seeds were stratified in moist, sterile sand for 4 weeks at 4°C before sowing in the prepared mineral-soil seedbeds on March 26-28, 1999. Seeds were lightly pressed into the soil at a 21 x 21 cm spacing. Additional seeds were planted in April to account for insect losses. Herbaceous vegetation was controlled twice during the summer of 1999 by making a surface application of glyphosate[2] (2% in water) using paint brushes. Because of drought conditions, beds were irrigated during July and August when weekly precipitation was below normal; precipitation averaged 6.4 cm/month below normal during this period.

Before applying treatments, the eight beds were assigned within four blocks based on a visual estimate of seedling height, and then the blocked beds were randomly assigned to winter and spring treatments. In early February 2000, beds were thinned to about 50 seedlings/bed to achieve a uniform spacing. Seedlings were then numbered using aluminum tags attached to wire pins pushed into the soil and were measured for stem diameter (to the nearest 0.1 mm) at a height of 2 cm above ground and height to the terminus and to the cotyledons (to the nearest 0.1 cm). The location of the cotyledons was apparent by attached remnants in most cases or, otherwise, the characteristic raised ring of tissue circling the stem at the point of their attachment (Fig. 1).

The clipping that simulated browse damage was applied on February 15, 2000, for the winter-treatment beds and April 4, 2000, for the spring-treatment beds. Prior to clipping, the 50 seedlings per bed were ranked by height, and then individual seedlings in successive groups of five were randomly assigned to the following five treatments for the point of clipping: at one-half the distance between the root collar and cotyledons and to retain 25, 50, 75, and 100% of the height from the cotyledons to the terminal's winter position (Fig. 1). For winter, the 100% treatment represented an unclipped control. For spring, the 100% treatment removed the new height growth, so that the seedling was the same height that it was during winter. Stems were clipped by making a horizontal cut using wire cutters. After clipping, the remaining portion of the seedling was evaluated for the presence of live primary and secondary needles, and the remaining number of lateral buds or shoots was counted. Seedlings were remeasured for height and diameter immediately before the spring clipping. During spring, the ovendry mass (105°C) of the new height growth was determined for the 40 seedlings from the 100% treatment. For these seedlings, lateral shoots associated with the terminal were counted, and needle length was measured to the nearest 0.1 cm.

No herbaceous control was conducted during the second growing season. Beds were irrigated with about 2.5 cm of water weekly during July and August 2000 because of another severe drought, when precipitation averaged 9 cm/month below normal. Living seedlings were remeasured for height and diameter in January 2001 using the same procedures as previously described; dead seedlings were recorded as such. In addition, seedlings were evaluated for multiple stems (when one or more stems were within 10% of the seedling's tallest stem) and damage to the terminal or associated buds by tip moths (*Rhyacionia* spp.).

[2] This publication reports research involving herbicides. It does not contain recommendations for their use nor does it imply that the uses discussed here have been rcgistercd. All uses must be registered by appropriate State and (or) Federal agencies before they can be recommended.

Nonlinear regression (SAS Institute Inc. 1988) was used to predict the second-year height or diameter of individual seedlings from their first-year height or diameter; the percentage of height above the cotyledons remaining after clipping; and the season of clipping, which was entered as an indicator variable. Second- and third-order interactions of independent variables were also tested in the full model. Variables were retained in equations if their regression coefficient significantly differed from zero at $P \leq 0.05$. The reported fit index for nonlinear equations is analogous to the coefficient of determination for linear equations. The probability that a seedling would have insect damage or multiple stems was determined by logistic regression (SAS Institute Inc. 1990), which has been effectively used in predicting ice damage to individual trees by Amateis and Burkhart (1996).

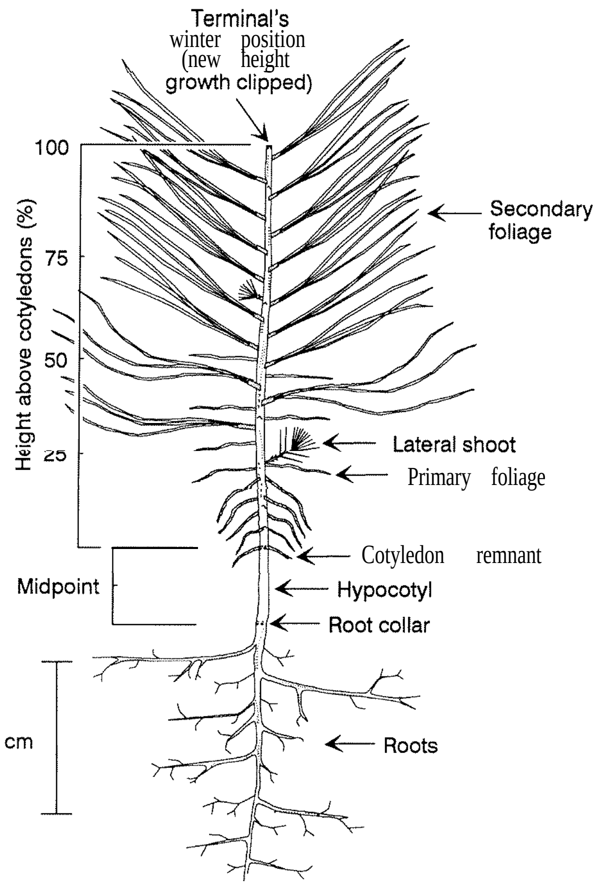
Results and discussion

We found no significant differences ($P > 0.05$) for first-year total height and diameter among clipping treatments before implementation. On average, 76% of the seedlings had set a terminal bud before their first winter. Seedling characteristics immediately after clipping are shown in Table I. Diameters in spring had increased by a mean of 0.9 mm. There were also some changes in foliar conditions between winter and spring for the 25% clipping treatment. The percentage of seedlings with live primary foliage decreased from 69% in winter to 41% in spring, and seedlings with no live foliage increased from 18% in winter to 34% in spring. When the spring treatment was implemented, terminal growth averaged 11 .O cm in length, and needles averaged 2.7 cm long. On the new growth, there was a mean of 2.9 lateral shoots developing with the terminal. The clipped new growth had a mean dry mass of 0.70 g/seedling.

The point of attachment of the cotyledons is critical to evaluating the potential for recovery, because this marks the beginning of the foliated portion of the stem (Fig. 1). The hypocotyl, which extends from the root collar to the cotyledons, does not produce foliage. For all living seedlings during first-year measurements, the mean height of the cotyledons, or the length of the hypocotyl, was 2.7 cm with a range of 1.5–4.0 cm and a coefficient of variation of 19%. Mann (1976) reported slightly longer hypocotyls (mean 3.9 cm) for newly germinated loblolly pine seedlings under greenhouse conditions.

All of the seedlings that were clipped at the midpoint of the hypocotyl died. Consequently, this treatment was not included in subsequent statistical analyses. This confirms the observation of Stone and Stone (1954) that the dormant buds of the southern pines are all associated with foliage. Wakeley's (1954) observation that seedlings may recover when clipped as low as 0.6 cm above the ground applies only to seedlings that are planted with the root collar below the soil surface. and this observation would certainly not apply to natural seedlings. Of the seedlings clipped above the cotyledons, only 0.3% died durin g the second year, and we felt that there was too little data for statistical analysis. Seedlings that died tended to be small (first-year total height was 25% below the overall mean), and most of this mortality (73%) was in the 25% clipping treatment, which was the most severe treatment retaining height above the cotyledons.

Fig. 1. Diagram of an average spring-clipped seedling with 100% of the first-year height remaining above the cotyledons but also showing the other four clipping locations. During winter, the 100% treatment would have retained the terminal and associated buds or shoots.



Recovery from clipping was observed to be a combination of activation of dormant buds associated with foliage and development of lateral buds or shoots into a dominant position. A mean of 56% of the seedlings was classified as having no lateral buds or shoots on the clipped seedling, so recovery of at least this proportion of the seedlings had to be from dormant buds associated with foliage.

The equation predicting second-year height from first-year height, the severity of the clipping treatment, and the season of clipping follows:

$$[1] \qquad H_2 = e^{2.923+0.03824H_1+0.007012\,\mathrm{PR}-0.3647S}$$

where H_2 is second-year total seedling height (cm), H_1 is first-year total seedling height (cm), PR is the percent remaining of first-year height above the cotyledons after clipping, and S is 0 for winter and 1 for spring; the regression coefficients were fit by nonlinear regression. The number of observations was 307, root mean square error was 12.97, and fit index was 0.63. The equation predicting second-year diameter from first-year diameter, the severity of the clipping treatment, and the season of clipping follows:

$$[2] \qquad D_2 = e^{0.9442+0.04501D_1+0.008529\,\mathrm{PR}-0.2546S}$$

where D_2 is second-year diameter (mm), D_1 is first-year diamcter (mm), and the other variables are as previously de-

Table 1. Mean characteristics of 1-year-old loblolly pine seedlings immediately after implementing the clipping treatments.

Height remaining by season (% of first year)*	Total height (cm)	Diameter (mm)	Percentage of seedlings with foliar type			No. of lateral buds or shoots/seedling†
			Primary foliage	Secondary foliage	No foliage	
Winter clipped						
100	15.5	3.5	74	100	0	2.6
75	12.6	3.3	74	94	0	0.7
50	9.2	3.5	58	84	5	1.0
25	6.0	3.4	69	31	18	0.8
Spring clipped						
100	15.7	4.4	73	98	0	1.8
75	12.3	4.2	69	95	0	1.5
50	9.2	4.4	68	90	0	1.6
25	6.0	4.5	41	27	34	1.1

*Evaluated above the point of attachment of the cotyledons.
†For the winter-clipped 100% treatment, the value does not include the terminal and associated buds or shoots.

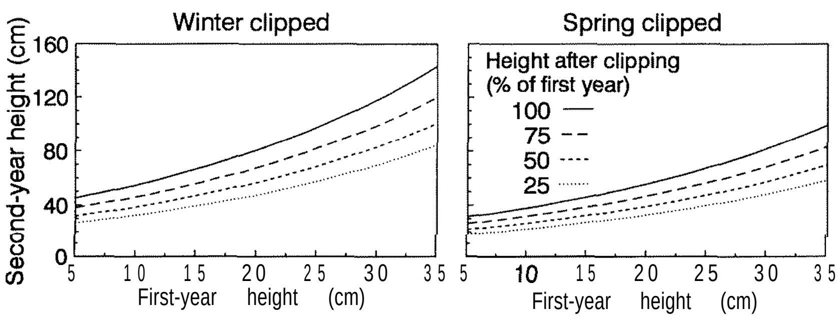


Fig. 2. Effects of first-year total height, percentage of first-year height remaining above cotyledons after clipping, and clipping season on second-year total height of loblolly pine seedlings subjected to simulated browse damage during their first year. Values were calculated from eq. 1.

fined. Root mean square error was 2.36, and fit index was 0.66. All of the coefficients in eqs. 1 and 2 were significant at $P = 0.0001$. In contrast, no interaction terms were significant ($P > 0.05$) when tested in the full model. In both equations, the effects of first-year size and the height remaining after clipping were positive, while seasonal effects were negative. The ranking of independent variables explaining variation in second-year height and diameter was as follows: first-year size > percentage of height remaining > season. Hunt and Gilmore (1967) also found the first-year size was a good predictor of future growth of loblolly pine seedlings.

We solved eq. 1 for a reasonable range of values, and values are plotted in Fig. 2. A mean first-year seedling (16 cm of total height) tripled its height during the second growing season when not damaged. If the seedling was severely damaged (25% of height remaining) during winter, height will still increase by 2.6 times during the second growing season but will increase only by 1.8 times if the same level of damage occurred in the spring.

Of all surviving seedlings, 9% were classified as having multiple stems. The probability of a seedling having multiple stems can be determined from the following series of equations:

$$[3] \quad P_S = \frac{e^{0.307+0.0371PR}}{1+e^{0.307+0.0371PR}}$$

$$[4] \quad P_M = 1 - P_S$$

where P_S and P_M are the probability that a seedling will have single or multiple stems, respectively; PR is as previously defined; and the regression coefficients were determined using logistic regression. The regression coefficient for PR had a Wald chi-square of 17 ($P = 0.0001$). The logistic regression had an R^2 of 0.07, a concordance of 63%, and discordance of 17%. Solving these equations revealed that the probability of a seedling having multiple stems was 23, 10, 4, and 2% when the first-year height remaining after clipping was 25, 50, 75, and 100%, respectively.

Of the surviving seedlings, 19% were classified as having damage from tip moths. The probability of a seedling having insect damage can be determined from the following series of equations:

$$[5] \quad P_N = \frac{e^{6.11-0.0371H_1-0.0270PR+0.832S}}{1+e^{6.11-0.0371H_1-0.0270PR+0.832S}}$$

$$[6] \quad P_I = 1 - P_N$$

where P_N is the probability the seedling will have no insect damage, P_I is the probability the seedling will have insect damage, and the other variables are as previously defined. All regression coefficients had a Wald chi-square >5 ($P \le 0.02$ in all cases), and the logistic regression had an R^2 of

0.15, a concordance of 81%, and discordance of 18%. Solving these equations revealed that the effects of both first-year height and percentage of height remaining were positive on the probability for insect damage, while the effects of season were negative. Since this was the same pattern revealed between treatment variables and second-year height, we suspected that a seedling's second-year height was responsible for the relationship with insect damage. A logistic equation was developed with second-year height, alone as the independent variable as follows:

$$[7] \qquad P_N = \frac{e^{4.67-0.0550H_2}}{1+e^{4.67-0.0550H_2}}$$

where all terms are as previously defined, and P_I is calculated using eq. 6. The R^2 was 0.15, concordance was 81%, and discordance was 18%. Because eq. 7 had goodness-of-fit statistics very similar to those of eq. 5, we felt that seedling size was the causal mechanism associated with insect damage, with the larger, more vigorous seedlings having a higher susceptibility. Tip moth damage has often been shown to vary with the intensity of silvicultural manipulations (Nowak and Berisford 2000). Solving these equations revealed that the probability of a seedling having insect damage was 4, 13, 37, and 70% when second-year height was 25, 50, 75, and 100 cm, respectively.

Management implications

This study demonstrated that the recovery of loblolly pine seedlings from simulated browsing damage strongly depends on the extent of damage. If seedlings are clipped below the cotyledons, mortality is inevitable, because all dormant buds in loblolly pine are associated with either primary or secondary foliage. If seedlings are damaged above the cotyledons, the potential for recovery is good in l-year-old seedlings, especially if the damage occurs during the dormant season. Although 9% of the clipped seedlings had multiple stems at the end of their second year, we expect this percentage to markedly decrease through time because of the strong apical dominance expressed by loblolly pine.

Browse damage reduces subsequent seedling growth, which reduces a seedling's ability to compete with herbaceous and nonpine woody vegetation. Reduction in competitive ability would probably be more of a disadvantage in natural stands, where low-intensity site-preparation methods are often used, than in intensively site-prepared plantations. Although our short-term results suggest growth reductions of up to about 40% during the second year from first-year browse damage, Hunt (1968) found that rabbit-damaged loblolly pines were within 17% of the height of undamaged seedlings after 4 years. Wakeley (1970) reported that growth reductions from rabbit damage to l-year-old loblolly pine seedlings were negligible after 30 years. Thus, the long-term potential for a full recovery from browse damage appears to be good for loblolly pine. In reviewing planting practices, Schultz (1997) recommended planting pine seedlings 5–10 cm deeper than normal to improve survival on well-drained soils, and there may be an added advantage to this practice in areas with a high potential for browse damage, so that the seedlings cannot be clipped below the cotyledons and lose all their dormant buds. Our results on the recovery of seedlings from simulated browse damage may also have implications for other types of damage, such as from logging, fire, and insects.

References

Amateis, R.L., and Burkhart, H.E. 1996. Impact of heavy glaze in a loblolly pine spacing trial. South. J. Appl. For. 20: 151–155.

Hunt, E.V. 1968. How serious is rabbit damage on loblolly pine seedlings? J. For. 66: 853.

Hunt, E.V., and Gilmore, G. 1967. Effect of initial height on loblolly pine seedling growth and survival. J. For. 65: 632-634.

Kramer, P.C., and Kozlowski, T.T. 1979. Physiology of woody plants. Academic Press, Inc. Orlando, Fla.

Larance, EC., Gill, H.V., and Fultz, C.L. 1976. Soil survey of Drew County, Arkansas. USDA Soil Conservation Service, Washington, D.C., and Arkansas Agriculture Experiment Station, Fayetteville, Ark.

Mann, W.F., Jr. 1976. Some characteristics of newly germinated seedlings of four major southern pines. Tree Plant. Notes, **27**(4): 23, 24.

Nowak, J.T., and Berisford, C.W. 2000. Effects of intensive forest management on insect infestation levels and loblolly pine growth. For. Entomol. 93: 336-341.

SAS Institute Inc. 1988. SAS/ETS user's guide, version 6. 1st ed. SAS Institute Inc., Cary, N.C.

SAS Institute Inc. 1990. SAS user's guide, version 6. 4th ed. Vol. 2. SAS Institute Inc., Cary, N.C.

Schultz, R.P. 1997. Loblolly pine-the ecology and culture of loblolly pine (*Pinus taeda* L.). U.S. Dep. Agric. Agric. Handb. 713.

Stone, E.L., Jr., and Stone, M.H. 1954. Root collar sprouts in pine. J. For. 52: 487-491.

Wahlenberg, W.G. 1960. Loblolly pine. School of Forestry, Duke University, Durham, N.C.

Wakeley, P.C. 19.54. Planting the southern pines. U.S. Dep. Agric. Agric. Monogr. 18.

Wakeley, P.C. 1970. Long-term effects of rabbit damage to newly planted southern pines. Tree Plant. Notes, **21**(2): 6-9.