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The Financially Optimal Loblolly Pine Planting Density and Management Regime for Nonindustrial Private Forestland in East Texas

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ABSTRACT: *Economic analyses were conducted to investigate the effects of initial planting density on the profitability of loblolly pine (*Pinus taeda *L.) on nonindustrial private forestland (NIPF) in East Texas. Five planting densities of 870, 725, 620, 540, and 484 trees per acre (tpa) representing spacings of 5×10, 6×10, 7×10, 8×10, and 9×10 ft, respectively, were investigated. Land expectation values were used to determine the financially optimal thinning and final harvesting schedules (including rotation length and the timing, frequency, and intensity of thinning). Five site indices (50–90), six real alternative rates of return (ARR) (2.5–15.0%), and three thinning options (0, 1, and 2) were employed. Results indicate that two thinnings appear to be the financially optimal number of thinnings for most site index-ARR scenarios. The planting spacing of 8×10 ft is optimal when ARR is low, and the 9×10 ft spacing is optimal when ARR is high. South. J. Appl. For. South. J. Appl. For. 29(1):16–21.*

Key Words: Optimal planting density, optimal forest management regime, profitability, net present worth, land expectation value.

Manipulating and controlling growing stock is essential in meeting forest landowners' management objectives; however, translating these objectives into initial planting density, thinning regime (if any), and rotation length to meet the requirements of specific management situations of landowners is not an easy task (Dean and Chang 2002). For all thinning types, the choice of planting density and intermediate treatments influences the number of trees per unit area at any age substantially (Arthaud and Klemperer 1988). Initial tree spacing, which determines stand density, can affect all aspects of forest management from planting costs to the quality and quantity of wood produced (Harms and Lloyd 1981). Specifically, initial spacing can affect both biological variables (height, diameter, crown, quality, basal area, and volume development) and operational factors (harvesting, thinning, site preparation, and other cultural treatments) (Smith and Strub 1991). The decision on the best initial spacing depends on several factors: (1) the product(s) desired, (2) the likelihood and intensity of intermediate stand treatments, and (3) the expected initial survival and spatial distribution of seedlings (Smith and Strub 1991).

Based on the products desired and rotation length, planting density recommendations were made by Smith and Strub (1991). When pulpwood grown on a short rotation is preferred, close spacing will insure high volume per hectare, and it will result in small tree size and higher associated logging costs. When sawtimber-sized material grown on a relatively short rotation (with no intermediate thinnings) is favored, wider spacings should be used, and it will result in large tree size and lower associated logging costs. Yet, this regime has the disadvantages of taking a longer period before crown closure during which competing species may flourish, producing larger knot size due to slower self pruning, and limiting opportunity to remove poor quality trees via intermediate thinnings. When a mixture of pulpwood from intermediate thinnings and sawtimber from final harvest is desired, closer spacings may be necessary. Because low pulpwood product value prohibits long haul distance, the existence of a pulpwood market close to the plantation is critical for this management regime. In addition to the factors associated with end-products and rotation length, site quality, tree survival rate, growth rate, management objectives, and financial policies are critical in the decision of initial spacing (Schultz 1997). Close spacings are more

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appropriate on good sites because they offer the greatest opportunity to maximize total volume or to select the best trees for final harvest (Schultz 1997). Wider spacings are best on inferior sites (Schultz 1997); however, if low survival rate presents a problem on poor sites, it is vital that initial planting density be high enough to ensure adequate stocking after early mortality (Mann and Dell 1971).

Using a computerized tree growth simulator, Broderick et al. (1982) performed economic evaluations to determine optimal management regimes for old-field loblolly pine plantations. Inputs used in the simulation included planting densities of 6×10, 8×10, and 10×10 ft, site indices (SI) 50 through 70 base age 25, single and multiple thinnings at varying ages and intensities, rotation ages of 20 through 40 years in 5-year increments, and 6% alternative rates of return (ARR). It was concluded that, on average old-field loblolly pine plantation sites without hardwood competition, for all product mixes, widening the planting spacing up to 10×10 ft yielded the greatest concentration of future volume in trees of larger diameter and high value. The 10×10 foot spacing generated the highest present value thanks to the lowest planting cost and little or no decrease in merchantable harvest volume. The optimal pulpwood rotation will require conducting a clearcut at age 20 with no thinnings. The mixture of pulpwood, sawlogs, and peelers rotation lengths ranged from 25 years on SI 70 to 30 years on SI 50 and SI 60, removing about 33% of cubic-foot volume at age progressing from 15 years on SI 60 and SI 70 to 25 years on SI 50.

Klemperer et al. (1987) estimated effects of hardwood competition on economically optimal timber-management regimes for old-field loblolly pine plantations. Their results show that, compared to a no hardwood competition case, the closer spacing of 6×10 ft yielded the highest present value when competition remains throughout the rotation. If hardwood competition ends by age 15, a 10×10 foot spacing is optimal. Arthaud and Klemperer (1988) used infinite-series NPV to compare the various management possibilities and seek economically optimal thinning regimes for high and low thinning in loblolly pine. One important feature of their optimal regimes is the superiority of the planting density of 441 trees per acre (tpa) over densities of 680 and 911 tpa.

Evidently, the effects of initial tree spacing on the growth and yield of loblolly pine plantations have been studied by many scientists over the years with the common conclusion that tree spacing is one of the most important factors in forest management. Researchers have recommended a financially optimal rotation age, the number, timing, and intensity of thinnings for loblolly pine (Huang and Kronrad 2002, Huang and Kronrad 2004); however, the financial impacts, and management implications of initial planting density with thinning operations have not been examined carefully. This research was designed to assist NIPF landowners in making the critical decisions of selecting the preferred planting density, thinning regime, and rotation length for their loblolly pine plantations to maximize relevant financial returns from loblolly pine plantations in East Texas. The variables employed in this study include planting density, timing, intensity, and frequency of thinnings, timing of the final harvest, individual landowner's ARR, site index, management costs, stumpage prices, and real price and cost increases. The option of thinning was ignored in most studies due to the complexity of determining the optimal timing, number, and intensity of the thinnings.

Methods

The Loblolly Pine Management Optimizer (LOPMOP) was developed to simultaneously determine the optimal initial density, rotation age, and timing and intensity of thinning(s) for loblolly pine plantations on NIPF in East Texas. This program used PTAEDA2 (Burkhart et al. 1987), a forest stand simulator, to predict stand growth data on diameter, height, and volume from establishment to final harvest. PTAEDA2 was linked to a financial program that performed cash flow analyses and calculated net present worth and land expectation values. Data for PTAEDA2 growth and yield model came from 186 permanent plots established in cutover, site-prepared plantations throughout much of the natural range of loblolly pine. PTAEDA2 data are applicable for a wide range of sites in both the Coastal Plain and Piedmont regions. Twenty-two percent of these plots are located in the West Gulf Coast region that includes Texas. Fifty-six percent of the sites are in the Coastal Plain, which are similar to sites in Texas. For a more complete description of these sites, see Burkhart et al. (1985).

Management Options

Site indices 50, 60, 70, 80, and 90 (base age 25), well within the possible site index range for PTAEDA2, were used in these analyses. Planting densities of 870, 725, 620, 540, and 484 tpa representing spacings of 5×10, 6×10, 7×10, 8×10, and 9×10 ft, respectively, were considered in this study. Rectangular spacings were chosen because they accommodate the use of mechanized equipment area between rows, and they are often preferable to square spacings (Sharma et al. 2002).

It was assumed that all plantings would occur on bare, site-prepared land. The maximum possible rotation length was limited to age 60. The method for the first thinning would be a combination of low and row thinning; the method for the second thinning would be a low thinning only. The first thinning could not be conducted until the stand was at least 10 years of age. The minimum years between thinnings, or between a thinning and the final harvest, could not be less than 5 years. For all runs, a "thinning and final harvest" regime would be considered to be operable only if it passed the following two threshold constraints: (1) every thinning or final harvest had to yield a minimum of 6 cd/ac of pulpwood and/or sawtimber; (2) the number of residual trees after each thinning had to be at least 80 per acre. The first constraint was set to guarantee that volume removed during the harvest would be sufficient for an operable cut. To successfully procure a logger or harvesting crew, it is crucial to adjust this constraint when the price of pulpwood is depressed, and pulpwood is the only product that loggers will harvest from the stand. The

Table 1. **Management activities, frequencies, labor costs, and other price related values.**

Activity	Cost ($/ac.)	Frequency	Start	End
Boundary location	20	Only once	Year 0	
Boundary maintenance	2	Every 10 yr	Year 10	Final harvest
Management plans (initial)[a]	5	Only once	Year 0	
Management plans (updates)	10	Every 10 yr	Year 10	Final harvest
Site preparation (chop)	90	Only once	Year 0	
Site preparation (herbicide)	85	Only once	Year 0	
Hand planting, labor	45	Only once	Year 0	
Seedlings				
5×10 (871 seedlings/ac)	44	Only once	Year 0	
6×10 (726 seedlings/ac)	36	Only once	Year 0	
7×10 (622 seedlings/ac)	31	Only once	Year 0	
8×10 (545 seedlings/ac)	27	Only once	Year 0	
9×10 (484 seedlings/ac)	24	Only once	Year 0	
Burning	40	Every 5 yr	Year 10	Final harvest
Thinning and final harvest costs	10% of revenues	As necessary		

[a] An initial management plan can be prepared for bare land at a lower cost than updates to existing stands because updates include the cost of timber cruising.

purpose of the second constraint was to avoid problems associated with inadequate residual stand density. Four thinning intensities were employed: 20, 25, 30, or 35% of basal area removal. The upper bound of thinning intensity was set at 35% to avoid opening up to much growing space and lead to regeneration. The number of possible thinnings was zero, one, or two. The same thinning intensity was used for all thinnings for a specific optimal solution regardless of the number of thinnings or age of thinnings.

Product Yields

NIPF landowners in Texas usually are paid only to the nearest half log (8 ft) for the merchantable sawlog portion of their timber. Amateis and Burkhart's taper functions (1987) were applied to the biological variables diameter at breast height (dbh) and total height from PTAEDA2 to estimate upper stem diameters and merchantable heights. Doyle log rule was used to compute board-foot volume. Although Doyle rule greatly underscales small logs and overscales large logs, it is used by many forest consultants and timber buyers to measure and purchase standing timber from NIPF landowners in East Texas. Cull percentages were not applied because it was assumed that cull trees would be removed in early thinnings before sawtimber harvests. A 10-in. dbh and one 16-ft log were set as minimum sawlog requirements. After the first 16-ft log, the minimum sawlog increment was assumed to be 8 ft. The merchantable height is the number of 8-ft logs that could be cut out of the tree up to a minimum top diameter of 6-in. inside bark. This is the method used by consultants in Texas to tally individual trees. Timber buyers review and determine a bid price based, in part or in whole, on the inventory provided by the consultant. Pulpwood volume was measured in cords to a 4-in. outside bark top diameter for trees in the 5-, 6-, 7-, 8-, and 9-in. dbh classes. Cordwood volumes were computed from the 1-in. dbh class conversion factors presented by Burkhart et al. (1972). These conversion factors range from 84 ft^3 ob/cd for the 5-in. dbh class to 95 for the 13-in. class and above (Burkhart et al. 1987). Even though the superior diameter growth induced by thinning usually improves wood quality because large trees tend to have better quality than small ones (Smith et al. 1997), any change in the quality of wood resulting from thinning was assumed to be negligible in this study.

Economic Evaluation

Six ARRs, which span the range of before-tax earning rates available for most landowners, were chosen for the economic analyses. They were 2.5, 5.0, 7.5, 10.0, 12.5, and 15.0% in real terms, meaning that inflation has been removed from these numbers. Because NIPF landowners in Texas receive timber revenues only from pulpwood and sawtimber sales, only these two products were considered for economic evaluation. Even though timber does not always appreciate above the rate of inflation, historically, Texas timber stumpage prices do grow above inflation in the long-term (Texas Forest Service 1984-2002). Based on the prices of sawlog and pulpwood (Texas Forest Service 2001) and the projections of stumpage prices to 2050 (Haynes 2003), the annual real rate of price increase for sawtimber and pulpwood in East Texas was assumed to be 0.5 and 0.4%, respectively. Labor costs were assumed to increase at a real rate of 1.12% per year (Council of Economic Advisors 2002). The price of sawtimber was assumed to be $400/mbf (Doyle), and pulpwood price was assumed to be $20/cd (Texas Forest Service 2000).

It was assumed that proper forest management activities would be conducted. In general, management costs are incurred for establishing, maintaining, and harvesting the stand. The management costs of this study were based on the price quotes gathered by Texas Forest Service (txforestservice.tamu.edu/shared/article.asp?DocumentID=596&mc=forest. Aug. 31, 2002). The property tax cost was not included because it was assumed that the revenue from a hunting lease would offset the cost of property taxes. The presumed site preparation methods were herbicide and mechanical (chop) treatments. Results of this site preparation method generate mean levels of hardwood competition, as reflected in the PTAEDA2 model. Assumed management activities, frequency, and labor costs for forestlands in Texas are presented in Table 1. An initial management plan can be prepared for bare land at a lower cost than updates to existing stands because updates include the cost of timber cruising.

Table 2. Financially optimal thinning and final harvest schedules and planting density for loblolly pine by site index and alternative rates of return.

Site index[a]	Alternative rates of return					
	2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
50	23–30–**44**[b]	<23[d]–28–**38**>	<20–25–**33**>	<20–25–**32**>	<20–25–**30**>	<20–25–**30**>
	(35%)[c]	(35%)	(35%)	(35%)	(35%)	(35%)
Planting density	8×10	8×10	9×10	9×10	9×10	9×10
60	20–31–**39**	17–24–**34**	<17–24–**29**>	<16–21–**28**>	<16–21–**27**>	<16–21–**27**>
	(20%)	(30%)	(30%)	(35%)	(35%)	(35%)
Planting density	8×10	8×10	8×10	8×10	9×10	9×10
70	24–29–**34**	18–23–**29**	18–23–**29**	<13–18–**23**>	<13–18–**23**>	<13–18–**23**>
	(20%)	(25%)	(25%)	(35%)	(35%)	(35%)
Planting density	8×10	8×10	8×10	8×10	8×10	8×10
80	14–24–**34**	17–22–**28**	17–22–**28**	12–17–**23**	<12–17–**23**>	<12–17–**23**>
	(30%)	(25%)	(25%)	(35%)	(35%)	(35%)
Planting density	8×10	8×10	8×10	9×10	9×10	9×10
90	15–**30**	15–**26**	15–**25**	13–18–**24**	11–16–**21**	<11–16–**21**>
	(35%)	(35%)	(35%)	(35%)	(35%)	(35%)
Planting density	8×10	8×10	8×10	8×10	8×10	8×10

[a] Base age 25.
[b] Bold type indicates final harvest age, and the number(s) to the left indicate ages(s) at thinning(s).
[c] Number in parentheses indicates the percentage of basal area removed during thinning(s).
[d] Brackets indicates a negative LEV. Schedule shown minimizes losses.

Given a range of site indices and real ARRs, discounted cash flow analyses were conducted to obtain net present worth (NPW) for all the operable management regimes. NPW of a project is the present value of its revenues minus the present value of its costs over one rotation. The classic Faustmann formula was then applied to calculate land expectation value (LEV). LEV, which is commonly used to calculate the NPW of bare land used for growing a perpetual series of forest crops, was used for comparing forestry investments of unequal rotation lengths. The management regime that had the highest LEV was chosen as the financially optimal thinning and final harvest schedule for each combination of site index and landowner's ARR.

Because this study used the Doyle log rule, and management costs and stumpage prices prevalent in Texas, the results of this study are valid only for NIPF landowners in Texas. However, with adjustments for sawtimber measurement and the use of local management costs and stumpage prices, LOPMOP can calculate financially optimal management regimes for nonindustrial and industrial forest landowners across the range of loblolly pine.

Results

Given a range of assumed landowners' ARRs, a total of 4,389,264 NPWs and LEVs were calculated for all operable thinning and harvest regimes on five site indices using five initial planting spacings. The optimal planting spacings and thinning and final harvest schedules that maximize LEV for each combination of site index and ARR are listed on Table 2, and their NPWs and LEVs are shown in Table 3. All monetary values are presented on a per acre basis.

Results indicated that forest management was only profitable for 2.5% ARR on site index 50 land but was profitable for all ARRs considered, except for 15.0%, on site index 90 land (Tables 2 and 3). The optimal initial planting spacing was either 8×10 or 9×10 ft (Table 2). The 8×10 ft planting density was optimal for site indices 70 and 90 regardless of landowner's ARR. Throughout the range of ARRs, employing two thinnings was crucial in achieving optimal management on site indices 50–80 land. For example, the financially optimal thinning and final harvest schedule on site index 50 land was to thin at stand ages 23 and 30 (35% of basal area removed) and final harvest at stand age 44 (Table 2). The LEV for the optimal management regime was \$275.79; the corresponding NPW was \$185.01 per acre (Table 3). The optimal management regimes for site index 90 required one or two thinnings; one thinning was optimal for low ARRs (2.5, 5.0, and 7.5%), and two thinnings was optimal for higher ARRs. The thinning intensity of 35% basal area removal was generally optimal especially for higher ARRs. The schedules shown in brackets on Table 2 indicate that using the five initial planting spacings, the specific site index-ARR combinations will generate negative LEVs under the assumed management options, and the optimal regime is to not plant trees unless there is an economic change in terms of management costs or stumpage prices or an increase of production resulting from modifying assumed thinning options or performing fertilization.

Discussion

The choice of initial planting density is one of the most important decisions a land manager has to make when it comes to establishing a plantation (Schultz 1997). This regeneration decision affects and is affected by future management decisions (Gong 1998). Taking into consideration financial (i.e., ARR) and management factors (i.e., initial planting density, intensity, frequency and timing of thinning, and rotation length), this study was designed to determine the financially optimal thinning and final harvest regimes for loblolly pine plantations in East Texas. Some general trends regarding the impact of the discount rate or site index on thinning and harvest schedule can be derived intuitively from Table 2. As ARR or site index increases,

Table 3. Net present worth (NPW), land expectation values (LEV), and optimal planting density for loblolly pine by site index and alternative rates of return.

Site index[a]	Alternative rates of return 2.5%	5.0%	7.5%	10.0%	12.5%	15.0%
50						
NPW	$ 185.01	–$ 122.65	–$217.88	–$253.31	–$267.18	–$273.73
LEV	$ 275.79	–$ 144.15	–$238.26	–$264.71	–$274.30	–$277.37
Planting density	8×10	8×10	9×10	9×10	9×10	9×10
60						
NPW	$ 573.75	$ 67.24	–$112.47	–$191.71	–$229.91	–$249.87
LEV	$ 914.24	$ 82.13	–$126.97	–$204.61	–$238.73	–$254.96
Planting density	8×10	8×10	8×10	8×10	9×10	9×10
70						
NPW	$1,142.02	$ 348.66	$ 41.68	–$ 96.01	–$165.98	–$207.58
LEV	$1,973.67	$ 453.62	$ 47.05	–$106.86	–$176.42	–$215.09
Planting density	8×10	8×10	8×10	8×10	8×10	8×10
80						
NPW	$1,873.35	$ 679.25	$230.23	$ 19.86	–$ 92.02	–$159.04
LEV	$3,237.57	$ 897.23	$262.46	$ 22.10	–$ 97.81	–$164.80
Planting density	8×10	8×10	8×10	9×10	9×10	9×10
90						
NPW	$2,767.79	$1,166.09	$517.08	$189.67	$ 15.51	–$ 85.86
LEV	$5,174.55	$1,592.69	$610.15	$208.96	$ 16.77	–$ 90.02
Planting density	8×10	8×10	8×10	8×10	8×10	8×10

[a] Base age 25.

the age of intermediate and final harvest operations of the financially optimal management regimes decreases. This is consistent with the findings of previous optimal management studies for loblolly pine using an initial planting spacing of 9×8 ft (Huang and Kronrad 2002, Huang and Kronrad 2004). The results of this study indicate that one thinning is optimal for site index 90 when the discount rate is low (2.5–7.5%), while two thinnings are optimal for all other site index values throughout the range of discount rates. The possible explanation is that because a low discount rate permits a later harvest, and high productivity land turns pulpwood products into sawlogs at an earlier age, landowners with low discount rates on high site index land profit from having more sawlog-sized trees on the stand at the time of final harvest by conducting only one thinning.

Five initial planting spacings, 5×10, 6×10, 7×10, 8×10, and 9×10 ft, were investigated in this study. For the majority of site indices and landowners' ARRs, forests established at an 8×10 or a 9×10 planting density generated the highest LEVs. Eight-by-ten-foot spacing was optimal for low ARRs (2.5%–7.5%), and 9×10-ft spacing was optimal for high ARRs (10–15%). In the few cases that 9×10 was not the optimal planting density for high ARRs, the differences in LEVs of 9×10 and the optimal spacing were never more than $7 per acre. This planting density-interest rate relationship is consistent with the finding that planting density decreases with increasing interest rates (Dean and Chang 2002). The reasonable explanation is that as ARR increases, the length of the financially optimal rotation will be shorter. Stands planted at 9×10-ft spacing reach optimal growth rate sooner, permitting early removal of pulpwood and early production of larger-sized sawtimber.

The optimal spacing was not sensitive to site index. This is different from the recommendations made by Schultz (1997) for unthinned loblolly pine plantations that wider spacings are best on poor sites and closer spacings are appropriate on good sites or when a mixture of pulpwood and sawtimber is desired. The possible explanation for these conflicting results is that our study provided the management option of up to two thinnings to determine optimal regimes. This gives forest managers the flexibility of removing merchantable volume early in the rotation, thus avoiding stands becoming crowded. In general, the 8×10 spacing, a wide spacing with lower seedling costs, appeared to be optimal because this spacing fully used growing space before thinning(s) occurs and grows at an optimum rate after thinning operation(s). The PTAEDA2 growth and yield model was examined to check if the model had any anomaly, in this case a nonsmooth yield surface, which might lead to a single optimal planting density regardless of site index, and the results indicate that nothing in the model should cause anomaly due to number of trees planted (H.E. Burkhart, University Distinguished Professor and Department Head, Department of Forestry, Virginia Polytechnic Institute and State University, Apr. 7, 2004).

The limitations placed on thinning frequency and intensity in this research may be one of the major reasons why wider planting density (8×10 or 9×10) is optimal. According to the results of this study, two thinnings appear to be the financially optimal number of thinnings for most site index-ARR combinations (Table 2). The corresponding thinning intensity is 35% (the upper bound of thinning intensity) in most cases, particularly for the site indices of 50 and 90 (Table 2). This indicates that if a higher thinning frequency or intensity were undertaken, more trees grown on higher planting density (5×10, 6×10, or 7×10) stands would be free from the competition of undesirable trees and become sawlogs at an earlier age, which may result in more sawtimber revenues at the time of harvest and the possibility that narrower spacings may become optimal.

Optimal planting density for varying site indices over a range of alternative rates of return is information that can increase return on investment. This research conducted sensitivity analyses for site index (50–90), alternative rate of return (2.5–15.0%), and planting density (484–871 tpa) and calculated more than 4 million NPWs and LEVs. The costs used in this study were based on costs reported by Texas Forest Service. However, actual costs may vary depending on the location and size of property, hazards, vegetative cover present, availability of contractors, etc. Any change in the financial data will affect the conclusions from this analysis. Sensitivity analyses to assess the impacts of changes in management costs and stumpage prices on optimal management alternatives are the subject of future research.

This analysis used the classic Faustmann formula over the generalized Faustmann model (Chang 1998), which allows the optimal harvest age to vary from timber crop to timber crop by letting the stumpage price, timber yield, regeneration cost, and interest rate vary from timber crop to timber crop. The drawback of using the classic Faustman formula is the assumption that the optimal management regime remains the same for all rotations. The rationale behind this decision is the complexity of this study, which involves determining profit-maximizing combinations of products (pulpwood and sawtimber) and monetary and physical trade-offs between the products when harvest occurs. Future research using the generalized Faustmann model will investigate the relationship between stumpage prices, interest rates, and optimal harvest age for loblolly pine plantations in East Texas.

Wood density, stem shape and quality, diseases and insects, and market fluctuations are not addressed in this analysis. The results of this optimal planting density study are applicable for landowners who have bare land, intend to plant loblolly pine, and want to maximize their profits. These results are not applicable to existing stands. Optimal management regimes for the existing loblolly pine plantations need to be investigated individually.

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