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Prescribed Burning and Water Quality of Ephemeral Streams in the Piedmont of South Carolina

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ABSTRACT. Soil and nutrient export were monitored before and after two prescribed burns 18 months apart. Burns were designed to prepare Piedmont pine stands for regeneration. Data from four pairs of treatment and control watersheds were analyzed as a randomized complete block experiment. The burns did not significantly affect storm runoff, sediment concentrations, or sediment export from the watersheds. Both runoff and sediment export increased from one watershed, but the effect was due to a bark beetle outbreak rather than to prescribed burning. Analysis showed no significant change in NO_3-N, NH_4-N, Ca, Mg, or K concentrations or export after either burn. Sodium concentration before burning was significantly different for the burned-unburned watershed pairs but not significant after either prescribed burn. This difference was attributed to factors other than burning. It was concluded that the two prescribed burns did not change water quality of the streams studied. FOREST SCI. 29:181–189.

ADDITIONAL KEY WORDS. Storm runoff, sediment yield, chemical properties, nutrients, loblolly pine, site preparation.

BECAUSE OF AN ALARMING DECLINE in pine regeneration in the South (Boyce and Knight 1979), increased emphasis is being given to preparing sites for natural or artificial regeneration after timber harvest. On steep slopes, commonly used mechanical methods expose mineral soil and accelerate erosion (Ursic and Douglass 1978, Beasley 1979). On many sites, prescribed burning is an alternative method of site preparation. Although much information exists on the effects of fire on erosion and water quality in the West (Tiedemann and others 1979), information specifically dealing with prescribed burning in the South is both limited and somewhat conflicting. However, published results are encouraging because increases in erosion, if they occur, are small. Ursic (1969) reported that prescribed burning in Mississippi reactivated a gully in an old field and increased sediment yield to 6,500 kg/ha, but soil loss dropped to less than 56 kg/ha the third year after burning. Ursic (1970) also reported increases of 48 to 119 percent in soil loss from two watersheds the first year after prescribed burning and injection of cull hardwoods, but these losses were still relatively small. Brender and Cooper (1968) reported that repeated prescribed burning had little effect on hydrologic properties of Piedmont soils in Georgia. Cushwa and others (1971) found no increase in erosion in established gullies after a single prescribed fire in the South Carolina Piedmont. In the less steeply sloping Coastal Plains, prescribed burning had limited effects on soils, nutrient cycling, and hydrologic systems of a pine forest and Richter and others (1982) concluded that prescribed burning is unlikely to have appreciable impacts on water quality of the region.

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TABLE 1. Characteristics of study watersheds and loblolly pine timber stands.

Watershed number and treatment		Size	Channel length[1]	Slope[2]	Soil series	Stand	
						Age	Basal area
		ha	*m*	*percent*		*years*	*m^2/ha*
61	Burned	0.65	23	13.0	Cecil, Madison	37	32.9
62	Unburned	1.54	12	19.0	Pacolet, Madison	37	43.9
63	Unburned	2.18	14	13.5	Pacolet	36	15.0
64	Burned	1.12	5	16.0	Pacolet	36	22.3
65	Unburned	0.40	99	10.0	Pacolet	36	18.9
66	Burned	1.24	206	10.5	Pacolet	36	17.9
67	Unburned	0.48	117	12.0	Cecil, Madison	36	23.9
68	Burned	0.60	174	12.0	Madison	36	23.0

[1] Length of uninterrupted channel immediately above the H-flume.

[2] Maximum-minimum elevation divided by distance.

This paper describes effects of such burning on water quality in ephemeral streams on sloping watersheds in the Piedmont Plateau in South Carolina. Watersheds were burned twice, 18 months apart.

METHODS

Watershed Descriptions.—Eight watersheds ranging from 0.48 to 2.18 ha, located on the Clemson Experimental Forest in the upper Piedmont of South Carolina, were selected for study. The area is characterized by rolling topography which drains toward the southeast. Important characteristics of the watersheds and their vegetative cover are shown in Table 1. Soils are Typic Hapludults; they are well drained and highly weathered soils formed on an eroded residuum derived primarily from granitic and gneissic materials. Prior to agricultural use, the surface layers of these soils were loams of varying textures. After decades of row cropping, much of the surface soil was lost as sheet and gully erosion, and the predominantly clay B horizon is now near the surface.

Middle and lower slopes on the experimental watersheds have well-developed ephemeral stream channels formed from healed gullies. Average slopes of individual watersheds ranged from 10 to 19 percent. Drainage patterns vary from linear on severely eroded to dendritic on the less severely eroded watersheds. On several watersheds, the drainage channel is interrupted by terraces either constructed in the 1930's or deposited during periods of intense erosion.

Annual precipitation averages 130 cm and is well distributed throughout the year. Winter is the wettest season with 30 percent of the annual precipitation. Maximum and minimum yearly temperatures average 22° and 9°C, respectively, while mean annual temperature is 16°C.

Watersheds were planted to loblolly pine (*Pinus taeda* L.) in 1939. Watersheds 61 and 62 have not been thinned; Watersheds 63 through 68 have been thinned twice. Pine basal area in 1975 is shown in Table 1. Site indexes for loblolly pine range from 24 to 27 m at 50 years. When the study began, the watersheds were entirely covered by a thick mat of pine needles, branches, and bark in various stages of decomposition. Major understory species included black cherry (*Prunus serotina* Ehrh.), blackgum (*Nyssa sylvatica* March.), eastern redcedar (*Juniperus virginiana* L.), dogwood (*Cornus florida* L.), oak (*Quercus* spp.), and hickory (*Carya* spp.).

Instrumentation and Sample Analysis.—Streamflow on each watershed was recorded by an analog-to-digital punch tape recorder connected to the stilling well

FIGURE 1. Flow from Watershed 64 during spring storm before treatment.

of a 0.3-m H-flume (Fig. 1). Flow volumes were calculated using the procedures described by Hibbert and Cunningham (1966). Storm runoff was sampled with a 0.61-m diameter Coshocton wheel set below each H-flume. Approximately 0.5 percent of the flow over the flume was diverted by the sampling slot in the wheel into plastic sample barrels where it was stored for weekly collection. During the winter when flow was relatively heavy, a 10:1 splitter was placed in the drainline to further reduce sample volume to about 0.05 percent of the total flow.

When the runoff sample was collected for analysis, water in the storage barrel(s) was stirred to uniformly mix the suspended solids, and a 1,000 ml sample was withdrawn. About 400 ml of this sample were used to determine sediment by filtration through a 0.42 μm pore fiberglass filter. Prior to filtration, 1 ml of concentrated HCl was added, and the sample was allowed to stand overnight to flocculate the fine clay colloids. Sediment weight was determined gravimetrically after drying at 105°C and was expressed as mg/liter.

Chemical analyses were performed by the Agricultural Chemical Services Department of Clemson University. A 250-ml aliquot of the original 1,000 ml runoff sample was centrifuged at 13,000 rpm for 15 minutes to remove colloidal material. Calcium (Ca^{++}), magnesium (Mg^{+}), potassium (K^{+}), and sodium (Na^{+}) in the supernatant were determined by atomic absorption spectrophotometry. Ammonium (NH_4-N) was determined spectrophotometrically by the Berthlot reaction, nitrate (NO_3-N) by reduction of nitrate to nitrite and reaction with sulfanilic acid, and orthophosphate (PO_4-P) by the molybdate blue method.

Treatment and Data Analysis.—The experiment design was a randomized complete block. Each of four blocks contained two adjacent watersheds, one of which was randomly selected for burning. Sampling began in June 1975. The first prescribed burn was applied on March 11, 1977, the third day after the passage of

TABLE 2. Precipitation (P) and runoff (RO) for unburned and treated watersheds which were burned on March 9, 1977, and September 20, 1978.

Watershed number and treatment		Preburn[1]		After first burn		After second burn[2]	
		P	RO	P	RO	P	RO
		cm/ha					
61	Burned	114.43	6.48	203.30	9.45	170.80	9.45
62	Unburned	114.43	3.10	203.30	13.82	170.80	14.39
63	Unburned	109.68	3.57	207.62	9.12	176.42	7.48
64	Burned	109.68	3.20	207.62	6.40	176.42	5.40
65	Unburned	109.68	10.07	207.62	26.40	176.42	20.46
66	Burned	109.68	12.67	207.62	29.02	176.42	25.18
67	Unburned	105.11	5.65	234.90	16.90	172.78	9.53
68	Burned	105.11	10.67	234.90	28.38	172.78	22.34

[1] June 1, 1976, to March 9, 1977.

[2] September 20, 1978, to September 12, 1979.

a cold front which delivered more than 2 cm of rain. Air temperature was about 10°C, relative humidity ranged between 50 and 35 percent, decreasing as the afternoon progressed, and wind speed was between 8 and 16 km/hour in the stands. The burning technique was to backfire along the upper ridge, and then ignite strip headfires at about 10 m intervals until the entire watershed had burned. Burning intensity varied considerably among and within watersheds, but the entire area of each watershed was burned. Flame heights averaged about 0.3 m on Watersheds 61 and 68 and about 1.0 m on Watersheds 64 and 66, the last two watersheds burned.

The same watersheds were burned a second time on September 20, 1978. Burning technique was as described above, but fires were less intense because less fuel was present, hence, flame height was somewhat less. Air temperature averaged between 26° and 32°C, relative humidity was between 38 and 50 percent, and wind speed was about 16 km/hour. It had been about 2 weeks since a significant rain, but high humidity prevented excessive drying of fuels.

The purpose of both burns was to reduce hardwood understory in preparation for natural seeding. A third burn on September 12, 1979, was designed to prepare seedbeds prior to harvest of overstory trees. This paper presents only the effects of the first two prescribed fires on water quality of the ephemeral streams.

Data were analyzed two ways: (1) analysis of variance techniques utilizing all eight watersheds and (2) the paired watershed approach.

RESULTS AND DISCUSSION

Runoff and Soil Export.—Because watershed pairs were separated by as much as 10 km, rainfall varied between study locations (Table 2). Variation in runoff between locations can be attributed to these rainfall differences, to differences in physical characteristics of individual watersheds which influence internal hydrology (Table 1), and to the difference in length of the three periods of measurement. Before statistical analyses were performed on runoff and soil export, data were adjusted to a common time period of 1 year to reduce some of this variability. The analysis of variance indicated that no significant differences in runoff or soil export existed between burned and unburned watersheds before burning or after either of the two prescribed burns.

Even though the analysis of variance indicates no effect of burning, runoff and soil export appeared to increase with time for Watershed 68 (Table 3). After this

TABLE 3. Sediment concentration and soil export for unburned and treated watersheds which were prescribed burned on March 9, 1977, and September 20, 1978.

Watershed number and treatment	Mean weighted sediment concentration			Soil export		
	Preburn[1]	After first burn	After second burn[2]	Preburn[1]	After first burn	After second burn[2]
	mg/l			*kg/ha/yr*		
61 Burned	13	20	13	11.4	12.4	12.2
62 Unburned	11	16	15	5.0	14.5	22.6
63 Unburned	22	32	21	11.1	18.8	16.0
64 Burned	46	45	20	20.3	18.9	11.1
65 Unburned	27	57	15	38.1	97.5	30.8
66 Burned	19	34	16	33.5	63.9	42.6
67 Unburned	23	23	21	18.5	25.8	18.9
68 Burned	28	43	87	40.7	79.4	198.0

[1] June 1, 1976, to March 9, 1977.

[2] September 20, 1978, to September 12, 1979.

watershed was first burned on March 9, 1977, an outbreak of the southern pine beetle (*Dendroctonus frontalis* Zimm.) occurred. Mortality was not severe enough to influence runoff in 1977, but by October 1978, 20 percent of the pine basal area was dead. Because evapotranspiration decreases and streamflow increases as live basal area is reduced, an increase in streamflow would be expected for that watershed. Suspended sediment concentrations progressively increased with time on Watershed 68, and because soil export is the product of concentration times runoff volume, an increase in both flow and export was expected. Because the experiment included four pairs of burned and unburned watersheds, regression techniques were used to examine the monthly stormflow between each watershed pair for the three periods.

In three of the four watershed pairs, there was no change in slope or intercept of the regression describing stormflow from burned and unburned watersheds (Fig. 2). Monthly flow data for the unburned and burned periods were combined and regression equations were derived for Watershed pairs 61–62, 63–64, and 65–66. Correlation coefficients (r values) for these pairs were 0.89, 0.96, and 0.98, respectively. However, the slope coefficient for the Watershed 67–68 pair differed significantly after the second burn ($P = 0.01$) from the combined slope coefficient derived for the calibration period and the period after the first burn (Fig. 3). Comparison of measured flow with predicted flow for the period after the second burn indicates that flow increased by 6.11 cm after southern pine beetles killed 20 percent of the pine basal area. This increase in flow alone could account for a 70 percent increase in soil export. But because suspended sediment concentration also increased with time on Watershed 68, soil export was even greater. Slope coefficients for soil export regressions before and after the second burn differed by eightfold and the difference was significant at the $P = 0.01$ level.

Because there was no evidence of overland flow, the increase in soil loss was attributed primarily to channel erosion. Observations of channels confirmed that by October 1978 the combination of fire, more rapid litter decomposition, and lack of litter deposition had exposed the channel on Watershed 68 to renewed erosion, whereas, channels of the other watersheds were still covered by a protective layer of needles. Annual soil export from Watershed 68 was 199 kg/ha

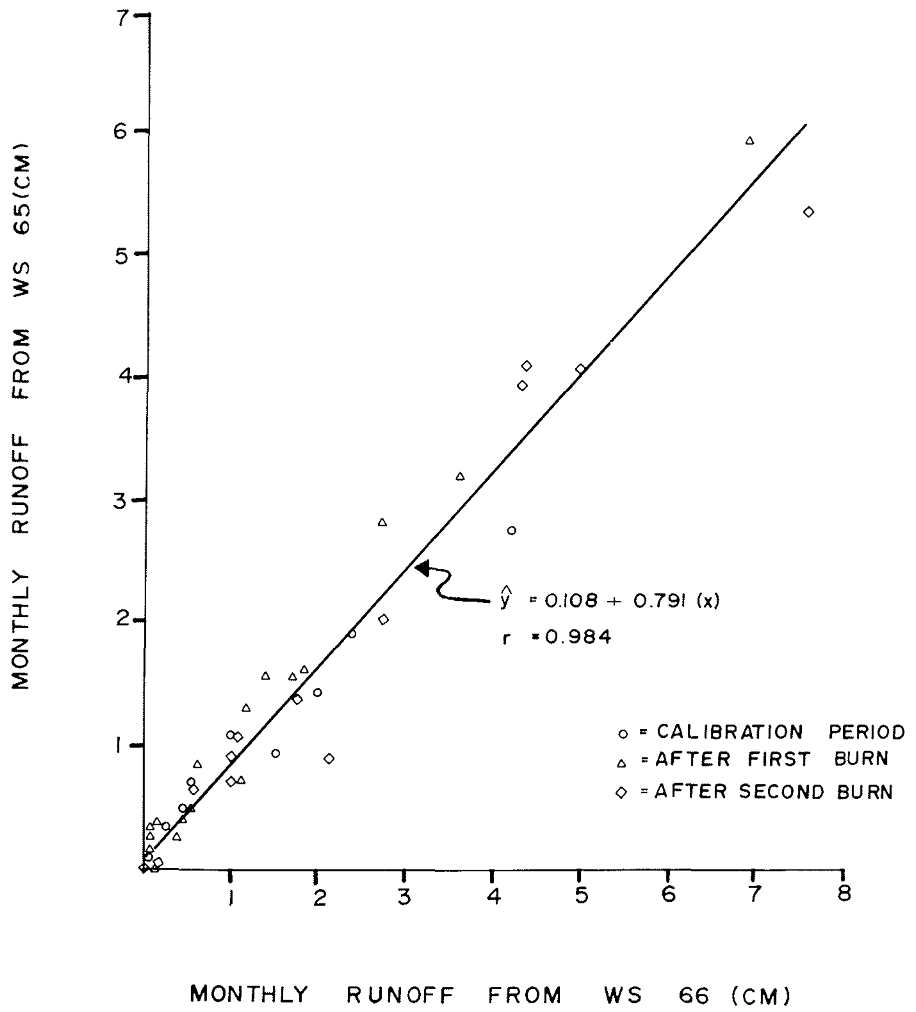

FIGURE 2. Monthly runoff from Watershed 65, a control watershed, was highly correlated with runoff from Watershed 66, which received two prescribed burns. Burning did not change the calibration relationship.

(223 lbs/acre) after the second burn compared to 22 kg/ha (25 lbs/acre) for the other seven watersheds and the increase in erosion from Watershed 68 is attributed to the beetle outbreak, not to burning. While the increase in export is significant, it is still well within the range of sediment yields observed for undisturbed forests of the Southeast (Douglass 1975, Ursic and Douglass 1978).

Because the mortality caused by the beetle outbreak produced a response that interfered with detection of a burning treatment effect, the analysis of variance was rerun omitting the data from Watershed 68 after the second prescribed burn; i.e., the period when stormflow increased on Watershed 68. This analysis confirmed the previous analysis that neither runoff, nor suspended sediment concentration, nor sediment export was changed by either prescribed burn.

Chemical Export.—Because the beetle kill that increased runoff and soil export from Watershed 68 also may have influenced chemical export, data from this watershed for the period after the second burn were omitted from the analysis.

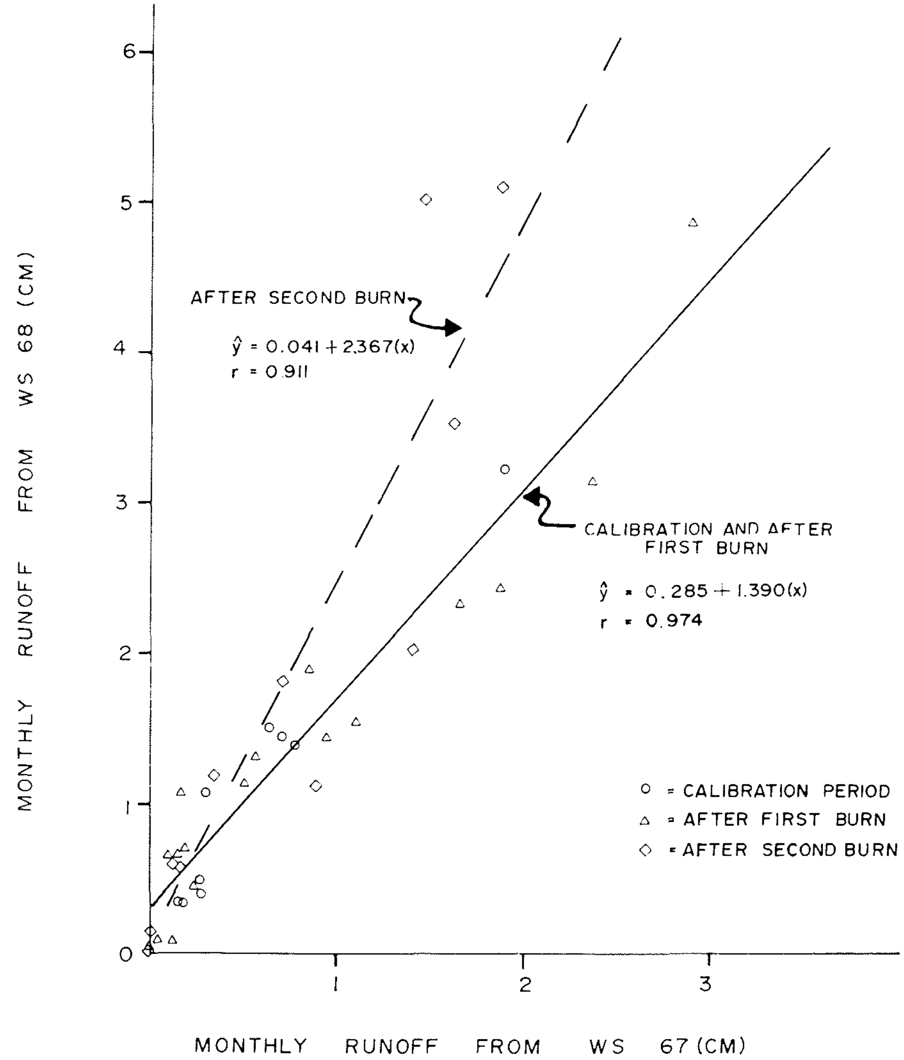

FIGURE 3. Runoff increased from Watershed 68, in relation to its control, after the second burn because southern pine beetles killed about 20 percent of the pine stand.

The mean weighted concentrations and exports of ions for all watersheds are presented in Tables 4 and 5 for periods before and after burning. Neither concentration nor export of Ca, Mg, K, NO_3-N, or NH_4-N differed significantly because of burning.

Export of PO_4-P and Na was not influenced by burning treatments. However, the concentrations of PO_4-P and Na differed significantly for treatment-control watershed pairs before but not after prescribed burning.

The difference in PO_4-P is probably due to contamination by field mice which built nests in the collection pans of the Coshocton wheel. These nests, not detected in the early part of the study, were high in phosphate. During runoff, leaching of nests contributed to the higher concentration of PO_4-P in the watersheds to be burned. Once detected, this source of contamination was corrected in subsequent

TABLE 4. Mean weighted concentrations of ions in runoff from burned and unburned watersheds in the Piedmont of South Carolina.

Period and treatment	NO_3-N	NH_4-N	PO_4-P	Ca	Mg	K	Na
Preburn period				*mg/l*			
Burned	0.02	0.04	0.011[1]	0.44	0.42	0.79	0.57
Unburned	.04	.05	.006	.57	.44	.90	.63[1]
After first burn							
Burned	.05	.07	.007	.63	.48	1.07	.60
Unburned	.05	.05	.004	.66	.49	.96	.53
After second burn							
Burned[2]	.05	.05	.021	.96	.49	1.04	.96
Unburned	.04	.06	.020	.90	.50	.95	.80

[1] Significantly higher at the 0.05 level.

[2] Excludes Watershed 68 because of bark beetle damage.

sampling. Although significant, the difference in PO_4-P concentration is quite small, averaging only 0.005 mg/liter (Table 4).

The significant difference in Na concentration between treatment and control watersheds before and not after burning is difficult to explain. Before burning, Na concentration of runoff from control watersheds was higher than from watersheds to be burned; Na concentration was less for the control watersheds after burning. Because the difference in concentration was just significant ($P > F = 0.04$), it could have occurred by chance. The lack of significant change in Na export after either burn supports this possibility. On the other hand, Lewis (1974) observed that prescribed burning of southern pine in the South Carolina sandhills significantly increased Na export in runoff and concentration in groundwater. He also found no increase in NO_3-N or PO_4-P export or in export of Ca, Mg, or K from plots even though burning significantly increased the free ion pool of these cations in the residual litter. Our results in the Piedmont are consistent with Lewis' findings in the sandhills, but we choose not to attach any meaning to the Na concentration data.

A final analysis was made to determine whether a difference in general level of ion concentration or export existed between periods; i.e., was there a time trend

TABLE 5. Nutrient export in runoff from burned and unburned watersheds in the Piedmont of South Carolina.

Period and treatment	NO_3-N	NH_4-N	PO_4-P	Ca	Mg	K	Mg
Preburn period				*kg/ha/yr*			
Burned	0.026	0.049	0.012	0.47	0.48	0.90	0.60
Unburned	.028	.036	.004	.38	.32	.70	.47
After first burn							
Burned	.069	.078	.009	.66	.57	1.31	.67
Unburned	.058	.057	.004	.63	.50	1.00	.56
After second burn							
Burned[1]	.058	.064	.027	1.27	.64	1.39	1.30
Unburned	.050	.071	.023	1.12	.61	1.16	1.08

[1] Excludes Watershed 68 because of the bark beetle damage.

Export of all ions from both burned and unburned watersheds increased with time. The length of record of chemical outflow is too short to know whether this increase with time signifies a change in biological activity and rate of nutrient cycling. The increase in export of ions studied could be due to chance or might indicate declining nutrient demands by the maturing pine forest. Definitive explanations will require additional study.

CONCLUSIONS

Two successive prescribed burns of pine forests in the Piedmont of South Carolina did not significantly increase sediment concentration or soil export. On one burned watershed, both sediment concentration and soil export were increased, but this effect was related to a bark beetle outbreak rather than to burning. No increase in concentration or export of NO_3-N, NH_4-N, PO_4-P, Ca, Mg, K, or Na occurred as a result of burning. It can be safely concluded that these two prescribed burns did not appreciably change water quality.

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