OAK MORTALITY TRENDS ON THE INTERIOR HIGHLANDS OF ARKANSAS

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Abstract—Using data from the U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis program, I studied mortality trends of oak (*Quercus* spp.) across four physiographic sections of the Interior Highlands in Arkansas. Surveys for 1978, 1988, and 1995 showed oak mortality levels of 3.9, 8.9, and 5.5 percent, respectively. Increases in mortality were strongly correlated with a major drought event in 1980 (reflected in the 1988 survey). The highest recorded mortality (1988 survey) was in the Arkansas Valley section. Other strata examined included ownership and stand-size classes. The highest mortality by ownership was on forest industry lands; by stand-size class, it was highest where diameters averaged ≥ 12.0 inches. Six oak species accounted for 95 percent of mortality. A high population resilience rate was evidenced by the rapid increase and decrease in oak mortality before and after the 1980 drought event.

INTRODUCTION

A recent outbreak of the red oak borer (*Enaphalodes rufulus* Haldeman) in Arkansas has raised interest and concern about oak mortality. Data currently available are not suitable to quantify the extent of infestation or the number of trees killed. However, U.S. Department of Agriculture (USDA) Forest Service, Forest Inventory and Analysis (FIA) data, which span three survey measurement periods, are available to quantify mortality trends prior to the borer outbreak. Although the most recent survey (dated 1995) predates the red oak borer outbreak, valuable information can be derived from older surveys to describe oak mortality patterns on the Interior Highlands of northwest and west Arkansas. By providing baseline data of mortality dynamics, it may be easier to put into perspective the extent of infestation now occurring in the oak component. With a better understanding of mortality dynamics, resource managers may better use silvicultural techniques to prevent, retard, or cope with mortality incidents (Nyland 1996). Little information has been reported about oak mortality patterns by physiographic regions, ownership, size class, and species.

I considered an area that includes the Interior Highlands of Arkansas (Fenneman 1938), where the oak-hickory forest type predominates. Oaks (*Quercus*) were the species of interest. A drought event in Arkansas in the early 1980s provided the opportunity to correlate oak mortality with drought during three survey periods (1978, 1988, 1995). I compared, over time, total oak mortality among Physiographic Sections (Fenneman 1938), ownership classes, and stand-size classes. I also examined mortality trends for select oak species.

METHODS

The inclusive area of the study is the Interior Highlands Physiographic Division (Fenneman 1938). In Arkansas, this Division includes four physiographic sections in two provinces: The Springfield-Salem Plateaus and Boston Mountains sections in the Ozark Plateaus Province and the Arkansas Valley and Ouachita Mountains sections in the Ouachita Province (fig 1).

The data of surveys conducted in 1978, 1988, and 1995 came from the USDA Forest Service, Forest Inventory and Analysis (FIA). Using geographic information system (GIS) software, I digitally traced the physiographic boundary lines of the four physiographic sections over a layer of FIA plot locations, thereby establishing the baseline data file to define FIA plots by physiographic strata. The scale of the map used to outline the physiographic boundaries was 1:7,000,000 (adequate for regional analysis).

The sample design for the three surveys consisted of sample plots located on a 3-mile by 3-mile grid. Only trees ≥ 5.0 inches in diameter at breast height (d.b.h.) were used in this study. These trees were tallied using a 37.5 basal area factor (B.A.F.) prism on 10 points dispersed over an area of 1 acre (see Rosson 2002 for more details on sampling methods in Arkansas).

Several plot- and tree-level attributes were sampled on each sample unit. Tree attributes important to this study were species, d.b.h., and tree history. Of particular interest in this study was tree history, which was used to identify mortality.

Because sample plots were remeasured, trees could be tracked over time and their history noted whether they were new trees, survivor trees, cut (removed) trees, or mortality trees (dead and standing, dead and broken off, or dead and completely down). Use of remeasured plots is one of the best techniques available to track tree mortality over time (Bonham 1989).

Mortality estimates were generated from weighted density data. Trees per acre (t.p.a.) was the metric used. The weighting was derived from the area factor—the amount of land area each plot represented. When weighting was applied, the resulting metric was the total oak population expanded by plot by strata.

Although it would seem that a dead tree could be easily identified, errors can be made. Because FIA data are collected

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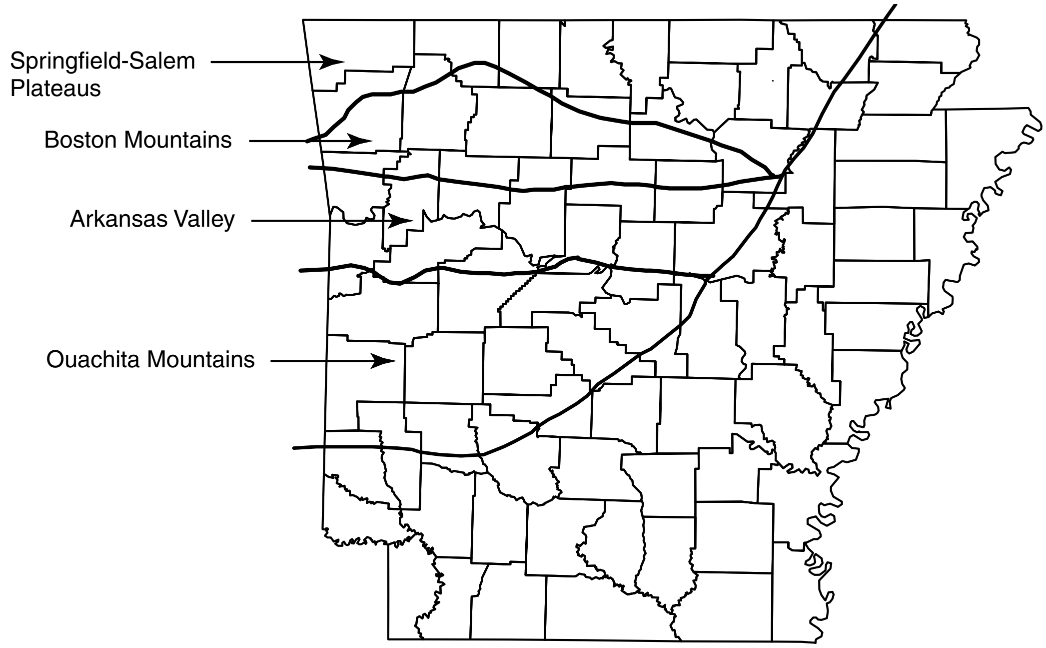

Figure 1—The four physiographic sections on the Interior Highlands of Arkansas (After Fenneman, 1938).

in all seasons, recently dead deciduous trees may escape detection from late fall through the end of winter. The assessment also may have missed trees that had died and were harvested between surveys; i.e., it was not possible to determine if a cut tree was dead or alive at the time of harvest. For these reasons, I chose not to include harvested trees in this study.

Tree measurement is another possible source of error. The d.b.h. of recently dead trees may be accurate, but those trees dead for a period of years may have fallen over, broken off, or the bole may be decayed to an extent that accurate measurement is not possible. In such cases, d.b.h. was derived from a model that estimates d.b.h. at the time of death. Time of death since the most recent survey was estimated in the field by the data collector. The d.b.h. model was only used to project from time of death the supposed growth of a living tree of the same size. This is important when sampling with variable radius plots because d.b.h. is used to determine tree density.

To evaluate changes in mortality, the average annual periodic mortality and annual periodic mortality rate were derived.

The average annual periodic mortality is,

$$AAPM = \left(\sum \left(N_d \times W_a / T \right) \right) / n \qquad (1)$$

where

AAPM = the average annual periodic mortality

N_d = the number of dead trees per acre per plot (by strata or species)

W_a = the area factor per plot

T = the elapsed time (in years) per plot between plot measurements

n = the number of sample plots per strata.

The AAPM is an estimator of the number of trees that died per strata or species for each survey period.

The annual periodic mortality rate is,

$$APMR = (N_{ld} \times W_a / N_d \times W_a) / T \times 100.0 \qquad (2)$$

where

APMR = the annual periodic mortality rate (in percent)

N_{ld} = the number of live and dead trees per acre per plot (by strata or species)

N_d = the number of dead trees per acre per plot (by strata or species)

W_a = the area factor

T = the elapsed time (in years) per plot between plot measurements.

The APMR is an estimator of the proportion of trees that died per strata or species.

Differences in oak mortality by physiographic type, ownership, and stand-size class were tested with a t-test procedure for the unplanned comparison of two means (Greig-Smith 1983, Kent and Coker 1992). This was derived by,

$$t_s = (\bar{y}_1 - \bar{y}_2) / \sqrt{SEM_1^2 + SEM_2^2} \qquad (3)$$

where

t_s = the t-statistic value

$\bar{y}_1$ = the mean of mortality at time 1

$\bar{y}_2$ = the mean mortality at time 2

SEM_1 = the standard error of the mean at time 1

SEM_2 = the standard error of the mean at time 2.

The tests were done at the 0.05 probability level.

RESULTS AND DISCUSSION

The Interior Highlands comprise 16.5 million acres in west and northwest Arkansas (fig. 1). Forty-two counties are included; 29 of them totally within the Physiographic Province and the remaining 13 partially inside the southern and eastern boundary line. A total of 10.2 million acres of timberland occur within the Interior Highlands (table 1).

The largest physiographic section is the Ouachita, which has 5.1 million acres of land area and 3.8 million acres of timberland. The largest ownership class is in nonindustrial

Table 1—Timberland area by Fenneman's Physiographic Sections and by ownership classes on the Interior Highlands of Arkansas[a]

Fenneman's Physiographic Section and Ownership Class	Total land area	Timberland area	n
	- - - *thousand acres* - - -		
Ouachita			
National forest		1,308.1	230
Public		136.1	25
Forest industry		1,201.3	212
NIPF		1,115.1	192
Total	5,073.6	3,760.6	659
Arkansas Valley			
National forest		161.1	30
Public		129.7	20
Forest industry		90.0	15
NIPF		1,344.1	214
Total	3,532.3	1,724.9	279
Boston Mountains			
National forest		738.8	131
Public		23.1	4
Forest industry		113.2	19
NIPF		1,510.6	258
Total	3,130.5	2,385.7	412
Springfield-Salem Plateaus			
National forest		125.6	26
Public		94.7	15
Forest industry		—	—
NIPF		2,091.5	333
Total	4,746.0	2,311.8	374
Interior Highlands			
National forest		2,333.5	417
Public		383.6	64
Forest industry		1,404.4	246
NIPF		6,061.3	997
Total	16,482.3	10,182.9	1,724

n = the number of timberland sample plots in each physiographic and ownership strata; NIPF = nonindustrial private forest; — = no sample plot.
[a] Area data is based upon plots measured in the 1995 survey.

private forest (NIPF), 6.1 million acres, followed by national forest, which is 2.3 million acres (table 1).

The average annual periodic mortality (AAPM) for all oaks sampled on the Interior Highlands increased from 1978 to 1988 and then fell to near the 1978 levels at the time of the 1995 survey (table 2). The largest increase in oak mortality was on the Arkansas Valley physiographic section, where the AAPM went from 954.1 to 5,306.7 trees per weighted plot, a highly significant change ($t_{0.05}$ = 6.60). The other physiographic sections also had significant increases in AAPM between 1978 and 1988, 1,081.0 ($t_{0.05}$ = 3.68), 2,499.5 ($t_{0.05}$ = 5.20), and 1,425.4 trees per weighted plot ($t_{0.05}$ = 2.73) for the Ouachita, Boston Mountains, and Springfield-Salem Plateaus sections, respectively.

The highest annual periodic mortality rate (APMR) was in the Arkansas Valley section in 1988, where 14.04 percent of all oaks died. The other sections also showed increases between 1978 and 1988, then returned to near their 1978 levels when the 1995 survey was conducted. There was no discernible pattern in the ranking of physiographic sections by APMR. The highest rankings by survey year were: the Springfield-Salem Plateau section, the Arkansas Valley, and the Boston Mountains for 1978, 1988, and 1995, respectively.

The patterns of AAPM by ownership and survey year were similar to those of the four physiographic sections. There was an increase between 1978 and 1988 followed by a decrease between 1988 and 1995 (table 3). There were no significant differences among ownerships in 1978. Specifically, there was no difference between national forest timberland and public timberland ($t_{0.05}$ = 0.52) nor was there a significant difference between forest industry and NIPF ($t_{0.05}$ = 1.17).

Statistically significant differences were evident between ownerships in 1988. The AAPM on national forest land increased to 3,883.5 trees per weighted plot, the highest of any ownership in the 3 survey years. National forest lands were significantly different from other public lands; 3,883.5 and 1,984.7 trees per weighted plot, respectively ($t_{0.05}$ = 2.81). There was a statistically significant difference between forest industry and NIPF lands, 2,071.4 and 3,766.4 trees per weighted plot ($t_{0.05}$ = 3.61). The 1995 survey showed that the AAPM had declined somewhat. Changes in AAPM by ownership between 1988 and 1995 were only significant for national forest ($t_{0.05}$ = 2.18) and NIPF timberland ($t_{0.05}$ = 4.30); other public and forest industry lands were not significantly different, $t_{0.05}$ = 1.11 and $t_{0.05}$ = 1.81, respectively. When comparing AAPM among ownerships within the 1995 survey, I found no difference between national forest and other public lands ($t_{0.05}$ = 0.36) but the difference between forest industry and NIPF was statistically significant ($t_{0.05}$ = 3.74). Additionally, there was no difference between national forest and NIPF lands in AAPM ($t_{0.05}$ = 0.94) or between other public lands and NIPF ($t_{0.05}$ = 0.76).

Stand-size classes were examined to discern differences among the size classes between years and within years (table 4). In 1978, there were no differences in the AAPM between the 5.0-7.9-inch and 8.0-11.9-inch classes ($t_{0.05}$ = 0.42); nor was there a difference between the 8.0-11.9- and the 12.0-15.9-inch classes ($t_{0.05}$ = 0.50) or the 12.0-15.9- and the ≥ 16.0-inch classes ($t_{0.05}$ = 0.33). As in the previous

Table 2—Average annual periodic mortality per plot and annual periodic mortality rate by year and Fenneman's Physiographic Sections[a]

Year	Fenneman's Physiographic Sections	Average annual periodic mortality	Annual periodic mortality rate	Variance of average annual periodic mortality	n
			percent		
1978	Ouachita	1,122.9	3.64	23,755,817.8	613
	Arkansas Valley	954.1	2.61	8,483,027.0	167
	Boston Mountains	1,834.0	3.87	18,770,468.8	302
	Springfield-Salem Plateaus	2,054.5	4.96	23,372,541.0	180
1988	Ouachita	2,203.9	8.16	31,112,018.5	657
	Arkansas Valley	5,306.7	14.04	99,604,425.9	265
	Boston Mountains	4,333.5	8.49	71,044,389.8	421
	Springfield-Salem Plateaus	3,479.9	7.15	51,183,438.2	357
1995	Ouachita	1,724.1	4.88	27,125,931.2	659
	Arkansas Valley	2,119.6	5.62	29,964,393.3	279
	Boston Mountains	3,071.4	6.12	40,688,129.3	412
	Springfield-Salem Plateaus	2,919.4	5.68	40,196,162.5	374

n = the number of timberland sample plots in each physiographic strata.
[a] The average annual periodic mortality is the number of trees per acre weighted by the area expansion factor each plot represents.

Table 3—Average annual periodic mortality per plot and annual periodic mortality rate by year and ownership class on the Interior Highlands[a]

Year	Ownership class	Average annual periodic mortality	Annual periodic mortality rate	Variance of average annual periodic mortality	n
			percent		
1978	National forest	1,505.5	3.45	17,264,299.1	387
	Public	1,245.2	4.23	8,333,702.2	40
	Forest industry	1,005.6	4.27	34,763,366.9	232
	NIPF	1,501.9	3.89	18,152,184.7	603
1988	National forest	3,883.5	9.04	69,280,316.1	416
	Public	1,984.7	5.67	17,147,416.7	59
	Forest industry	2,071.4	11.05	40,547,095.8	251
	NIPF	3,766.4	8.74	57,929,807.3	974
1995	National forest	2,775.2	5.81	37,901,590.2	417
	Public	3,101.7	7.07	46,059,335.8	64
	Forest industry	1,188.4	5.65	19,066,464.8	246
	NIPF	2,444.0	5.32	34,850,646.2	997

n = the number of timberland sample plots in each ownership strata; NIPF = nonindustrial private forest.
[a] The average annual periodic mortality rate per plot is the number of trees per acre weighted by the area expansion factor each plot represents.

Table 4—Average annual periodic mortality per plot and annual periodic mortality rate by year and stand-size class on the Interior Highlands[a]

Year	Stand-size class in inches at d.b.h.	Average annual periodic mortality	Annual periodic mortality rate	Variance of average annual periodic mortality	n
			percent		
1978	<5.0	0.0	0.00	0.0	68
	5.0 – 7.9	1,324.5	2.90	39,913,321.3	250
	8.0 –11.9	1,501.9	3.90	16,594,270.2	862
	12.0 –15.9	1,817.5	7.45	21,333,720.0	73
	?16.0	1,438.4	10.97	9,514,229.2	9
1988	<5.0	55.7	0.27	367,409.0	248
	5.0 – 7.9	3,457.9	8.94	52,296,977.3	306
	8.0 –11.9	4,324.8	9.60	69,783,893.8	1,029
	12.0 –15.9	3,364.1	11.22	48,486,792.1	100
	?16.0	3,668.8	27.91	50,125,944.4	17
1995	<5.0	818.9	4.77	12,284,125.3	131
	5.0 – 7.9	1,201.1	3.88	17,616,440.5	270
	8.0 –11.9	2,687.9	5.43	37,734,153.9	1,187
	12.0 –15.9	3,472.2	10.18	47,316,184.3	123
	?16.0	2,744.6	18.95	57,227,065.9	13

D.b.h. = diameter at breast height; n = the number of timberland sample plots in each stand-size strata. Note that some trees ?5.0 inches in d.b.h. may occur in the <5.0 inch stand-size class because the class is the average of all trees on the sample plot.
[a] The average annual periodic mortality rate per plot is the number of trees per acre weighted by the area expansion factor each plot represents.

physiographic and ownership tests, the 1988 survey showed a large increase in AAPM for all the stand-size classes, although no statistically different averages occurred among any of the classes. By 1995, the AAPM was still significantly different from what it had been in 1978 for the 8.0-11.9-inch stand-size class ($t_{0.05}$ = 4.02). The remaining size classes were not significantly different.

The APMR was highest for the largest stand-size class (≥ 16.0 inches d.b.h.). This class averaged 11, 28, and 19 percent mortality for 1978, 1988, and 1995, respectively; but the inferences were not as strong because of the small sample size (table 4). However, the magnitude of the APMR for this size class does support the notion that mortality rates will be higher in older stands when conditions of stress exist (Oliver and Larson 1990).

Six oak species accounted for 96 percent of the total oak density (trees ≥ 5.0 inches d.b.h.) on the Interior Highlands. The relative ranking of these oaks was *Quercus alba* (35 percent), *Q. stellata* (24 percent), *Q. velutina* (14 percent), *Q. rubra* (11 percent), *Q. falcata* (7 percent), and *Q. marilandica* (5 percent), and it remained the same throughout the three survey periods despite increases and decreases in mortality.

These six oaks also accounted for 95 percent of the total oak mortality (AAPM) for the three survey periods, although their ranking did shift somewhat between surveys. *Quercus alba* had the most trees die in 1978, accounting for 28 percent of total oak mortality. Following were *Q. velutina, Q. stellata, Q. rubra, Q. marilandica,* and *Q. falcata,* accounting for 20, 19, 12, 9, and 7 percent of total oak mortality. By 1988, the proportion of *Q. alba* mortality had decreased to 24 percent while *Q. velutina* increased to 24 percent. *Quercus velutina* led in the proportion of oak mortality in 1995 (23 percent) while *Q. alba* had declined even more (down to 18 percent), third in rank behind *Q. velutina* and *Q. stellata*.

There were shifts among species rankings depending on whether AAPM or APMR were used when estimating mortality. The AAPM provided information about the total number of trees that died, while the APMR revealed the proportion of a stratum or species that died. With regard to the latter, most oak death recorded in the 1988 survey occurred in *Q. alba*, although the proportion of that species' population to have died was only 6 percent (table 5).

The ranking of the six important oaks by APMR in 1978 was *Q. marilandica, Q. velutina, Q. rubra, Q. falcata, Q. alba,* and *Q. stellata* (table 5). *Quercus marilandica* led in all three surveys with 8, 21, and 15 percent APMR for 1978, 1988, and 1995, respectively.

Damage due to the 1980 drought was most apparent in the 1988 survey, but only a slight shift in species ranking occurred. *Quercus falcata* surpassed *Q. rubra*, 12 percent versus 8 percent, respectively. By 1995, the ranking was the same as in 1978 except that *Q. stellata* surpassed *Q. alba* (5 percent versus 3 percent, respectively).

Empirical data have depicted *Quercus* species mortality trends on the Interior Highlands of Arkansas since 1969. The data were analyzed by physiographic section, ownership, stand-size class, and species. There were significant

Table 5—Annual periodic mortality rate (percent) of select *Quercus* species on the Interior Highlands of Arkansas by survey year[a]

Species	1978	n	1988	n	1995	n
	%		%		%	
Quercus alba L.	3.03	70	6.48	205	2.90	92
Q. falcata Michx.	4.02	20	11.68	63	5.18	34
Q. falcata var. *pagodifolia* Ell.	3.59	3	18.64	9	13.61	5
Q. lyrata Walt.	12.51	3	4.88	3	3.24	4
Q. marilandica Muenchh.	7.67	29	20.86	91	14.72	66
Q. michauxii Nutt.	0.00	0	0.00	0	4.92	1
Q. muehlenbergii Engelm.	0.77	3	1.00	1	4.69	8
Q. nigra L.	2.52	1	5.19	11	7.36	6
Q. nuttallii Palmer	4.78	2	3.93	7	15.51	1
Q. palustris Muenchh.	0.00	0	6.90	3	0.00	0
Q. phellos L.	5.50	6	14.44	14	8.98	11
Q. rubra L.	4.07	50	8.28	112	7.18	105
Q. shumardii Buckl.	7.29	4	6.52	4	1.48	3
Q. stellata Wangenh.	2.99	56	6.40	133	4.62	106
Q. velutina Lam.	5.48	62	13.05	179	8.59	153

n = the number of sample plots where mortality was recorded for at least one *Quercus* species ?5.0 inches in d.b.h.

[a] Only *Quercus* species that occurred (live or dead) on at least five sample plots in any of the three survey years were included. Total n was 1,262 for 1978, 1,700 for 1988, and 1,724 for 1995.

differences among surveys for all categories. The most logical cause for these differences was the 1980 drought, which significantly increased tree mortality.

Despite increases in mortality in 1988, the *Quercus* population (trees ≥ 5.0 inches d.b.h.) increased across the Interior Highlands by 1995. Only one species of the highest ranking six oaks decreased—*Q. marilandica*. The highest AAPM by physiographic section was on the Arkansas Valley; the highest AAPM by ownership was on forest industry land; and the highest AAPM by stand size was in classes ≥ 12.0 inches, all in 1988. Overall, across the Interior Highlands, the *Quercus* APMR was 3.9 percent in 1978, 8.9 percent in 1988, and 5.5 percent in 1995.

Although FIA data cannot be used to test cause and effect hypotheses, correlation inferences between natural or man-induced disturbance events, and supporting data, can be quite strong. In this mortality study, strong, statistically significant increases in oak mortality were evident for the 1988 survey. Trees measured in 1988 reflected responses that occurred between 1978 and 1988. A period of drought occurred around 1980, early in the 1988 survey period. This left enough time for stressed trees to respond (death or survival). If the event had occurred closer to the end of the survey period, the response may not have been evident by the time of measurement and thus would not have been detected until the following survey measurement. This is one type of situation that makes strong cause-and-effect inferences difficult to interpret when using survey data.

Because mortality increased between 1978 and 1988 but had declined by 1995, it can be assumed that the drought, directly or indirectly, caused the increase in oak mortality reflected in the 1988 survey period. However, it is not known what constitutes a normal AAPM or APMR for oak on the Interior Highlands. If it can be assumed that the mortality levels for the 1978 survey period (years 1969 to 1978) are close to normal, then this study shows an increase in mortality in the 1988 survey followed by a fairly quick return to mortality levels reflected in the 1978 survey. This may indicate a high rate of population resilience to short-term stress when viewed at the macro scale of sampling (Begon and others 1986, Kimmins 1997).

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