Changes in Crappie Population Structure Following Restrictive Harvest Regulations[1]

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Abstract: Crappie *Pomoxis* spp. population structure on Arbuckle Reservoir was monitored from 1984–1997 using fall trap-net samples. A creel survey was conducted from 1985–1995. A 254-mm length limit/15-fish daily creel regulation was placed on the lake 1 January 1993. Prior to the length limit, the population was characterized as fast-growing and short-lived. Angler harvest steadily increased after the length limit and in the final year of the creel survey, yield (kg/ha) was higher than in 5 of the 8 years data were collected prior to the length limit. Angler acceptance of the length limit was high. Growth rates remained unchanged following implementation of the length limit. Although no differences in mortality rates could be demonstrated using the trap-net data, size and age structure of the crappie population improved. Based on the data collected, the length limit regulation met the objectives as stated.

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Historical crappie (*Pomoxis* spp.) management practices have focused on liberal harvest limits, mechanical removal, and commercial harvest to compensate for what managers perceived to be the tendency of crappie to overpopulate (Schneberger 1982, Hanson et al. 1983, Schramm et al. 1985). Overexploitation was generally not considered to be a management problem. However, with the increased number and proficiency of crappie anglers, the potential for higher exploitation rates has led to the adoption of restrictive size limits on crappie populations in the southeastern and midwestern United States over the past decade.

The ability of restrictive size limits to meet stated management objectives for crappie populations has varied. Colvin (1991*a*) found that peak yield occurred in Missouri reservoirs when crappie were harvested at age 3 and that a higher proportion of the harvest shifted to age-3 and older crappie following implementation of restrictive harvest regulations. RSD-P, defined as the proportion of fish ≥130 mm to

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Table 1. Mean lengths (mm) at the end of the growing season for crappie from fall trap-net samples at Arbuckle Reservoir, Oklahoma, 1984–1997.

Year	Age 1	2	3	4	5	6
1984	101	201	254			
1985	132	210	268	300		370
1986	110	179	279		355	
1987	101	218	256	275	250	
1988	106	204	275	274	370	
1989	165	237	276		297	370
1990	130	237	289	310	230	240
1991	128	224	287	279	310	
1992	160	236	276	330		
Mean	126	216	273	295	302	327
254-mm length limit						
1993		217	269	290	310	
1994	155	225	278	290	305	
1995	145	224	282	301	290	370
1996	87	223	275	301	307	313
1997	103	193	268	296	310	340
Mean	122	216	274	296	304	341

those that are ≥250 mm (Gabelhouse 1984), of crappie in 2 Texas reservoirs increased following implementation of a 254-mm length limit (Webb and Ott 1991). However, a 254-mm minimum length/15-fish daily creel limit regulation on Ft. Supply Reservoir, Oklahoma, was rescinded after 5 years because angler harvest rates failed to improve and anglers expressed a high degree of dissatisfaction with the regulation (Boxrucker 1999). Larson et al. (1991) and Reed and Davis (1991) recommended against the use of minimum size limits due to high rates of natural mortality in the populations that they studied.

The use of predictive models has demonstrated that an increase in yield following restrictive regulations occurs only under a relatively narrow set of population characteristics. Using a Jones modification of the Beverton-Holt equilibrium yield model (Ricker 1975), Allen and Miranda (1995) found that increasing yield by decreasing exploitation (μ) was the exception rather than the rule for crappie. By using published data from crappie populations across the southeastern and midwestern United States, Allen and Miranda (1995) stated that only under conditions of fast growth and low natural mortality would minimum length limits improve yield in crappie populations. Conditional natural mortality (*n;* Ricker 1975) averaged 49%in these studies, but ranged from 8% to 92%. Maceina et al. (1998), using the Beverton-Holt model, found that a 254-mm minimum length limit would increase yield of crappie on Weiss Lake, Alabama, only if conditional natural mortality rates were <35% and then anglers would have to accept decreased numbers of crappie in the creel in exchange for increased average weight.

It was believed that the crappie population on Arbuckle Reservoir fit these criteria. Growth rates were considered excellent by Oklahoma standards, with age-2 and age-3 crappie averaging 216 mm and 274 mm, respectively, in fall trap-net samples (Table 1). Exploitation rates were not estimated, consequently conditional natural mortality rates could not be determined. However, there was evidence from the creel surveys conducted prior to the length limit that anglers were influential in shaping crappie population structure (Boxrucker 1998).

The objectives of this study were to 1) determine if increases in angler catch and harvest rates (*N*/hour) along with yield (kg/ha) following the length limit could be demonstrated through creel survey estimates, 2) monitor changes in growth rates before and after the regulation, and 3) improve size structure by increasing RSD-P and increase the percentage of age-4 and older crappie in the population through the use of restrictive harvest regulations.

Methods

Arbuckle Reservoir is a 951–ha impoundment of Guy Sandy, Buckhorn, and Rock creeks located in southcentral Oklahoma. Construction was completed in 1967 and the reservoir is operated by the Bureau of Reclamation. Arbuckle Reservoir has a mean depth of 9.4 m and a maximum depth of 24.3 m, a shoreline development ratio of 5.4, and a secchi disk visibility of approximately 120 cm in the main pool in August. Littoral fish habitat consists primarily of submersed aquatic vegetation, rock, and some flooded timber in the upper ends of the creek channels. The shorelines are typically steep and consist largely of rock bluffs. The largemouth bass *(Micropterus salmoides)* population is characterized as dense with below average growth rates and is currently managed with a 330–406 mm slot length limit. White crappie *(P. annularis),* black crappie *(P. nigromaculatus)* and white bass *(Morone chrysops)* are the other major predators in the lake. Gizzard shad *(Dorosoma cepedianum),* threadfin shad *(D. petenense),* and sunfish (*Lepomis* spp.) are the principal forage species.

A non-uniform, daylight 9-month (March through November 1985–1995) roving creel survey was conducted to estimate angler catch and harvest. Twenty 10-hour days (13 weekend/7 weekday) were randomly creeled per season. Creel data presented are for anglers seeking crappie only. The creel survey was discontinued in 1996 due to personnel and equipment limitations.

Annual fall (October) trap-net samples were collected from 1984–1997. Trap nets were constructed from 2 183-cm wide by 91.5-cm high steel frames with 4 76-cm diameter hoops covered with 12.7-mm square mesh knotless nylon netting material. Each net had a 19.8-m long lead, 91.5 cm in depth constructed of 12.7-mm square mesh knotless nylon netting material. Nets were located at 10 fixed sampling stations and fished for 4 consecutive days for a total effort of 40 net-nights. Nets were run at approximately 48-hour intervals providing 20 samples per year. Catch rates (CPUE) were expressed as number of crappie per net divided by 2 (for 48-hour sets). Precision of the untransformed CPUE estimates was expressed using the coefficient of variation of the mean ($CV\bar{x}$; Cyr et al. 1992).

White crappie comprised approximately 80% of the crappie collected in the trap-net samples, with black crappie comprising the remainder. The data presented in this report are for both species combined. Totals lengths (mm) and weights (g) were taken on all crappie collected. Otoliths (sagittae) were removed from 20 crappie per available 20-mm length group for age analysis. Ages were assigned to all individuals in the sample using methods described by Ketchen (1950). Because the data were collected in the fall, ages referred to in this report reflect the number of growing seasons. Hence, the 1997 year class is referred to as age 1 in the fall 1997 samples.

Age-1 crappies were not fully recruited to the sampling gear (Colvin 1991*b*). Linear regression of $\log_e$-transformed CPUE+1 of age-1 crappie in year x to $\log_e$-transformed CPUE+1 of age-2 crappie in year x+1 indicated that CPUE of age-1 crappie was not representative of recruitment (R^2=0.03; P=0.57). Therefore, I defined recruitment as CPUE of age-2 crappie (Table 2). Recruitment in pre-length limit years (1984–1992) was compared to recruitment in post-length limit years (1993–1997) by testing the $\log_e$-transformed CPUE+1 using a repeated-measures split-plot analysis of variance (ANOVA); α=0.10. Log_e -transformed CPUE+1 of quality- (≥200 mm) and preferred-sized (≥250 mm) crappie for pre-length limit years was compared to post-length limit years using a repeated-measures split-plot ANOVA. Catch curves of age-2 and older crappie were used to calculate total annual mortality rates (A) after Ricker (1975). Based on mean length at age data (Table 1), the length limit protected age-2 crappie from harvest. Length-limit induced reductions in mortality should then have been most pronounced between ages 2 and 3. Sur-

Table 2. Catch rates (CPUE; N/net) with coefficient of variation of the mean ($CV_{\bar{x}i}$; in parentheses), total annual mortality rates (A), estimated from catch curves, and survival (S) from age 2 to age 3 of crappie from fall trap-net samples from Arbuckle Reservoir, Oklahoma, 1984–1997.

Year	$CPUE_{age2}$		$CPUE_{\geq 200mm}$		$CPUE_{\geq 250mm}$		A	S_{age2-3}
1984	0.46	(0.35)	0.89	(0.27)	0.45	(0.36)		
1985	4.15	(0.43)	7.57	(0.24)	2.29	(0.23)	50	
1986	10.40	(0.38)	3.19	(0.19)	0.88	(0.32)	49	8
1987	0.37	(0.32)	7.57	(0.33)	5.00	(0.30)	20	81
1988	3.38	(0.36)	2.55	(0.28)	0.87	(0.28)	29	0
1989	0.95	(0.20)	1.32	(0.19)	0.60	(0.22)	21	18
1990	3.52	(0.24)	4.65	(0.25)	1.83	(0.33)	33	50
1991	3.78	(0.22)	4.25	(0.21)	1.38	(0.20)	39	27
1992	4.20	(0.40)	5.90	(0.39)	2.83	(0.45)	41	40
254-mm length limit								
1993	3.18	(0.29)	3.48	(0.27)	1.35	(0.30)	37	20
1994	2.88	(0.30)	4.21	(0.30)	1.61	(0.36)	31	39
1995	2.45	(0.64)	3.95	(0.66)	2.05	(0.63)	33	42
1996	7.12	(0.26)	10.30	(0.30)	5.28	(0.32)	41	70
1997	2.18	(0.38)	3.65	(0.42)	2.30	(0.51)	29	27

vival of age 2 to age 3 was compared between pre-length limit and post-length limit years by dividing the CPUE of age 2 in year x by the CPUE of age 3 in year x + 1 after Ricker (1975; Table 2).

Beverton-Holt equilibrium yield models were used to compare predicted yield, using population data from the trap-net samples, to actual yield measured in the creel survey. Length at age data were averaged for the 9 pre-length limit years and the relationship was defined using the von Bertalanffy (1957) equation. Since samples were collected in October, ages were assigned as 1.5, 2.5, 3.5, etc. The length-weight relationship was also derived from the pre-length limit samples. The relationship between weight (W) and total length (TL) was $W=0.000001\ (TL^{3.4291})$. The constants used in the model were as follows:

$L\infty = 330.6$, where $L\infty$ is the maximum theoretical length;
$k = 0.592$, where k is the growth coefficient derived from the von Bertalanffy equation;
$t_0 = -0.311$, where t_0 is the hypothetical age at which the fish length would be 0.

Yields were modeled over ranges of exploitation from 0–0.6. Conditional natural mortality rates (n) used in the model were 0.25, 0.35, and 0.45. Since exploitation was not estimated and, as a result, conditional natural mortality could not be calculated, ranges of these values were used to compare predicted yield resulting from a 203-mm length limit (crappie smaller than this length are seldom found in angler creels when no length limit is imposed) and a 254-mm length limit.

Age and size structure of the crappie population were estimated from the trap-net samples. Age structure was defined as the percentage of crappie that were age-4 and older (excluding age 1). An age structure of 10% or higher is considered satisfactory (Boxrucker 1989). RSD-P was used as a measure of size structure, with a RSD-P $\geq$20% considered satisfactory (Boxrucker 1989).

A 254-mm minimum length limit with a 15-fish daily creel went into effect 1 January 1993. The statewide limit for crappie in Oklahoma is a 37-fish daily creel with no minimum length limit. The daily creel was reduced in concert with the length limit in response to anglers expressing the desire for a daily creel reduction. However, simulations based on pre-length limit creel data indicated that a 15-fish daily creel limit would not significantly reduce harvest.

Results and Discussion

Angler harvest of crappie at Arbuckle in 1993 was the lowest recorded since creel survey inception in 1985 (Fig. 1). Angler harvest declined during the first year of the length limit due to restricting harvesting of age-2 crappie without the protection of previous year classes. The reduction in harvest was also due to fishing pressure being the lowest recorded since 1985 (approximately 10,000 angler-hours; Fig. 1). The low level of fishing pressure in 1993 was part of a declining trend beginning in the late

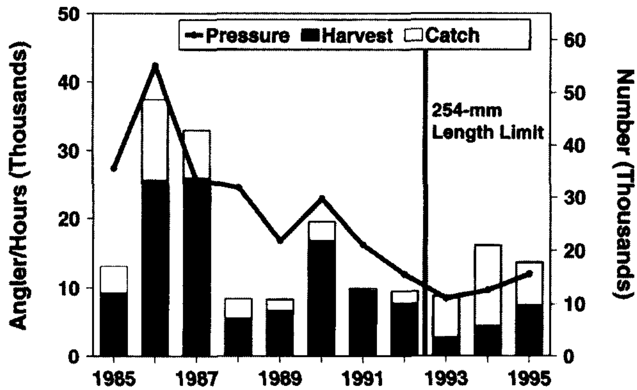

Figure 1. Angler pressure and catch and harvest (by number) of crappie from Arbuckle Reservoir, Oklahoma, 1985–1995.

1980s which led to concerns regarding the fishery and precipitated consideration of harvest regulations. Pressure increased slightly in 1994, but was still the second lowest recorded. Fishing pressure continued to increase in 1995, surpassing the 1992 estimate (the year prior to the length limit going into effect). Angler catch rates (*N*/hour) in 1993, 1994, and 1995 (1.4, 1.6, and 1.5, respectively) were among the highest recorded (Fig. 2). Harvest rates increased steadily following the length limit with the 1995 harvest rate (0.8 fish/hour) being comparable to the harvest rates in 1991 and 1992 (the 2 years prior to the length limit going into effect; Fig. 2). Yield (kg/ha) increased steadily during the post-length limit years (Fig. 2). Yield in 1995 was higher than 5 of the 8 pre-length limit years.

Although no formal angler opinion surveys relative to the acceptance of the

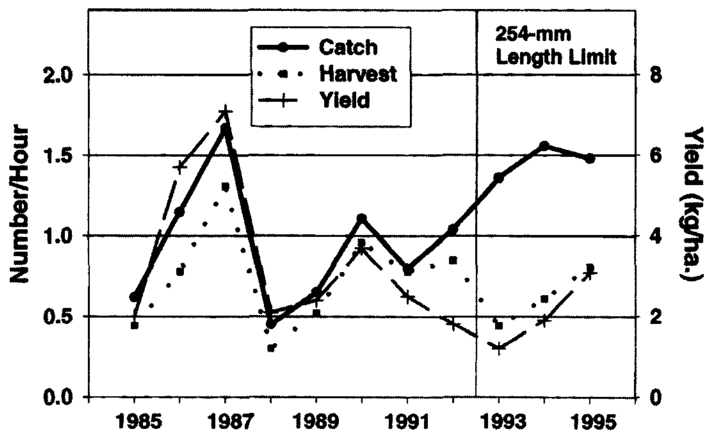

Figure 2. Angler catch and harvest rates (by number) and yield (kg/ha) of crappie from Arbuckle Reservoir, Oklahoma, 1984–1995.

length limit regulation were conducted, creel clerk contacts with anglers were overwhelmingly favorable. Few reports of dissatisfied anglers were received by game wardens and fisheries staff.

Increased abundance of the sizes of crappie protected by a length limit has the potential to decrease growth rates of that size fish. A decrease in growth rates can be counterproductive to the objectives of a length limit by delaying the age at which crappie enter the creel and increasing potential losses due to natural mortality. Mean lengths at age (ages 2–6) for pre-length limit years were no different than those from post-length limit years (Table 1; 1-way ANOVA; $\alpha=0.10$). Mean lengths at age for age-1 crappie from pre-length limit years and post-length limit years were not compared due to size selective bias of the sampling gear (discussed previously).

Age structure steadily increased post-length limit, exceeding the recommended level of 10% (Boxrucker 1989) in the 1995 (12%), 1996 (22%), and 1997 (18%) samples (Fig. 3). Age structure of pre-length limit samples was ≥ 10% in only 2 of 9 years (Fig. 3). RSD-P exceeded 30% in each post-length limit sample and approached 50% in 1995, 1996, and 1997 (Fig. 3). RSD-P fluctuated widely prior to the length limit, but stabilized in the post-length limit samples (Fig. 3). Webb and Ott (1991) also found an increase in RSD-P of crappie in 2 Texas Reservoirs following implementation of a 254-mm length limit.

Improvements in the size and age structure could not be explained by decreases in mortality rates as a result of the length limit. Total annual mortality (A) averaged 35.3% pre-length limit and 34.2% post-length limit (Table 2). Survival from age 2 to age 3 increased slightly after the regulation, averaging 32% in pre-length limit years and 40% in post-length limit years (Table 2). Estimates of A in this study were lower than those reported by Allen and Miranda (1995) and Allen et al. (1998). The mortality estimates should be viewed with caution because they were based on only 3 (ages 2–4) and occasionally 4 (ages 2–5) age classes.

The apparent contradiction between the data presented in Fig. 3 and the mortal-

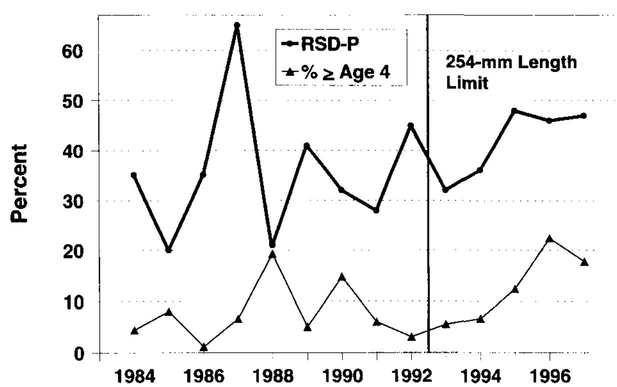

Figure 3. Size structure (RSD-P) and age structure (%≥age 4) of crappie from Arbuckle Reservoir, Oklahoma, 1984–1997.

ity estimates in Table 2 could be explained if crappie recruitment was higher in post-length limit years. Even if mortality rates remained unchanged following enactment of the length limit, higher recruitment could result in an increase in older and hence larger crappie in the population. However, no difference in recruitment (CPUE of age 2) between the pre- and post-length limit years was detected from the trap-net data (Table 2; repeated measures ANOVA; $F=0.32$; $df=1, 9$; $P=0.10$). The trap-net data did indicate that recruitment in pre-length limit years was more variable [variance $s^2=9.27$] than in post-length limit years ($s^2=4.10$). This may help explain the variable nature of the age and size structure data prior to the length limit (Fig. 3).

CPUE of both quality- and preferred-sized crappie did not change following implementation of the length limit (Table 2; repeated measures ANOVA; $F=1.96$; $df=1, 9$; $P>0.10$ for quality-sized fish and $F=2.5$; $df=1,9$; $P>0.10$ for preferred-sized fish). Precision of the CPUE data was low with $CV_{\bar{x}}$'s averaging 0.31 for quality-sized crappie and 0.35 for preferred-sized crappie (Table 2). Lake morphometry makes sampling crappie with trap-nets at Arbuckle Reservoir difficult. Arbuckle Reservoir is typical of Ozark-type impoundments found in eastern Oklahoma with clear water and steep rocky shorelines. This type of shoreline structure makes it difficult to set nets in areas of prime crappie habitat. Typical catch rates at Arbuckle Reservoir were <5 crappie/net (Table 2). These low catch rates may not be a true reflection of crappie abundance relative to other Oklahoma impoundments. Robson and Regier (1964) suggested that a 25% confidence interval around the mean would be an appropriate target for management studies. A $CV\bar{x}=0.125$ corresponds to this standard. Clearly, the trap-net data in this study fell short of this standard. However, precision of our CPUE data was similar to that reported from Kansas reservoirs by Guy et al. (1996) and Mississippi reservoirs by Miranda et al. (1990). Precision of our CPUE data may have been improved by increasing soak time of our nets. Webb and Ott (1992) found an increase in precision of crappie trap-net CPUE data by increasing soak time from 1 to 3 days. The mortality estimates may also be suspect due to the poor precision of the catch rate data used to generate them.

We found a significant station effect on CPUE in our analysis. Randomizing stations would remove this effect and could allow use of more powerful statistical tests for detecting treatment effects.

Using the Beverton-Holt Equilibrium Yield model provided us a tool to predict the outcome of the length limit over a range of exploitation and natural mortality rates (Fig. 4). Exploitation rates were not estimated in this study but ranged from 8%–84% in the literature (Allen et al. 1998). Previous exploitation estimates of crappie populations in Oklahoma were 8% at Sooner Reservoir (Angyal et al. 1987), 49%–53% at Skiatook Reservoir (Zale and Stubbs 1991), and 40% at Ft. Supply Reservoir (Boxrucker 1999). Accepting the estimate of A as 35%, the predicted yield from the regulation would be obtained from Figure 4A. Since conditional natural mortality is defined as the natural mortality rate in the absence of angling mortality (Ricker 1975), *n* would be expected to decrease with increasing exploitation. Since A=exploitation rate + natural mortality rate (Ricker 1975), it seems reasonable to assume that exploitation of the Arbuckle Reservoir crappie population would be

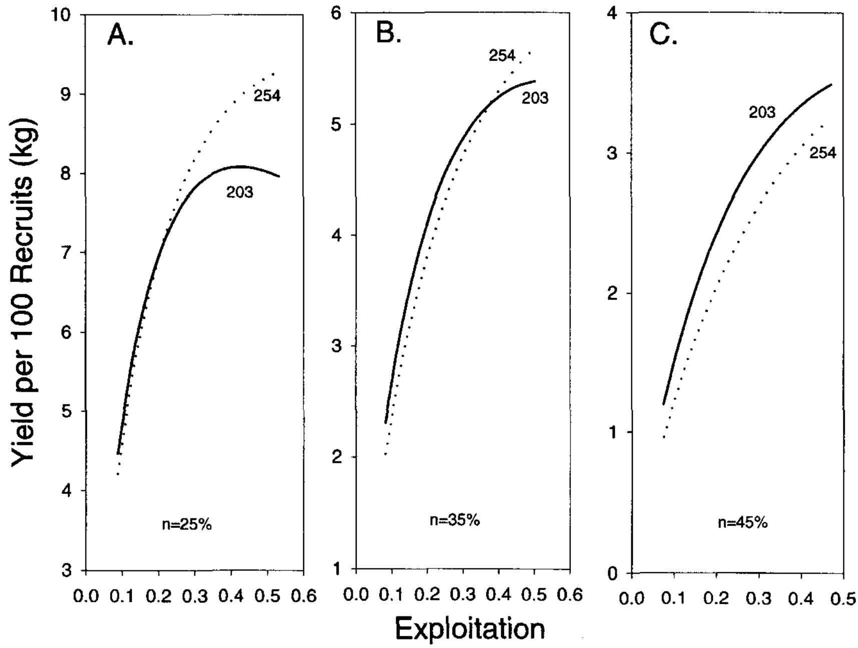

Figure 4. Predicted yield per recruit against exploitation over 3 levels of conditional natural mortality *(n)* in Arbuckle Reservoir, Oklahoma. Numeric values of 203 and 254 represent minimum length limits.

>0.2. Predicted yield increased at exploitation rates >25% with a 254-mm length limit (Fig. 4A). No increase in yield with a 254-mm length limit would be expected if $n \geq 35\%$, irrespective of the exploitation rate (Fig. 4B, 4C). Yield estimated from the creel survey in 1995 was higher than 5 of 8 years prior to the length limit (Fig. 2). Assuming that μ and n fell within the ranges previously discussed, the model accurately predicted increased yield as a result of the length limit. It was unfortunate that the creel survey could not be continued for the final 2 years of the study to see if the increasing trend to yield continued.

In spite of our inability to show decreases in total annual mortality rates resulting from the length limit, we concluded that the objectives of the study were met based on creel results and size and age structure improvements in the trap-net data. The population currently consists of older, larger fish than in pre-length limit years. Angler harvest by weight in 1995 surpassed 5 of the 8 years prior to the length limit. When our survey data were coupled with apparent angler acceptance of the length limit, we considered the objectives met and recommended continuation of the length limit regulation.

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