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Effects of a 40-Inch Minimum Length Limit on Muskellunge in Wisconsin

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Abstract.—Management agencies commonly use high minimum length limits for muskellunge *Esox masquinongy* to achieve the goal of trophy fisheries. Evaluations of length-limit effects on muskellunge populations have been limited. We evaluated the effects of a 40-in minimum length limit (total length) on seven northern Wisconsin lakes and compared the results to eight lakes that remained at the statewide minimum length limit of 32 or 34 in. Five years after its implementation, the 40-in minimum length limit did not increase adult muskellunge abundance or size structure compared with reference lakes. Variation among lakes dictates that low-density species such as muskellunge be monitored for extended periods and that reference waters also be monitored to aid interpretation of data and development of meaningful management recommendations.

Management strategies for muskellunge *Esox masquinongy* are most often directed toward establishing trophy fisheries (Hanson et al. 1986; Wingate 1986), and management agencies have used a variety of length, bag, and season limits to develop and maintain trophy muskellunge fisheries. However, the term *trophy* has been difficult to define. Angler definitions of trophy size may range from less than 30 in to more than 50 in, based largely on angler experience (all lengths herein are total lengths). Margenau et al. (1994) quantified the definition of a trophy muskellunge from an opinion survey for anglers who fish muskellunge in Wisconsin. Most anglers (98%) surveyed believed that a muskellunge needed to be at least 40 in to be a trophy, 50 in being the most common response (36%). Using information such as that provided by the angler survey, Wisconsin established, between 1990 and 1992, a 40-in minimum length limit for muskellunge in approximately 50 waters.

Evaluations of length limits for muskellunge are limited. This paucity of information is due, in part, to the naturally low density of adult muskellunge, which makes sampling and biological interpretation of results difficult (Hanson et al. 1986). Using information obtained from angler diaries, MacLennan (1996) declared that implementation of a 40-in length limit was successful in Lake St. Clair; i.e., relative abundance of fish in the protected length-group (30–40 in) increased 15% annually and the stock doubled in 7 years. Cornelius and Margenau (1999) used muskellunge population data collected over a 31-year period to monitor effects of increased length limits in Bone Lake, Wisconsin. Their results suggested that adult density of muskellunge increased with higher length limits, whereas condition of muskellunge decreased, probably because of intraspecific competition for food resources.

More evaluations such as those by MacLennan (1996) and Cornelius and Margenau (1999) are necessary to understand how muskellunge populations will respond to high minimum length limits under varying environmental conditions. Our objectives were to determine whether implementation of a 40-in minimum length limit for muskellunge would increase their population numbers (32–40 in and those longer than 40 in) in a variety of northern Wisconsin lakes. We were primarily interested in changes in adult population abundance and size structure but also considered growth rates.

Methods

We selected 15 study lakes across northern Wisconsin. Lake selection was nonrandom and based on several criteria, including the lake's historical potential for production of large fish, growth rates, and sampling logistics. Lakes ranged in size from 269 to 5,039 surface acres and had various his-

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TABLE 1.—Surface area, sampling year, growth index, and growth rate, and stocking history of muskellunge in 15 Wisconsin study lakes, 1988–1997.

Lake	Surface acres	Years sampled[a]	Growth index	Years to reach length					Stocking history
				Male		Female			
				30 in	34 in	30 in	34 in	40 in	
Treatment lakes									
Pine	312	1992, 1997	78.9	6.2	8.5	6.4	7.9	10.7	No stocking since 1975
Moose	269	1990, 1995	72.1	8.5		8.3			Annual fgl[b] stocking
Bone	1,781	1990, 1995	86.3	5.0	7.1	5.2	6.6	9.9	Annual fgl stocking
Papoose	428	1992, 1997	81.0	6.5		6.0	7.9	13.5	Alternate-year fgl
Two Sisters	705	1992, 1997							Alternate-year fgl; inconsistent year fry
Allequash	426	1990, 1995							No fgl stocking since 1989; no fry stocking since 1994
Big	850	1990, 1995							No fgl since 1991; fry stocked in 1995
Reference lakes									
Lake of the Pines	273	1992, 1997	70.1	7.8	10.6				Alternate-year fgl stocking
Lac Courte Oreilles	5,039	1992, 1997	85.2	5.4	7.9	5.3	7.2	12.9	Annual fgl and fry stocking
Deer	807	1988, 1993	85.8	5.7	8.0	5.2	6.8	10.5	Annual fgl stocking
Amnicon	426	1992, 1997	75.4	8.2		6.5	9.2		Alternate-year fgl stocking
Phillips Chain	1,236	1992, 1997	77.0	6.7	9.3	7.9			Annual or alternate-year fgl stocking
White Sand	728	1992, 1997							No stocking since 1987
North/South Twin	3,430	1991, 1996							No fgl since 1989; fry stocking in 1993, 1995
Little St. Germain	980	1992, 1997							Alternate-year fgl
Mean				6.7	8.6	6.4	7.6	11.5	
Standard deviation				1.3	1.2	1.2	1.0	1.6	
Number				9	6	8	6	5	

[a] Indicates first year of 2-year sampling period.

[b] fgl = fall young of the year, mean length 8–11 in total length.

tories of stocking muskellunge fry and fingerlings (Table 1). Lakes were separated into two groups: a treatment group for which a 40-in minimum length limit was implemented ($N = 7$) and a reference group for which lakes remained at the statewide minimum length limit ($N = 8$). The statewide minimum length limit was 32 in at the initiation of the study, but in 1995 was increased to 34 in. All study lakes were sampled during a pretreatment period (before length-limit change) and again 5 years following regulation implementation. All sampling occurred between 1988 and 1998 (Table 1).

We monitored abundance and length distribution of adult muskellunge, and although we had initially intended to monitor growth changes of muskellunge, difficulties in accurate interpretation of scale images (Fitzgerald et al. 1997) precluded the growth evaluation. We collected cleithrum bones from a sample of fish during the posttreatment period on nine of the study lakes. Cleithra, a major bone of the pectoral girdle, is a more reliable method for age determination of esocids (Casselman and Crossman 1986). From each lake we attempted to collect a maximum of 12 adult fish (6 of each sex) that we believed to be representative of that population's size structure. Growth information derived from cleithra was compared with a growth standard for the species (provided by Casselman and Crossman 1986) by calculating percentages of the standard.

Adult muskellunge were captured in two consecutive years using fyke nets during the spring spawning period (Hanson 1986). Electroshocking was used on some waters to supplement capture of muskellunge for population estimates, but fish sampled by electroshocking were not used for length-frequency comparisons. Muskellunge were measured to the nearest 0.1 in and marked with a finclip, preopercle (Johnson 1971), or anchor tag. When anchor tags were used, fish were either double-tagged or also given a finclip. It was assumed that with the marks used, loss of a mark over the 1-year period was negligible. Sex of muskellunge was determined (when possible) by presence of eggs or milt, or by visual inspection of the uro-

TABLE 2.—Total number of adult muskellunge handled, number handled and percent (in parenthesis) 30 in or longer, population estimate (≥30 in), coefficient of variation (CV = 100 × SD/mean), density, and change in abundance in 15 Wisconsin study lakes, 1988–1997. Treatment lakes were subject to a 40-in minimum length limit; the statewide minimum of 32 in or 34 in applied to reference lakes.

		Pretreatment				
Lake	Years sampled[a]	Number handled	Number ≥30 inches	Population estimate	CV	Density (number/acre)
Treatment lakes						
Pine	1992, 1997	95	71 (75)	56	14.0	0.18
Moose	1990, 1995	148	60 (41)	135	20.5	0.50
Bone	1990, 1995	631	573 (91)	1,114	10.4	0.63
Papoose	1992, 1997	221	199 (90)	161	8.1	0.38
Two Sisters	1992, 1997	102	94 (92)	93	14.0	0.13
Allequash	1990, 1995	69	62 (90)	101	25.0	0.24
Big	1990, 1995	377	275 (73)	369	11.9	0.43
Mean						0.36
SD						0.18
Reference lakes						
Lake of the Pines	1992, 1997	110	81 (74)	176	28.9	0.64
Lac Courte Oreilles	1992, 1997	260	241 (93)	454	15.3	0.09
Deer	1988, 1993	350	331 (95)	755	16.0	0.94
Amnicon	1992, 1997	218	144 (66)	390	27.1	0.92
Phillips Chain	1992, 1997	159	129 (81)	188	21.9	0.15
White Sand	1992, 1997	155	135 (87)	153	14.1	0.21
North/South Twin	1991, 1996	390	313 (80)	1,399	12.7	0.41
Little St. Germain	1992, 1997	73	51 (70)	462	24.8	0.47
Mean						0.48
SD						0.33
Total (all lakes)		3,358	2,759			
Mean						0.42
SD						0.27

[a] Indicates first year of 2-year sampling period.

genital pore (LeBeau and Pageau 1989); those that could not be classified (unknowns) were considered mature if they were as long as the smallest sexually mature female for that water or 30 in or longer. Fish of unknown sex constituted a small portion of the total muskellunge handled.

Abundance of adult muskellunge was estimated using the Bailey modification of the Petersen method (Ricker 1975). We determined abundance of adult muskellunge 30 in or longer because of a systematic bias in sampling fish less than 30 in (Hanson 1986). Muskellunge captured in the first year made up the marking sample, and those in the second year composed the recapture sample. Numbers in the recapture sample were adjusted for recruitment over a 1-year period using sex-specific and lake-specific growth rates determined from cleithrum or scale interpretation. We recognized the limitations of using scale interpretations for recruitment adjustments, but this error was not expected to change the overall study results. For populations with a considerable portion of adult fish smaller than 30 in (e.g., Moose Lake), the number of muskellunge 30 in or longer was determined by multiplying the proportion of muskellunge 30 in or longer handled in the marking sample times the abundance estimate for mature fish 20 in or longer.

Length-frequency distributions for muskellunge captured during the marking period were compared with the recapture period using a Kolmogorov–Smirnov test. Where differences in distributions were not significant, the 2 years were pooled. Where differences occurred, the data were reviewed to identify possible bias and to determine which year best represented the length distribution. Differences typically occurred when one of the sampling years targeted another species (e.g., walleye *Stizostedion vitreum*) so that sampling effort focused on habitats other than those sampled when muskellunge were the primary target species. Length-frequency distributions were summarized using relative stock density (RSD; Anderson and Gutreuter 1983), where 30 in was stock size (Hanson 1986).

We used two-sample *t*-tests (pooled variances) to compare pre and posttreatment abundance between treatment groups. We $\log_{10}$-transformed the

TABLE 2.—Extended.

	Posttreatment					
Lake	Number handled	Number ≥30 inches	Population estimate	CV	Density (number/acre)	Percent change
Treatment lakes						
Pine	93	62 (67)	52	16.5	0.17	−7
Moose	100	33 (33)	106	30.3	0.39	−22
Bone	837	815 (97)	1,772	9.4	0.99	59
Papoose	85	69 (81)	78	16.9	0.18	−52
Two Sisters	148	127 (86)	248	21.7	0.35	167
Allequash	65	59 (91)	132	35.9	0.31	31
Big	336	236 (70)	457	15.5	0.54	24
Mean					0.42	29
SD					0.28	71
Reference lakes						
Lake of the Pines	118	75 (64)	106	17.3	0.39	−40
Lac Courte Oreilles	193	183 (95)	240	12.6	0.05	−47
Deer	354	345 (97)	717	13.7	0.89	−5
Amnicon	193	133 (69)	195	17.7	0.46	−50
Phillips Chain	205	141 (69)	251	21.5	0.20	34
White Sand	67	55 (82)	88	30.6	0.12	−43
North/South Twin	1,184	1,147 (97)	1,758	5.8	0.51	26
Little St. Germain	175	119 (68)	178	19.9	0.18	−62
Mean					0.35	−23
SD					0.27	37
Total (all lakes)	4,153	3,599				
Mean					0.38	
SD					0.27	

abundance estimates to stabilize variances; thus, the data for the test were differences between periods in $\log_{10}$-transformed abundance estimates. We also used paired *t*-tests to compare pre and posttreatment abundance estimates within treatment groups. Changes in size structure were evaluated with a two-sample *t*-test using the difference between periods in untransformed RSD values. Linear regression was used to estimate the relationship between growth (percent of the growth standard) and population size structure (RSD). A critical value of $\alpha = 0.05$ was used for all statistical analysis.

Results

We sampled more than 7,500 adult muskellunge during the study period. The number of muskellunge handled in individual lakes ranged from 65 to 1,184 (Table 2). Most were longer than 30 in (85%), but in some lakes as few as 33% of the adult population were longer than 30 in (Table 2).

Mean density of adult muskellunge (≥30 in) in all lakes was 0.42/acre during the pretreatment period and 0.38/acre during the posttreatment period (Table 2). Density of adult muskellunge during the study ranged from 0.05/acre to 0.99/acre. Average adult density in the treatment lakes did not change significantly during the study ($t = 0.87$, df = 6, $P = 0.42$). Similarly, average adult density in reference lakes did not change significantly during the study ($t = 1.93$, df = 7, $P = 0.10$). Adult muskellunge numbers increased an average of 29% in treatment lakes and decreased 23% in reference lakes, though the response was quite variable in both groups. Treatment lake abundance changes ranged from −52% to 167%; reference lakes responses ranged from −62% to 34% (Table 2). Muskellunge in four treatment lakes increased in abundance and decreased in abundance in three lakes. In comparison, muskellunge in two reference lakes increased in abundance and in six lakes decreased in abundance. Because the changes were in opposite directions, the difference in population change between treatment and reference lakes was of borderline significance ($t = 1.88$, df = 13, $P = 0.08$).

Mean (the proportion of fish of stock length 30 in that are 34 in or longer) RSD-34 for all lakes was 54 during the pretreatment period, 59 during the posttreatment period, and ranged from 2 to 83 (Table 3). Mean RSD-40 was 10 during the pre-

TABLE 3.—Relative stock density (RSD) under length limits of 34 and 40 in and 95% confidence intervals (in parentheses) of adult muskellunge in 15 Wisconsin study lakes, 1988–1997. Stock densities were computed using 30 in as minimum stock length.

	Sexes Combined				Males	
	RSD-34		RSD-40		RSD-34	
Lake	Pre	Post	Pre	Post	Pre	Post
Treatment lakes						
Pine	34 (11)	39 (12)	7 (6)	2 (4)	33 (15)	27 (14)
Moose	2 (4)	18 (13)	0	0	7 (11)	15 (24)
Bone	65 (4)	75 (3)	9 (2)	10 (2)	56 (5)	67 (4)
Papoose	65 (7)	74 (10)	7 (4)	6 (6)	60 (8)	71 (15)
Two Sisters	79 (8)	52 (9)	9 (6)	17 (7)	52 (12)	42 (12)
Allequash	77 (10)	76 (11)	29 (11)	20 (10)	71 (16)	69 (17)
Big	69 (5)	50 (6)	13 (4)	7 (3)	60 (8)	40 (10)
Mean (SD)	56 (28)	55 (22)	11 (9)	9 (7)	44 (22)	47 (22)
Reference lakes						
Lake of the Pines	32 (10)	55 (11)	4 (5)	5 (6)	24 (13)	46 (16)
Lac Courte Oreilles	71 (6)	83 (5)	22 (5)	36 (7)	58 (8)	81 (8)
Deer	63 (5)	78 (4)	10 (3)	8 (3)	49 (7)	68 (6)
Amnicon	27 (7)	25 (7)	1 (2)	2 (3)	20 (9)	14 (8)
Phillips Chain	71 (8)	57 (8)	17 (6)	23 (7)	50 (12)	39 (12)
White Sand	68 (8)	78 (11)	10 (5)	40 (13)	63 (10)	76 (17)
North/South Twin	37 (5)	59 (3)	3 (2)	6 (1)	29 (6)	40 (4)
Little St. Germain	49 (14)	68 (8)	8 (9)	16 (7)	43 (16)	58 (13)
Mean (SD)	52 (18)	63 (19)	9 (7)	17 (15)	42 (16)	53 (22)
All lakes						
Mean (SD)	54 (23)	59 (20)	10 (8)	13 (12)	45 (18)	50 (22)

treatment period, 13 during the posttreatment period, and ranged from 0 to 40 (Table 3). Adult muskellunge RSD-34 remained similar for treatment groups during the treatment period ($t = 1.57$, df = 13, $P = 0.14$), even though reference lakes had a mean positive shift of 11, whereas treatment lakes decreased by 1 (Table 3). Large muskellunge (RSD-40) differed significantly ($t = 2.13$, df = 13, $P = 0.05$) as reference lake mean RSD-40 increased by 8, whereas mean RSD-40 in treatment lakes decreased by 2. The change in RSD-40 was the result of a significant increase in female RSD-40 in reference lakes of 9 whereas treatment lake RSD-40 decreased by 6 ($t = 2.64$, df = 13, $P = 0.02$). Male RSD-40 remained similar during the treatment period ($t = 0.98$, df = 10, $P = 0.35$). RSD-34 changes in treatment lakes ranged from −27 to 16 and from −14 to 23 for reference lakes (Table 3).

It took an average of 6–7 years for muskellunge in our study lakes to reach 30 in (Table 1). Female muskellunge reached 34 in in 7.6 years (SD = 1.0, $N = 6$ lakes) compared with 8.6 years (SD = 1.2, $N = 6$ lakes) for male muskellunge (Table 1). Female muskellunge reached 40 in in an average of 11.5 years (SD = 1.6, $N = 5$ lakes; Table 1). Growth rates of muskellunge positively affected muskellunge population size structure. Growth index values were significantly related to size structure (RSD-34) in both pre- and posttreatment periods ($r^2 = 0.58$, df = 7, $P = 0.02$). However, percent of large fish (RSD-40) was not related to growth ($r^2 = 0.21$, df = 7, $P = 0.22$). The absolute change in RSD values was also not related to growth (RSD-34: $r^2 = 0.001$, df = 7, $P = 0.92$; RSD-40: $r^2 = 0.04$, df = 7, $P = 0.60$).

Discussion

Implementation of a 40-in minimum length limit on muskellunge did not increase the number of adult muskellunge 30 in or longer, so RSD did not change. Expected results of increased length limits would be increased abundance of fish below the established length limit, in this case 40 in, and an associated increase in the average length of fish.

Providing an explanation of the lack of muskellunge population response among lakes in our study is difficult because numerous factors are probably interacting. Mechanisms that can mask the effect of length limits include variation in recruitment and mortality. Recruitment is affected by stocking of cultured fish, natural reproduction, and growth. Mortality factors include natural deaths in the population and deaths from fishing.

Stocking scenarios differed considerably among lakes and over time. Lake managers set stocking

TABLE 3.—Extended.

Lake	Males		Females			
	RSD-40		RSD-34		RSD-40	
	Pre	Post	Pre	Post	Pre	Post
Treatment lakes						
Pine	0	0	35 (16)	58 (19)	15 (12)	4 (10)
Moose	0	0	16 (15)	20 (21)	0	0
Bone	1 (1)	2 (1)	79 (5)	88 (3)	20 (5)	21 (4)
Papoose	0	0	78 (10)	77 (15)	22 (10)	10 (12)
Two Sisters	0	5 (6)	95 (8)	68 (12)	20 (12)	33 (12)
Allequash	6 (10)	3 (8)	84 (13)	86 (15)	53 (17)	36 (18)
Big	1 (2)	0	79 (7)	62 (8)	28 (8)	12 (6)
Mean (SD)	1 (2)	1 (2)	67 (29)	66 (23)	23 (16)	17 (14)
Reference lakes						
Lake of the Pines	2 (6)	0	44 (16)	64 (16)	6 (9)	11 (12)
Lac Courte Oreilles	8 (4)	12 (6)	91 (6)	99 (3)	45 (10)	73 (10)
Deer	0	0	84 (6)	93 (4)	25 (7)	19 (7)
Amnicon	0	1 (3)	39 (12)	42 (14)	2 (4)	4 (6)
Phillips Chain	3 (6)	2 (6)	95 (9)	74 (10)	44 (15)	42 (11)
White Sand	1 (3)	16 (17)	78 (12)	80 (14)	26 (13)	60 (18)
North/South Twin	0.4 (1)	1 (1)	62 (11)	84 (3)	12 (7)	12 (3)
Little St. Germain	6 (9)	4 (6)	60 (25)	77 (10)	13 (21)	27 (11)
Mean (SD)	3 (3)	5 (6)	69 (21)	77 (18)	22 (16)	31 (25)
All lakes						
Mean (SD)	2 (3)	3 (5)	68 (24)	71 (20)	22 (16)	24 (21)

quotas for individual lakes to establish or sustain the muskellunge fishery in that water. Annual hatchery production of muskellunge fingerlings is also quite variable and affects stocking density and frequency. How these quotas are modified and how well stocked fish survive can affect the adult muskellunge population years later. The release of one muskellunge cohort can alter size structure of the adult population at different time intervals as they recruit into different size groups.

The time required for a fish population to respond to a regulation change is determined by longevity of the affected species and should be taken into account when designing evaluations. Length-limit evaluations for warmwater species are commonly less than 5 years (Serns 1978; Paragamian 1984; Webb and Ott, Jr. 1991; Lyons et al. 1996; Slipke et al. 1998), unless special conditions allow for longer evaluations (Kempinger and Carline 1978). Short evaluations are probably due to combinations of factors, including the biology of the species evaluated, time or logistical constraints, or political limitations. In our study the statewide minimum length limit for muskellunge was increased from 32-in to 34-in 2 years following the implementation of the 40-in length limit on the majority of study lakes. This change probably neutralized the treatment effects for at least 1 year because fish from all lakes recruited to the new minimum length limit. In five of our study lakes growth projections suggested it would take approximately 4 years for female muskellunge to grow from 34 to 40 in. Hence, a 5-year evaluation was an absolute minimum and was probably too brief to allow muskellunge populations to respond to a regulation change. Long-lived species that occur in low numbers, such as muskellunge, require longer periods to detect biological responses resulting from regulations such as length limits. Cornelius and Margenau (1999), who used data collected over 31 years to demonstrate effects of length limits on muskellunge size structure and population abundance in Bone Lake (included in this study), also showed negative effects, such as lower fish condition. Our study period was limited to 5 years and may not have allowed some populations time to fully respond to the regulation change.

Mortality from fishing can affect abundance and size structure. The only significant drop in size structure we observed was for large female muskellunge. In four treatment lakes RSD-40 declined, in two lakes RSD-40 remained unchanged, and in one lake RSD-40 increased. Most muskellunge anglers consider a trophy muskellunge to be at least 40 in (Margenau et al. 1994). Imposing a 40-in minimum limit may attract more anglers who feel their chance of catching a trophy is greater in these lakes. Margenau et al. (1994) found that a lake's potential for large trophy muskellunge is an important reason why anglers select a water to fish. Cornelius and Margenau (1999) found that size structure declined in Bone Lake shortly after a length-limit increase and attributed the decrease to increased angling pressure and harvest that may have resulted from the uniqueness of a higher length limit. Similarly, Clady and Campbell (1975) found a significant reduction in large smallmouth bass *Micropterus dolomieu* due to increased angling pressure following the imposition of a high length limit.

Conversely, length limits imposed by anglers for social reasons could increase size structure and abundance of muskellunge populations. Many anglers probably practice live release of fish that were longer than the statewide length limit (32 or 34 in) but less than a size they would consider a trophy. Simonson and Hewett (1999) found that fishing effort increased and harvest rates declined during the 1980s and 1990s.

When examining length-limit changes, natural and anthropogenic variability in fish populations requires replication (multiple waters) of treatment and reference lakes. Single lake case histories can lead to erroneous conclusions. Buynak et al. (1991) found that effects from a regulation change for largemouth bass *Micropterus salmoides* could not be separated from effects that may have resulted from changes in water quality. For example, adult muskellunge abundance in Two Sisters Lake increased 167% while in Papoose Lake adult muskellunge declined 52%. Replication helps account for such variability and leads to more conclusive results.

Management Implications

To better determine effects of regulation changes such as minimum length limits on muskellunge populations, long-term monitoring using established protocols is needed. Natural low abundance and longevity of adult muskellunge can cause considerable uncertainty in understanding the effects of minimum length limits on muskellunge population density and size structure. Such population dynamics suggest that, compared with other species, longer periods may be needed for muskellunge populations to respond and stabilize following changes in management strategies. Short-term evaluations may show an initial response to the change, but in some cases the long-term effects (not always a benefit) may be masked. In addition, some short-term responses may lead to erroneous conclusions regarding a regulation change, such as an initial increases in angling pressure following implementation of higher length limits, which eventually subsides.

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