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Age and growth of pallid sturgeon in the free-flowing Mississippi River

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Summary

Trotlines were used to capture pallid sturgeon in the free-flowing Mississippi River, which extends from the Gulf of Mexico to the mouth of the Missouri River. Trotlines were baited with worms, and set overnight usually along the channel border. The pectoral fin rays of 165 pallid sturgeon caught in the Mississippi River were aged; 118 were from the lower Mississippi River (LMR) between the Gulf and mouth of the Ohio River, and 47 were from the middle Mississippi River (MMR) between the mouths of the Ohio and Missouri rivers. Initial agreement within ±1 year between two readers ranged from 53% for the LMR specimens, which were read first, to 84% for the MMR. Final age was agreed upon by both readers. For LMR pallid sturgeon, final age estimates ranged from 3 to 21 years with a mean (±SD) of 11.0 ± 4.7. For MMR pallid sturgeon, final age estimates ranged from 5 to 14 years with a mean of 9.5 ± 2.1. Seven pallid sturgeon marked with coded wire tags (CWT), indicating hatchery origin, were collected in the MMR. Age estimates for CWT fish were 7–8 years representing 1997 stocked fish, and 11–12 years representing 1992 progeny stocked in 1994. Von Bertalanffy growth equations for length indicated that pallid sturgeon in the MMR had higher growth rates for a given age than pallid sturgeon in the LMR. However, there were no significant differences (ANOVA, $P > 0.5$) in the length–weight relationships between reaches. In the LMR, pallid sturgeon fully recruited to trotlines at age 11 and instantaneous total mortality (Z; slope of catch curve) was estimated at -0.12 ($n = 10$ year classes, $r^2 = 0.55$, $P = 0.01$). Of the 118 sectioned rays from the LMR, 28 could not be reliably aged (only one section from the MMR could not be aged). Therefore, age was predicted from length using the von Bertalanffy equation. The catch curve was re-calculated using the predicted ages of the 28 pallid sturgeon in the LMR resulting in $Z = -0.07$. In the MMR, pallid sturgeon fully recruited to trotlines at age 9 and Z was estimated at -0.36 ($n = 6$ year classes, $r^2 = 0.67$, $P = 0.04$), which was significantly higher (ANOVA, $P = 0.04$) than the LMR estimate. Higher mortality in the MMR may be due to habitat limitations compared to a larger, more diverse channel in the LMR, and incidental take of larger, older individuals during commercial harvesting of shovelnose sturgeon. Commercial take of shovelnose does not occur in the LMR except in the northern portion of the reach. Considering the presence of pallid sturgeon with CWT, recruitment of older individuals in the MMR may have been influenced by stocking a decade earlier. Management strategies for this endangered species should consider the differences in mortality rates among reaches, the impacts of commercial fishing on recovery of pallid sturgeon in the MMR, and the long-term effects of hatchery fish now recruiting into the free-flowing Mississippi River.

Introduction

Pallid sturgeon (*Scaphiryhnchus albus*) are long-lived fish with a broad distribution in the Mississippi River basin. They occur throughout the Missouri River, albeit at low abundance, including the impounded reaches above Gavin's Point Dam and the lower Missouri River (Bailey and Cross, 1954; Dryer and Sandvol, 1993). Information on age and growth of pallid sturgeon are based principally on observations of adults in the Missouri River. Individuals from the northern part of the range are known to attain 167 cm total length (TL) and 31 kg, although adults 53–88 cm TL are probably typical (Carlander, 1969; Lee, 1980; Kallemeyn, 1983). Age of one individual in the upper Missouri River measuring 140 cm (fork length, FL) and 17 kg was estimated at 41 years; pallid sturgeon probably attain greater ages than this (Keenlyne et al., 1992). However, age and growth of pallid sturgeon in the free-flowing Mississippi River below the mouth of the Missouri River remain undocumented.

Recent studies of pallid sturgeon in the free-flowing Mississippi River indicate latitudinal differences in morphology (Murphy et al., 2007) and larger average sizes of individuals in the Middle Mississippi River between the mouths of the Ohio and Missouri rivers (Killgore et al., 2007). It may be that fish tend to live longer and achieve greater sizes with increasing latitude (Garvey and Marschall, 2003). Latitudinal gradients in age and growth of pallid sturgeon would have implications for distinguishing this species from the closely related shovelnose sturgeon (*S. platorynchus*), both of which undergo allometric growth of taxonomic features (Murphy et al., 2007). Furthermore, stocking pallid sturgeon is an ongoing practice for enhancing recovery of the species. Using brood stock from disparate geographic areas for stocking elsewhere may impact the genetic integrity of local populations. More importantly, if recovery of populations is recognized based on year-class strength and longevity of individuals, managers must consider differences in age and growth throughout the range of the species.

The age of a sturgeon is typically determined by counting the number of annuli of the sectioned pectoral fin ray read under magnification (Helms, 1974; Carlson et al., 1985; Morrow et al., 1998; Everett et al., 2003). Aging bias, or disagreement among readers on the individual age of a fish, has been documented for sturgeon aged with rays (Hurley et al., 2004; Whiteman et al., 2004). However, pectoral fin rays are the only aging structures that can be removed without harming the fish (Parsons et al., 2003), and aging data are necessary to evaluate demographic patterns throughout the range of this federally endangered species.

A 6-year study of pallid sturgeon in the free-flowing Mississippi River was completed in 2005. One of the principal objectives was to age each pallid sturgeon captured during the study. This article summarizes the age-length distribution of pallid sturgeon and estimates their instantaneous rates of total mortality (Z) in two different reaches of the free-flowing Mississippi River.

Materials and methods

From 2000 to 2006, pallid sturgeon were captured with trotlines in the free-flowing Mississippi River extending 1847 river kilometers (rkm) from its mouth at the Gulf of Mexico upstream to the mouth of the Missouri River (Killgore et al., 2007). Data were separated into two reaches for analytical purposes: lower Mississippi River (LMR) below the mouth of the Ohio River, and middle Mississippi River (MMR) between the mouths of the Ohio and Missouri rivers. A unique feature of the MMR is the chain of rocks (COR) at rkm 1839.5, a naturally occurring low water dam, reinforced with concrete and rip-rap, which is the only obstruction (at low water) to upstream movement of sturgeon and other fish in the MMR and LMR.

For each pallid sturgeon captured, FL and weight were measured, additional morphometric measurements and meristic counts were taken to verify species designation *a posteriori* as described by Murphy et al. (2007), and a non-encrypted PIT (passive integrated transponder) tag was inserted at the base of the dorsal fin. Beginning in the autumn of 2004, all sturgeon were scanned for coded wire tags (CWT) to determine if individuals were of hatchery origin. Prior to release, an approximately 12-mm segment of the anterior-most fin ray, usually the right ray, was removed. The segment was taken proximal to the body of the fish (approximately 5 mm from body surface) using wire cutters (for small fish with relatively thin rays) or a Dremel® rotary tool (for larger fish with relatively thick rays). This technique was intended to remove a usable segment of the oldest part of the ray while preserving normal articulation and most of the anterior edge of the fin. Sturgeon handled in this manner retain normal hydrodynamic function (Parsons et al., 2003).

The ray segment was air dried and later cut perpendicularly on a Buehler Isomet® slow speed saw into a 0.46–0.58 mm section; two sections were cut from each ray. Sections were mounted on a microscope slide using clear fingernail polish and labeled with a unique identification number (typically the number of the PIT tag implanted in that fish). All sections were examined by readers using a binocular microscope and variable magnification with light transmitted from the bottom through the section.

Fish were aged by counting each concentric continuous band, beginning with the first (resembling a star), and ending with the last (just inside the margin of the ray). Bands were translucent or clear and appeared ‘raised’. They alternated with darker, frequently wider bands that appear ‘recessed’. Separation (and discrimination) of bands was greatest at the posterior lobes of the ray. The pattern of a thin light zone followed by a darker zone was used to define each annulus (except at the margin of the section). Determining age was problematic when the light (translucent) zones were incomplete, doubled (or grooved), or indistinct. In some cases, the band(s) could be traced around the section to determine whether they originated as individual or as multiple structures. In other cases, the slide was reversed and examined from the opposite surface. If the count could not be determined reliably, the second section of the same fin ray was examined, and the process repeated. To minimize bias in age determinations, readings were done with no data on the size of the individual fish.

Sectioned rays were read independently by two people with prior training in recognizing diagnostic features of the annuli. If counts were identical, age was accepted. If counts differed by 1 year, fish were assigned the higher age. This was based on the conservative assumption that a reader was more likely to underestimate age by overlooking a partly-obscured section (e.g. near the edge of the cross-section) than to overestimate age by counting an anomaly or artifact (e.g. false annulus). If counts differed by 2 years or more, sections were re-examined and read collaboratively with a third reader. Those sections which were difficult to read and readers lacked consensus on number of annuli were evaluated separately.

Data for all years were combined for analysis. Rarity of pallid sturgeon precluded demographic analysis for separate years or seasons, adjusting age estimates for the time of annulus formation relative to time of capture, or tracking of individual year classes. However, cursory examination of age distributions among study years did not show differences in year-class strength. Therefore, we assumed that recruitment, growth, and mortality were similar among all years of the study.

A von Bertalanffy growth equation (Von Bertalanffy, 1938) using the Gulland modification (Ricker, 1975) was calculated for fork length (FL) as follows:

$$\mathrm{FL} = L_{\infty}(1 - \mathrm{e}^{-K(t-t_0)})$$

where L_{∞} is the mean asymptotic FL (mm), t is age (years), t_0 is the hypothetical age at length 0, and K is the Brody growth coefficient. A weight–length relationship was estimated after Ricker (1975) as follows: $\log_{10}(\mathrm{W}) = \log_{10}\mathrm{a} + \mathrm{b}(\log_{10}\mathrm{FL})$ with weight (W) measured in grams, length FL measured in millimeters, $\log_{10}$a is the y-axis intercept, and b is the slope of the equation. The instantaneous mortality rate (Z) was estimated with a catch curve, and this value was converted into the annual mortality rate (Ricker, 1975). Catch curves were generated from the linear regression of the $\log_{10}$ number of individuals per year class (Ricker, 1975). The slopes of the regression lines among the reaches for both the weight–length relationships and the catch curves were statistically compared using analysis of co-variance with log-transformed values. Statistical Analysis System (SAS) was used for all calculations (Version 9.1, SAS Institute, NC, USA).

Results

A total of 165 spine sections, 118 from the LMR and 47 from the MMR, were read independently by two readers. For LMR sections, eight were deleted initially because of major impairments in the quality. During the second reading, 20 more were deleted because annulus counts varied by more than 6 years after repeated attempts to reach agreement. Mean (±SD) FL (mm) of deleted sections was 730 ± 79 and the range was 540–892. This resulted in a total sample size of 90 sections for the LMR. MMR sections were read after completing all counts for LMR sections, and therefore, readers had the benefit of this experience. Only one section (FL = 995 mm) was deleted for MMR pallid sturgeon, resulting in a total sample size of 46.

Initial agreement between readers differed substantially for LMR spines (Table 1). Readers agreed on the same age 21% of the time, and 33% differed by 1 year. In contrast, readers agreed on the counts within 1 year or >83% of the time for MMR spines. For counts that differed by one or more, both primary readers along with a third reader viewed the sections together to determine a final age estimate. For LMR sections, final age estimates ranged from 3 to 21 years with a mean (±SD) of 11.0 ± 4.7 (Fig. 1). For MMR sections, final age

Table 1
Percent agreement of the initial annulus counts between two readers for pallid sturgeon rays, lower (LMR, n = 90) and middle (MMR, n = 46) Mississippi River

	Percent agreement of annulus counts within				
Reach	±0	±1	±2	±3	> ±4
LMR	21	33	23	15	8
MMR	44	40	10	5	2

estimates ranged from 5 to 14 years with a mean of 9.5 ± 2.1. A total of seven pallid sturgeon were collected in the MMR that contained CWT. Age estimates for these fish were 7–8 and 11–12 years with a mean of 9.7 ± 2.2.

Von Bertalanffy growth equation parameters for length were L_∞ = 847.6 mm FL (SE = 23), t_0 = −1.307 (SE = 0.75), and K = 0.1609 (SE = 0.0247). For MMR spines, growth equation parameters for length were L_∞ = 890.2 mm FL (SE = 139.5), t_0 = −1.5843 (SE = 5.7131), and K = 0.1802 (SE = 0.1853). Pallid sturgeon in the MMR grew faster and attained greater length for a given age compared to pallid sturgeon in the LMR (Fig. 2). However, differences in growth rates were negligible in older individuals.

A weight–length relationship was calculated for all pallid sturgeon captured during the study with data pooled across sampling years. Sample size was 226, including 169 fish from the LMR and 57 for the MMR (Fig. 3). Scatter plots indicated that COR pallid sturgeon, which included all CWT sturgeon, had a different weight–length relationship than the other two reaches and were evaluated separately. However, ANOVA indicated no significant (P > 0.5) difference in the slopes of the three log-linear regression lines. Although not statistically significant, several observations were made on length–weight relationships among reaches. MMR pallid sturgeon have the propensity to reach heavier weights (>4 kg). All pallid sturgeon caught at the COR, however, were more slender than their MMR counterparts. Of the 29 pallid sturgeon caught at the COR not designated with CWT, 48% were caught in spring (mostly April) and 52% were caught during autumn (late November–early December). Of the seven CWT pallid sturgeon, 71% were caught in late November–early December and the remaining in March.

In the LMR, pallid sturgeon fully recruited to trotlines at age 11 (Fig. 1). In the MMR, we assumed that pallid sturgeon fully recruited to trotlines at age nine even though peak abundance occurred at age 10. However, these two ages differed by only one individual. Mortality estimates would increase if recruitment was assumed to be at age 10. Instantaneous rate of total mortality (Z) in the LMR was estimated at −0.12 (r^2 = 0.55, P = 0.01) which yields an annual rate of total mortality of 11% (Ricker, 1975). Using von Bertalanffy growth equation parameters, age was calculated for LMR sections that could not be reliably aged under magnification (n = 28). The length of three of these pallid sturgeon exceeded L_∞ and were assigned the next highest age actually calculated (25 years). When these sections were included in the catch curve, Z was estimated at −0.08 (r^2 = 0.90, P = 0.002) which yields an annual rate of total mortality of 7%. In the MMR, instantaneous rate of total mortality was estimated at −0.36 (r^2 = 0.67, P = 0.04) which yields an annual rate of total mortality of 30%.

Discussion

Relatively high disagreement in initial age estimates has been noted in other studies of pallid and shovelnose sturgeon. In the Missouri River, between-reader agreement of pallid sturgeon age was 46.9% (Hurley et al., 2004). For shovelnose sturgeon, two readers agreed on the same age only 18% of the time (Whiteman et al., 2004). Similarly, readers agreed 31.5% on the exact ages of shovelnose sturgeon in the lower Mississippi River (Morrow et al., 1998). These studies, and our own experience, indicate that difficulty in reading pallid sturgeon rays was caused by damaged sections, anomalous annuli, and compressed annuli on the anterior fin ray margin of older fish. However, our study also indicates that agreement can be reached on most fin ray sections once lower quality sections are removed from the data base, and that experience in reading pallid sturgeon fin rays increases agreement between readers. We did not notice a difference in the readability of high quality rays between the LMR and the MMR sturgeon, and we assumed that sturgeon in the southern latitudes produce annuli similarly to those in the northern latitudes. However, the time of annulus formation was not determined in this study, although slower growth may occur in the summer when pallid sturgeon are inactive (Killgore et al., 2007). We had only one validated spine from a pallid sturgeon caught in the LMR with an external floy tag indicating hatchery origin (Killgore et al., 2002). Two readers blindly aged this fish to be 5-years old, which was correct based on release from the hatchery and date of recapture. Ages may vary by 1 or 2 years among readers, but a certain level of error should be acceptable for long-lived species considering the importance of age data in management of pallid sturgeon.

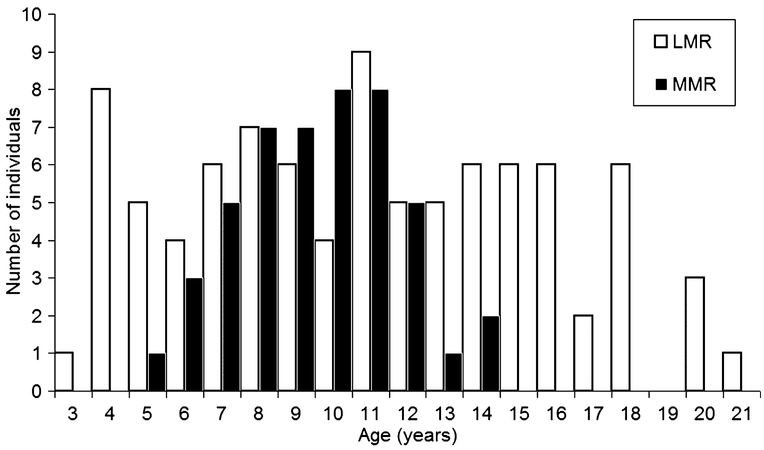

Fig. 1. Age distribution of pallid sturgeon in the lower Mississippi River (LMR) and middle Mississippi River (MMR)

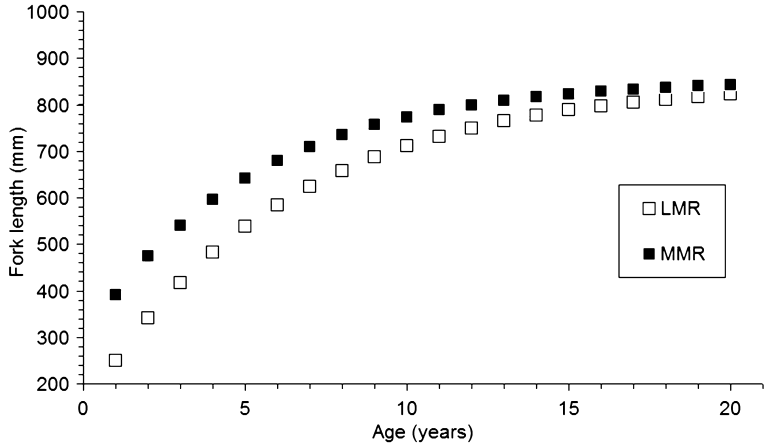

Fig. 2. Growth curves for pallid sturgeon in the lower Mississippi River (LMR), and middle Mississippi River (MMR)

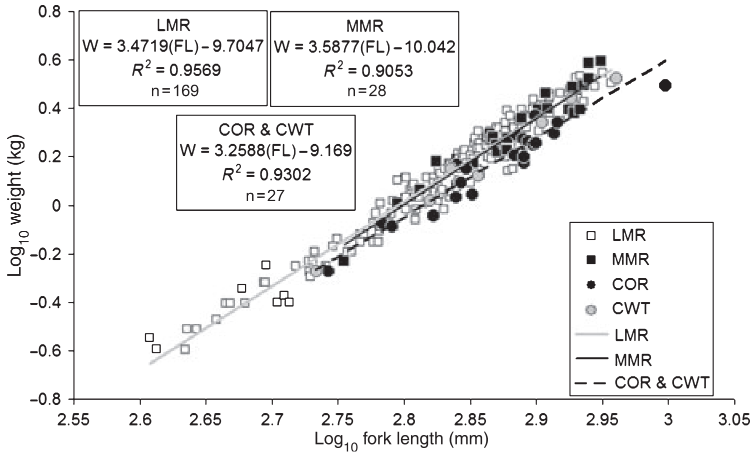

Fig. 3. Weight–length relation for pallid sturgeon in the lower Mississippi River (LMR), middle Mississippi River without chain-of-rocks (MMR), and all individuals caught only at the chain-of-rocks (COR) which includes those with coded wire tags (CWT)

Mortality rate of pallid sturgeon in the MMR ($Z = -0.36$) was triple that of LMR ($Z = -0.12$). High mortality rate ($Z = -0.36$) of pallid sturgeon in the MMR has also been noted in a recent study (Colombo et al., 2007). Differences in habitat between the two reaches may account for part of this disparity. The LMR has fewer dikes per kilometer of river and a much larger channel than the MMR (Killgore et al., 2007). Therefore, the reduced influence of river training structures in the LMR as well as the greater availability of channel and channel border habitat typically used by pallid sturgeon may enhance survival.

Incidental take during commercial fishing operations may be another reason for higher mortality in the MMR. Commercial fishing for shovelnose sturgeon has been closed in the LMR for over 10 years except for states in the northern portion of the reach (Kentucky, Missouri, and Tennessee), all of which have restricted harvest regulations and comprise only 25% of the total length of the LMR. In contrast, commercial fishing for shovelnose in the MMR is intensive (Colombo et al., 2007). Incidental take of pallid sturgeon during commercial fishing operations may be one reason older individuals (> 14 years) are not being caught in the MMR, thus leading to higher mortality rate estimates. Absence of older fish in the MMR was also noted almost 30 years ago. Maximum age of 11 pallid sturgeon caught in the Mississippi and lower Missouri Rivers in 1978–1979 was 14 years during a time of continuing commercial fishing (Carlson and Pflieger, 1981). Recently, take of pallid sturgeon by commercial fishermen has been documented by law enforcement agencies (e.g. Jeff Quinn, Arkansas Game and Fish Commission, 2006, pers. comm.).

The COR harbors a seemingly different size group of pallid sturgeon, which are relatively abundant at this location compared to other reaches in the free-flowing Mississippi River (Killgore et al., 2007). In this study, all pallid sturgeon caught at the COR, including hatchery fish (CWT), were less heavy for their size than their MMR counterparts. We can speculate that pallid sturgeon captured at the COR had recently spawned (spring collections) or undergone long migrations (spring and autumn) resulting in a decrease in weight. Regardless, the collective information on the unique characteristics of the sturgeon population and habitat at the COR support development of specific management strategies for this unusual location near the upstream terminus of the free-flowing Mississippi River.

We were unable to differentiate sex and this likely contributed to only moderate squared correlation coefficients ($R^2 < 0.68$) of the catch curves. Carlson et al. (1985) reported that females outnumbered males 2 : 1 throughout the Missouri and Mississippi Rivers, and females are generally larger than males at a given age. Age of sexual maturity is 5–7 for males, 9–12 for females, but first spawning may not begin until age 15–17 or later (Keenlyne and Jenkins, 1993). Therefore, the absence of older fish in the MMR and the increased demand for caviar may result in higher mortality rates of females.

The age distribution in the LMR indicates strong year classes of pallid sturgeon, beginning at age four, being recruited into the population and older age classes are present up to 21 years. This differs from the upper Missouri where pallid sturgeon are not naturally recruiting, but are comprised of older individuals that can reach ages greater than 50 years (Dryer and Sandvol, 1993). The larger sizes and older individuals in the Missouri River, compared to the LMR, suggest latitudinal variation in growth and longevity. Latitudinal differences in morphology and relative abundance of pallid sturgeon have also been reported (Killgore et al., 2007; Murphy et al., 2007).

Based on trotline catches, the MMR age distribution lacked younger fish suggesting reduced recruitment compared to the LMR. In the MMR, strong year classes begin to appear at age eight and persisted through age 11. Coincidentally, the seven pallid sturgeon with CWT were comprised of older individuals (7–8 and 11–12 years). Pallid sturgeon were first stocked in the lower Missouri River and MMR in 1994 when individuals were approximately 2 years old (Krentz et al., 2005), which corresponds to the 12-year old pallid sturgeon collected with a CWT in 2004. Killgore et al. (2007) reported that CWT fish comprised 47% of pallid sturgeon caught in the MMR during a period when all fish were routinely scanned. This proportion of CWT fish does not account for tag loss, if any. Therefore, the abundance and age of CWT fish may be evidence that recruitment of older fish in the MMR is now being influenced by release of hatchery fish years earlier.

The pallid sturgeon population in the MMR is influenced by multiple factors that contribute to uncertainty in recovery. These factors include the increasing presence of hatchery fish in the MMR, unknown movement patterns between the MMR, LMR, and Missouri River, and the growing demand for domestic caviar. Despite the uncertainty in the MMR, our study does indicate low mortality and self-recruiting populations of pallid sturgeon in the LMR. Latitudinal and site-specific differences in weight–length relationships among the LMR, MMR, COR, and CWT fish were not documented, although the average size of pallid sturgeon in the MMR is higher compared to the LMR (Killgore et al., 2007). Differences in mortality between the two reaches suggest that management and recovery options may differ. The LMR may serve as an unexploited reference population with low mortality, whereas the MMR is an exploited population with high mortality. Ultimately, a better understanding of long-term population trends in both reaches of the free-flowing Mississippi River will depend on reproductive success, which is the focus of ongoing studies of pallid sturgeon.

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