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Size and weight relationships of the purpleback flying squid, *Sthenoteuthis oualaniensis* (Cephalopoda: Ommastrephidae), from Arabian Sea

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Original Article

Abstract

The size and weight relationships and morphometrics of 390 individuals of the purpleback flying squid, *Sthenoteuthis oualaniensis,* collected from the tropical Arabian Sea were studied. The length-weight relationship was $W = 0.0320\ DML^{3.0972}$ for females, $W = 0.0318\ DML^{3.1288}$ for males, and $W = 0.0382\ DML^{3.0395}$ when sexes were combined indicating an isometric growth pattern. Most of the morphometric characters showed a high degree of correlation among the compared characters. The relationships between ten morphometric characters against the dorsal mantle length of both the sexes were analysed and it indicated a very high degree of correlation in females compared to males. Females in the samples were twice the size of males, indicating sexual dimorphism in body size.

***Keywords**: Sthenoteuthis oualaniensis, length-weight relationship, Arabian Sea*

Introduction

The purpleback flying squid, *Sthenoteuthis oualaniensis* (Lesson, 1830), is an oceanic ommastrephid squid species, widely distributed in the equatorial and tropical waters of the Indo-Pacific Ocean (Young and Hirota, 1998). The squid is of special interest for effective and rational use of the world ocean's biological resources (Trotsenko and Pincukov, 1994). This squid is characterized by having a wide ecological niche and complex intraspecific structure (Nesis, 1993; Zuyev *et al.,* 1985). Nesis (1993) has described a complex population structure for this squid, that incorporates three major and two minor forms. Similarly, three populations with distinguishable size ranges were identified (Yatsu, 1997). Recently, Jeena *et al.* (2023) reported four genetically distinct and novel lineages of *S. oualaniensis* in the Indian Ocean, representing three morphotypes from the Arabian Sea (dwarf forms, giant form, and middle-sized forms). The maximum mantle length (ML) of *S. oualaniensis* is reported as 690 mm dorsal mantle length (DML), and the life span is about 0.5 to 1 year (Trotsenko and Pincukov, 1994). The Arabian Sea is considered one of the richest regions for these oceanic squids in the Indian Ocean and the most promising area for the development of a large-scale fishery for *S. oualaniensis* (Zuyev *et al.,* 2002; Mohamed *et al.,* 2018). The current global biomass is estimated to be between 8 and 11.2 million t (Wang *et al.,* 2017). Due to its huge biomass and nutritional value, it is a potentially lucrative catch for open ocean fisheries (Wang *et al.,* 2018). Current average biomass is estimated at 4.21 t/km^2 and there is sufficient fishable biomass in the area to possibly launch a new targeted squid fishery from the western seaboard of India, using a precautionary approach (Mohamed *et al.,* 2018).

The morphometrics and length-weight relationship of the purpleback squid, *S. oualaniensis* from the Indian Ocean were previously reported by several authors (Nesis, 1993; Chesalin, 1993; Yatsu *et al.,* 1998; Snyder, 1998; Mohamed *et al.,* 2006; Chen *et al.,* 2007). Chembian and Saleena (2014) studied the morphometric variations in the medium and dwarf forms of the *S. oualaniensis* from the Arabian Sea. Few detailed studies have been performed on morphometrics and the size-weight relationship of *S. oualaniensis* from the Arabian Sea. However, considering the commercial prospects of this species, information on the morphometric characters will help in the assessment and management of the species from the Arabian Sea. Therefore, the present study is an attempt to gather information on the size, weight, and other morphometric parameters of *S. oualaniensis* from the tropical Arabian Sea.

Material and methods

Study area and sample collection

The study covered the oceanic waters of the eastern Arabian Sea from 8 to 17° N latitude and 64 to 76° E longitude at a depth range from 200 to 4000 m covering an area of 0.6 million km^2 (Fig. 1). Samples were collected during the surveys conducted under the ICAR/World Bank funded project "Utilization strategy of Oceanic Squids in the Arabian Sea: A value chain approach". The exploration of purpleback flying squid was carried out from MV Titanic, a 20 m length overall (LOA) trawler converted into a squid jigger, from August 2010 to March 2012. All the months were not covered during this period, and repeat sampling was done principally from January to March, which is the fair-weather season in the Arabian Sea. Due to rough weather conditions during the monsoons, research cruises were not undertaken from May to August. Each sampling survey coincided with the new moon phase of the lunar cycle every month (Masuda *et al.,* 2014). The squid jigging operations were conducted at each sampling station from dusk to morning (17.00 to 04.00 h) and metal halide lights (0.5-5 kW×18) were used to illuminate the area around the vessel to attract the phototropic squids. A total of 58 stations were covered during the study period. The individuals were caught from 23 stations by using an automatic squid jigging machine, hand jigging, gillnet and trammel net. The squids were iced immediately after collection and were transported to the laboratory (CMFRI, Kochi, India).

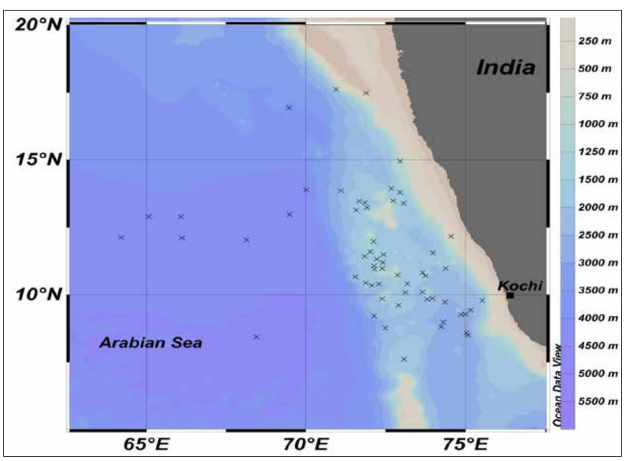

Fig. 1. Study area in the Southeastern Arabian Sea depicting the specimen collection sites

Morphometric measurements

A total of 390 individuals (126 males and 264 females) of typical mid-sized purpleback flying squids were used for this study. All samples were cleaned with water, examined externally and sexed. The measurements were made in millimetres (mm) and weight was taken in nearest gram (g) by a Hercules™ electronic hanging scale (Maximum 10 kg, Minimum 20 g, e=1 g). Eleven length measurements of external morphology were recorded by measuring scale (scale: 1-500 mm) according to Roper and Voss (1983). These include DML, mantle width (MW), head length (HL), head width (HW), arm length (AL) I, II, III and IV, fin length (FL) fin width (FW) and tentacle length (TL) (Table 1). The relationship between weight against the dorsal mantle lengths (LWR) of both females and males was analysed by the linear regression model:

$$W = a\,L^b$$

or in the linear form Log W = log *a* + *b* * Log L

Where 'W' is the weight in 'g', 'L' is the total length in mm, and '*a*' (intercept) and '*b*' (slope) are fitted constants. Where *a* and *b* were estimated using ordinary least square regression

Table 1. Morphometric measurements (in mm) for males and females of *S. oualaniensis* from the Arabian Sea. Dorsal mantle length (DML), mantle width (MW), head length (HL), head width (HW), arm length (AL), fin length (FL) fin width (FW) and tentacle length (TL)

Variables	Male				Female			
	N	Range	Mean	SD	N	Range	Mean	SD
DML	121	90-162	121	12.5	263	95-343	161.4	50.4
MW	121	25-62	46	6.6	257	23-125	61.2	21.8
HL	121	10-54	30	6.8	257	15-78	37.6	11.4
HW	121	12-58	30.7	7.4	256	18-87	39.5	12.7
AL1	121	32-75	53.1	7.5	257	12-172	68.6	24.7
AL2	121	32-81	62.3	8.2	258	32-190	82.6	28
AL3	121	37-92	68.2	10.1	255	30-197	93.4	29.9
AL4	121	46-109	78.1	12	251	26-194	85.9	30.2
FL	121	30-70	46	7	259	20-175	63.6	23.2
FW	121	70-140	104.3	12.7	257	46-284	133.9	40.5
TL	89	130-205	165	17.55	190	160-513	238.7	95.35

(Ricker, 1973; Jenson, 1986). The values for mean weight by sex were compared by a two-sample *t*-test.

The relationship between DML and various other morphometric measurements was worked out according to the linear regression model by using the formula:

$y = a + b.x$

Where y is the dependent variable, x is the independent variable and '*a*' and '*b*' are constants.

Statistical analysis

The relationship between mantle length and total weight was determined according to the power regression model. Student *t*-test was utilized to compare the regression coefficient *b*, to evaluate the isometry of relative growth (Ricker, 1973) and to compare the mean values of length and weight. The analysis of covariance (ANCOVA) on the regression equations was used to compare slopes according to Snedecor and Cochran (1967). Sexual dimorphism in mantle lengths for males and females was analyzed by a Chi-square test. Morphometric variables were subjected to descriptive statistics such as minimum, maximum, arithmetic mean, standard deviation and coefficient of variation. The significant differences in morphometric characters of male and female individuals were analysed using *t*-test. Pairwise linear regression of morphometric variables with DML was carried out and regression coefficient *b* was assessed for the underlying allometric/isometric pattern of the variables. In the length-to-length relation, the *b* value of 1 is considered isometric and the *b* value above or below 1 is considered allometric.

Results and discussion

Length-weight relationship

The squid size ranged from 95 to 343 mm DML for females (mean 160 mm) and 29 to 1600 g weight (mean 237.3 g). In males, the size ranged from 90 to 162 mm DML (mean 120 mm) and 20 to 152 g weight (mean 80.7 g). The size of the female squids was found to be double that of males. There was a significant difference in the LWR between the two sexes ($P < 0.001$ ANCOVA). The *b* values obtained for both females, males and sexes pooled were 3.0972, 3.1288 and 3.0395 respectively (Table 2, Fig. 2, 3 and 4). The *b* value for males was found to be slightly higher than

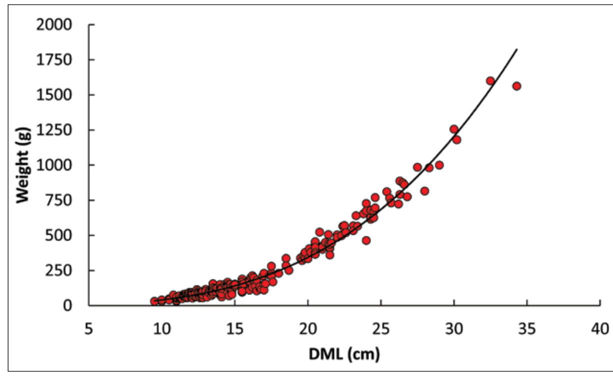

Fig. 2. Length-Weight relationship of female *S. oualaniensis* from the Southeastern Arabian Sea

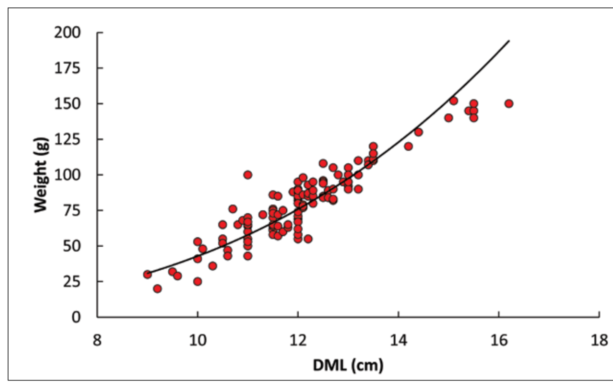

Fig. 3. Length-weight relationship of male *S. oualaniensis* from the Southeastern Arabian Sea

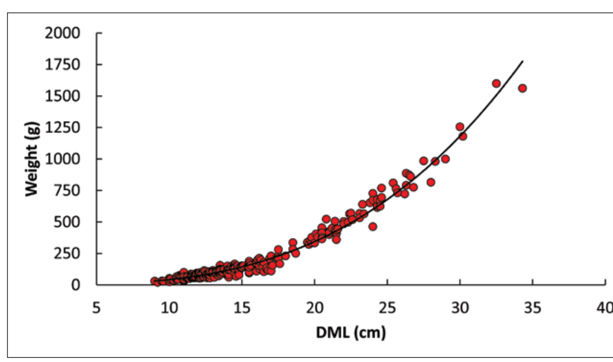

Fig. 4. Length-weight relationship of *S. oualaniensis* (sexes combined) from the Southeastern Arabian Sea

Table 2. Sex-wise Length-weight relationships of *S. oualaniensis* from the Southeastern Arabian Sea. E= standard error, R= regression coefficient, n= number of animals sampled

		Length (cm)	Weight (g)	Constants		Parameters of relationship		
Sex	n	Min-Max	Min-Max	a	B	SE (a)	SE (b)	R^2
Female	264	9.5-34.3	29-1600	0.032003	3.0972	0.11866	0.04312	0.95
Male	126	9.0-16.2	20-152	0.03188	3.1288	0.33596	0.1351	0.81
Pooled	390	9.0-34.3	20-1600	0.038247	3.0395	0.09563	0.03583	0.94

Table 3. The relation between DML and morphometric measurements of male and female *S. oualaniensis* from the Southeastern Arabian Sea. For variable abbreviations, see Table 1. R^2 = goodness of fit, CI – Confidence Interval (95%), ($P<0.05$).

Variables	*n*	Sex	R^2	a+bx	CI (b)	P(b)	Growth
DML–MW	257	F	0.88	29.94 + 2.13×x	2.03, 2.23	0.00	+ Allometric
	121	M	0.64	25.03 + 2.05×x	1.77, 2.33	0.00	+ Allometric
DML–HL	257	F	0.81	09.19 + 4.04×x	3.81, 4.28	0.00	+ Allometric
	121	M	0.58	24.64 + 3.68×x	3.12, 4.23	0.00	+ Allometric
DML–HW	256	F	0.83	15.00 + 3.74×x	3.53, 3.95	0.00	+ Allometric
	121	M	0.53	69.84 + 1.70×x	1.42, 1.99	0.00	+ Allometric
DML–AL1	257	F	0.86	31.91 + 1.86×x	1.77, 1.94	0.00	+ Allometric
	121	M	0.55	51.98 + 1.29×x	1.08, 1.50	0.00	+Allometric
DML–AL2	258	F	0.87	20.77 + 1.70×x	1.62, 1.77	0.00	+ Allometric
	121	M	0.56	42.57 + 1.25×x	1.05, 1.45	0.00	+ Allometric
DML–AL3	255	F	0.91	08.89 + 1.62×x	1.56, 1.68	0.00	+ Allometric
	121	M	0.53	56.39 + 0.94×x	0.78, 1.10	0.00	- Allometric
DML–AL4	251	F	0.9	23.74 + 1.59×x	1.53, 1.66	0.00	+ Allometric
	121	M	0.61	55.96 + 0.83×x	0.71, 0.95	0.00	- Allometric
DML–FL	259	F	0.96	11.30 + 2.36×x	2.30, 2.42	0.00	+ Allometric
	121	M	0.8	45.73 + 1.63×x	1.48, 1.78	0.00	+ Allometric
DML–FW	257	F	0.93	03.06 + 1.16×x	1.12, 1.20	0.00	+ Allometric
	121	M	0.71	35.02 + 0.82×x	0.72, 0.91	0.00	- Allometric
DML- TL	190	F	0.9	37.94 + 0.52×x	0.50, 0.55	0.00	- Allometric
	89	M	0.66	12.92 + 0.65×x	0.55,0.75	0.00	- Allometric

for females. Statistical analysis indicated that the value was not significantly different ($P>0.01$) from the isometric value 3 (*t*-test) hence it was concluded that both males and females show an isometric growth pattern.

The corresponding exponential formula in the form of $W = aL^b$ can also be expressed as follows.

Female W = 0. 032003 $DML^{3.0972}$
Male W = 0.03188 $DML^{3.1288}$
Pooled W = 0.038247 $DML^{3.0395}$

The isometric growth pattern reported in the present study is in accordance with the previous research carried out in Hawaiian water (Suzuki *et al.,* 1986), the Arabian Sea (Mohamed *et al.,* 2006; Chembian and Saleena, 2014), and South China Sea (Basir, 2000). However, in contrast, a negative allometric growth for *S. oualaniensis* was reported in the Northwest Indian Ocean (Chen *et al.,* 2007) and in the western Philippines waters, *S. oualaniensis* follows a positive allometric growth (Siriraksophon *et al.,* 2000). In general, length-weight relationships can vary, depending on the season, the size range of the population, or annual changes in environmental conditions (Froese, 2006). The isometric growth pattern was also observed in another ommastrephid squid *Ommastrephes bartramii* (Chen and Chiu, 2003; Aneeshkumar *et al.,* 2014). In Northwest Spain, the length-weight relationship of *Illex coindetii* was isometric for immature specimens and allometric for mature individuals, positive for males and negative for females (Gonzales *et al.,* 1996). Whereas, the neritic squids generally follow a negative allometric growth pattern (Nair *et al.,* 1992; Karnik and Chakraborty, 2001; Shivashanthini *et al.,* 2009) and the oceanic squid species generally follow an isometric to positive allometric growth and some of the oceanic squid species sexes shows a negative allometric growth pattern. This may be due to several reasons such as the difference in the growth rate in males and females, different populations of the same species, the geographical difference of the species, environmental conditions and/or the availability of food (Forsythe, 1993)

Linear morphometric relationship

Length-length relationships by pairwise linear regression of morphometric measurements of (Y variable) against the DML showed a regression coefficient *b* value ranging from 0.50 to 4.04 for MW, HL, HW, AL1, AL2, AL3, AL4, FL, FW and TL, clearly indicating the allometric growth of these variables concerning DML. A lower value of *b* was observed for the DML relationship with AL3 (0.94), AL4 (0.83), FW (0.82) and TL (0.65) in males and females, only the TL variable had a low value (0.52) revealing negative allometric growth (Table 3). A higher value of *b* ranges 1.16-4.04 was observed for MW, HL, HW, AL1, AL2, AL3, AL4, FL, and FW in females and males it ranges from 1.25 to 3.68

for MW, HL, HW, AL1, AL2 and FL showing positive allometry with DML (Table 3).

The relationship between DML and other morphometric measurements was significant ($P<0.05$) as the R^2 value was greater than 0.8 (Table 3). A significant relation between the DML and other morphometric variables has been observed in females. However, in males, only a moderate relationship between DML and other variables was observed. A high degree of correlation was observed in females for all morphometric variables such as mantle width (MW), head length (HL), head width (HW) left arms 1,2,3 and 4 (AL1, 2, 3 & 4), fin length (FL) fin width (FW) and Tentacle length (TL). The R^2 value ranged from (0.81 to 0.93). Whereas, in males, the DML and other variables such as MW, HL, HW, AL of four arms, FW and TL, show only moderate correlation (0.43 to 0.7) and a high degree of correlation was obtained only for FL (0.80).

The relationships between ten morphometric characters against dorsal mantle length of both female and male squids were analysed and a high degree of correlation (R^2 0.81-0.96) was observed in females, whereas in males, DML and other variables show only a moderate correlation. Conversely, a high degree of correlation was observed between fifteen morphometric characters against the dorsal mantle length of both females and males of the Indian squid, *L. duvaucelii* from off Mumbai waters, west coast of India (Karnik and Chakraborty, 2001). Zuyev *et al.* (2002) observed that *S. oualaniensis* arms and tentacles are characterized by negative allometric growth in large-sized adults with DML from 36-40 and 60-65 cm. Chembian and Saleena (2014) also observed the allometric growth between DML and other morphometric variables in *S. oualaniensis* from the Arabian Sea. In their study, they observed most of the morphometric variables with DML show negative allometry and only two variables show positive allometry.

The relationship between mantle length and most of the dependent variables in near-shore loliginid squid *U. duvaucelii* in the coastal waters of Karachi showed negative allometry (Rashad *et al.,* 2010). Further, he reported that the relation of total length to mantle length showed positive allometry in both females and males, while the tentacle length to mantle length was isometric in males and positive allometric in females. Similarly, Emam *et al.* (2014) reported significant differences in the relationship between DML and other morphometric measurements between sexes of *L. forbesi* from the Mediterranean waters and that the DML with other morphometric variables showed negative allometric growth. In *S. oualaniensis* females from the Arabian Sea, most of the morphometric variables against DML growth show positive allometry and in males, six variables follow positive allometry and four variables follow negative allometric growth. However, in near-shore loliginid squids, most of the morphometric variables against DML growth show negative allometry (Nair *et al.,* 1992; Karnik and Chakraborty, 2001; Shivashanthini *et al.,* 2009).

Cephalopods generally and squids, in particular, are known to exhibit considerable morphological variations in life (Ngoile, 1993). Most oceanic squids, particularly, ommastrephid squids follow an isometric growth pattern (Suzuki *et al.,* 1986; Belcari, 1996; Gonzales *et al.,* 1996; Basir, 2000; Chen and Chiu, 2003; Ceriola *et al.,* 2006; Mohamed *et al.,* 2006; Aneeshkumar *et al.,* 2014; Chembian and Saleena, 2014) to positive allometric and negative allometric growth (Chesalin, 1993; Gonzales *et al.,* 1996; Belcari, 1996; Siriraksophon *et al.,* 2000; Ceriola *et al.,* 2006; Chen *et al.,* 2007; Liu *et al.,* 2010). This may be due to the differential growth rates in males and females. Gong *et al.* (2018) reported that sexual size dimorphism occurred in the arm, tentacle, and beak of *D. gigas* with the same gladius length which scales with body size. Cephalopod growth is highly variable and influenced by biotic and abiotic factors such as temperature, diet, age, gender and level of maturity (Forsythe and Heukelem, 1987; Forsythe and Hanlon, 1988; Forsythe, 1993). The reasons for differences in morphometric characters and dimensions in the same species in different geographical locations need to be studied further.

Sexual dimorphism

In *S. oualaniensis*, females attain a larger size than males. The smallest female observed in the sample was 95 mm DML and the largest female squid size was 343 mm DML with a mean size of 159 mm. The smallest male observed was 90 mm and the largest size observed was 162 mm DML with a mean size of 119 mm. In terms of length, there was a distinct sexual dimorphism between males and females (x^2 test; $P<0.05$). The male squids were comparatively smaller than the females. We observed that the largest female squids had a size twice that of the largest male (Fig. 5).

Male squids in the family Ommastrephidae start maturing before females, leading to a differential growth between sexes; thus

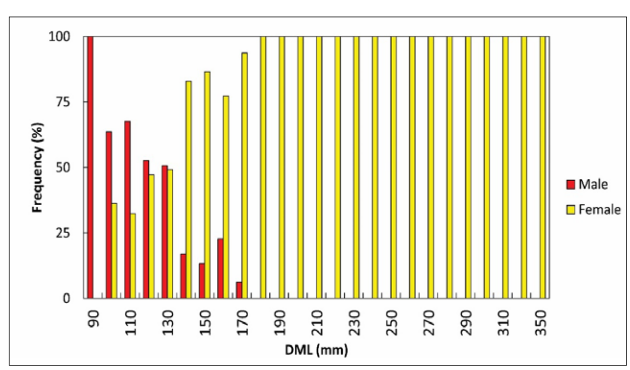

Fig. 5. Sex-wise length-frequency distribution of *S. oualaniensis* from the Southeastern Arabian Sea

females reach larger sizes (Arkhipkin and Murzov, 1986). Males attaining maturity in smaller sizes may be the reason for the slow growth rate and also the reason for the lack of good correlation between morphometric characters as compared to females. The relationship between morphometric characters against the dorsal mantle length of females showed a high degree of correlation and the relatively moderate correlation in males may be due to males attaining earlier maturity. Besides, the low sample size of males also may be a reason for the moderate correlation of morphometric variables with DML growth. There are reports that female *S. oualaniensis* always grows faster than males (Takagi and Yatsu, 1996; Zakaria, 2000; Sukramongkol *et al.,* 2007; Liu *et al.,* 2016). Squid hatch in different seasons and areas and experience different conditions, such as temperature and food availability, which influence their growth and can lead to temporal and spatial differences (Arkhipkin *et al.,* 2000; Arkhipkin, 2004). As functional feeding apparatuses, the observed sex-wise size variations in arms, tentacles, and beaks indicate differences in food resource use between female and male squid (Hanlon and Messenger, 1996). Sexual dimorphism in size is common to all three forms of *S. oualaniensis,* and is a common feature of other ommastrephids (Arkhipkin and Mikheev, 1992). Clearly, sexual dimorphism is expressed in body size; the females are 1.5–2 times larger than males. Zuyev *et al.* (2002) reported that sexual dimorphism in adult males can be easily distinguished from females by their more compact, narrow and streamlined body, wider fin and pointed back end of mantle, presence of hectocotylus and sometimes spermatophores, which become visible in the mantle cavity.

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