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Short Communication

Fecundity traits of young ovigerous females of yellow-line-arrow spider crab *Stenorhynchus debilis* (Brachyura: Inachoididae) in Bahía de La Paz Baja California Sur, México

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ABSTRACT. The southwestern Gulf of California is an important source of ornamental marine species traded worldwide, wherein spider crabs *Stenorhynchus debilis* are popular items. However, little is known about species biology and ecology. This study involves young ovigerous females (28 in total) recollected at Bahía de La Paz, Mexico, into bivalve mariculture devices cleaned every 3-4 months. Total carapace length (TL) and carapace width (CW), weight without eggs (TW), and fecundity (F, number of eggs) were analyzed for multiple relationships. F varied into 162 and 2205 eggs ($\bar{x}$ = 1171 ± 689 eggs), their diameter into 0.38 to 0.45 mm ($\bar{x}$ = 0.396 ± 0.027 mm). Three persistent and interactive modes were detected: low/moderate/high F, small/medium/large size (TL and CW), and light/middle/heavy TW. Log-linearized allometric regressions were applied to determine the relative fecundity constants (RFC) by body complexion, finding high parallelism between TL and CW related to step-wise growth and size categorization upon the isosceles-shaped carapace. In contrast, TW denoted an increase in body complexion across intermolt phases. *S. debilis* likely completes three maturation/molt cycles within 3-4 months after the first crab instar. RFC values confirmed positive trends by body complexion where egg size and F are related to species size and shape, establishing the trade-off proportions in this study case.

Keywords: *Stenorhynchus debilis*; fecundity; morphogeometry; juvenile females; ornamental marine crabs; Gulf of California

The genus *Stenorhynchus* (Brachyura: Inachoididae) contains four species: *S. seticornis* and *S. yangi*, distributed in the Caribbean-Antilles region, *S. lanceolatus* does so throughout the tropical-subtropical Eastern Atlantic and into the Mediterranean. *S. debilis* likewise shows wide latitudinal distribution -and zonation as deep as 50 m in some sites- this one across the tropical-subtropical Eastern Pacific included the Gulf of California (World Register of Marine Species, WoRMS). This report targets *S. debilis*, whose main captures are concentrated by the coral-rock reefs that populate the southwestern coast and islands of the Gulf of California. Up to 5-6% of the 2500-2600 ornamental marine species (OMS) traded in the world are extracted in high numbers from those areas, principally fishes (Lango-Reynoso et al. 2012), and it is recognized that the share of *S. debilis* is not negligible (Monteforte et al. 2018). Nevertheless, sporadic data regarding biology and ecology are available for this crab, all issued from indirect recollections in research cruises or field expeditions (Crane 1937, Garth 1991, García-Guerrero & Hendrickx 2004).

Further reasons other than filling the information gaps led us to undertake this study. The source of speci-

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mens, for instance, because they are members of the peculiar benthic community that colonizes bivalve mariculture devices, in the current case containing adults of pearl oyster *Pteria sterna* in suspension modality (10-12 m of depth over a sandy sea bed 28-30 m below). Hence the study site is a private pearling farm installed at Bahía de La Paz, southwestern Gulf of California. Also, cleaning routines are performed every 3-4 months, ensuing recollections of some actual or potential OMS in juvenile and young stages. Nevertheless, previous studies on the mariculture of bivalves and pearl oysters developed nearby the farm had revealed the incidence of ovigerous females in almost all the brachyuran crabs habitually colonizing devices like this kind, despite the undedicated design (large mesh aperture, inadequate shape, a non-benthic *P. sterna*-only shelter) and short immersion time with cleaning schedules (Monteforte 2005). Thus 10-11 species of brachyuran crabs, of which at least eight -including *S. debilis*- are actual or potential OMS, were regular encounters (seasonal or annual) during maintenance and monitoring routines (Monteforte 2005). Since *S. debilis* was found in the devices of the present farm, the aim is now on (young) ovigerous females (OFs) to seek morpho-geometric constants underlying the relation, or trade-off proportion, between body complexion and number/size of eggs at early size/age. Adults can grow 300% larger at 12-15 years of age or older (Monteforte et al. 2018). Finally, the genus *Stenorhynchus* displays the most isosceles-shaped carapace among the Majoidea, in which the rostrum turns into a dimorphic character (Guinot 2012, Davie et al. 2015). This fact was taken to validate whether the natural range of trade-off proportions of *S. debilis* would be affected so far compared to the gradient of small crabs (Table 1).

Following Monteforte et al. (2018) described procedures for field collection, transport treatments, and general handling of crabs in the laboratory, seven expeditions to the farm were implemented. Based on previous observations, they merged with their maintenance routines during the warm season (July-August) when OFs were expected to occur (Monteforte 2005). Roughly 20-30 devices were inspected each expedition, summing to 195-200 in total. The average number of *S. debilis* per device was 3-4 individuals with moderate frequency (20-25%) of zero catch or only one. The total harvest was 165: 75 males, 86 females (28 ovigerous), and 4 individuals too small to identify sex.

Standard carcinologic data were analyzed for the 28 young OFs: total carapace length (TL, rostrum tip to

Table 1. Compilation of basic descriptors for ovigerous females of some ornamental spider crabs with comparative data of *Stenorhynchus debilis* issued from the present study. OF: ovigerous females, TL: total carapace length, CW: carapace width, F: fecundity, n/d: no data.

Species	Reference	Location	Collection	OF	TL (mm)	CW (mm)	F	Egg diameter (mm)	Regression resume
Sternorhynchus debilis	This work	La Paz Bay Mexico	In bivalve culture devices	28	19.17-32.48	5.67 - 9.39	162 - 2205	0.38 - 0.45	see Figure 3
	García-Guerrero & Hendrickx (2004)	Mazatlan Bay Mexico	Mechanical. Punctual	29	n/d	9.5 - 14.4	790 - 1950	n/d	$F = 1518.5CW-709.4$ $R^2 = 0.95$
	Garth (1991)	Hancock exp.	Mechanical. Punctual	n/d	15	n/d	n/d	0.20	n/d
	Crane (1937)	Crocker exp.	Mechanical. Punctual	9	n/d	17 - 24.5	215 - 975	0.38 - 0.4	n/d
Stenorhynchus seticornis	Okamori & Cobo (2003)	Ubatuba, Brazil	SCUBA. One year	113	n/d	9.24 ± 1.52	69 - 1850	0.48 - 0.57	$F = 1.27CW^{2.7}$ $R^2 = 0.43$
Stenorhynchus lanceolatus	No studies on this theme								
Mithrax pygmaeus	Simpson et al. (2016)	Caribbean	n/d	25	n/d	4.4 - 7.0	75 - 310	0.63 - 0.72	$F = 42.91CW-86.457$ $R^2 = 0.38$
Mithraculus forceps	Cobo & Okamori (2008)	São Paulo Brazil	SCUBA. One year, seasons (1) and (2)	68	n/d	9.04 - 14.0	60 - 1123	0.56 ± 0.06	(1) $F = 0.13CW^{3.28}$ $R^2 = 0.82$ (2) $F = 5.46CW^{1.68}$ $R^2 = 0.41$
	Hernández-Reyes et al. (2001)	Margarita Is. Venezuela	SCUBA. One year	129	16.64 (average)	n/d	34 - 4777	0.58 - 0.61	$F = 267.8CW-3698$ $R^2 = 0.49$

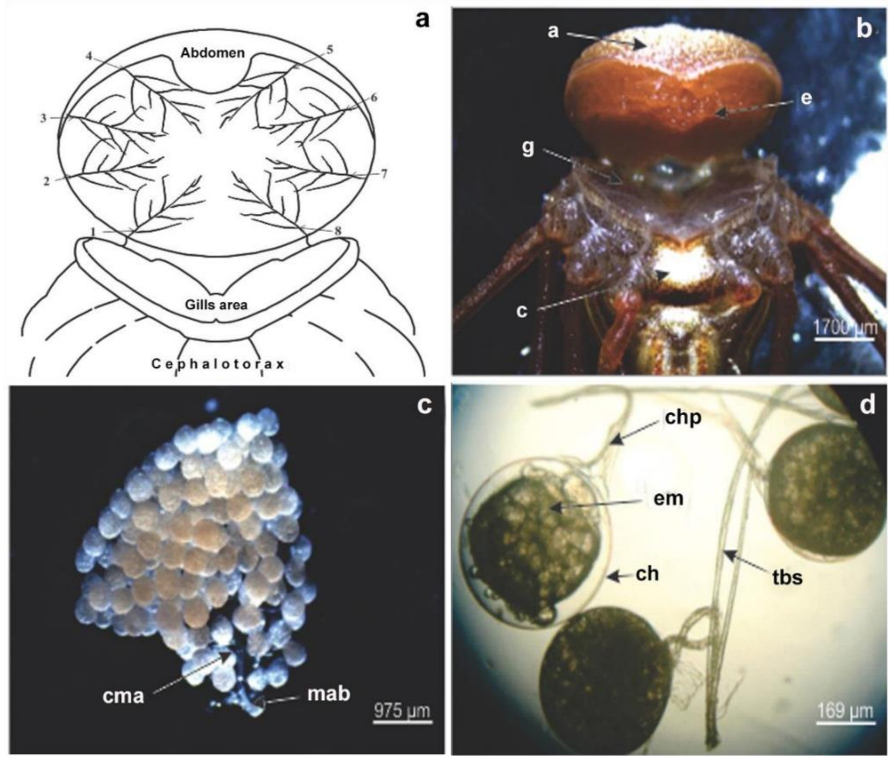
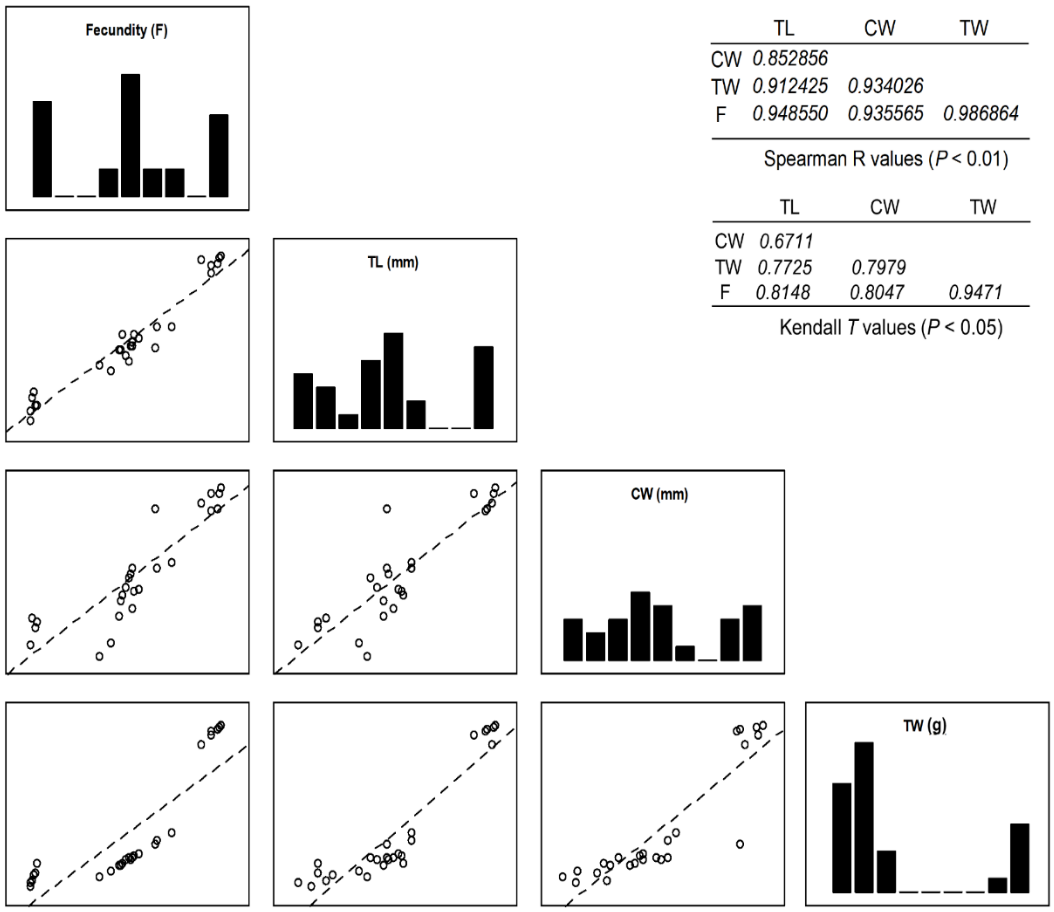


Figure 1. Views of *Stenorhynchus debilis* ovigerous female. a) Sketch of eggs distribution; b) female carrying eggs (a: abdomen pleon, g: gills, c: cephalothorax, e: eggs); c) clutch of eggs (mab: main axis base, cma: cluster main axis); d) detail of eggs (ch: chorion, em: embryo, chp: chorionic peduncle, tbs: tertiary branch of the stem).

posterior margin of the carapace) and width (CW, longest axis between branchial margins) with digital caliper ±0.01 mm of precision, and total body weight (TW, eggs and main stems removed) with electronic balance ±0.01 mg of precision. Total eggs per female (fecundity, F) were counted into a 50 mm square with a 1 mm grid layer using SigmaScan Pro 5.0 color edging procedures on TIFF/RAW photographic files shot with a Canon EOS camera with a macro-lens adaptor to a Zeiss stereoscope.

OFs had the egg mass distributed in four pairs of clutches affixed to the pleon internal margin (Figs. 1a-b). A total of 32,804 eggs (about 1.3 mg of mass weight) were counted. F values varied from 162 to 2205 eggs ($\bar{x}$ = 1171 ± 689), which looked nearly spherical with diameters varying between 0.38 and 0.45 mm ($\bar{x}$ = 0.40 ± 0.03 mm) (Fig. 1c). They come attached to secondary and tertiary ramifications through chorionic peduncles disposed of like coil/helix around a stem 0.59 ± 0.025 mm of length (Figs. 1c-d). The general structure recalls a dense carpet of orange-reddish grape bunches (Figs. 1b-c), close to what is normally seen in brachyuran crabs. Twenty-two of the 28 OFs were smaller than 30 mm leg span. The smallest (18.29 mm TL by 5.41 mm CW) also had the lowest F (162 eggs), alike the largest (32.48 mm TL by 9.39 mm CW) corresponded to the highest F (2205 eggs). These data show a good fit to previously obtained on the species and comply as well with the ranges of small crabs (Table 1).

Next, morpho-geometric analyses were performed under MS-Excel 2019 and CSS-Statistica 12 to assess possible assemblages by size-weight and F and to investigate RF constants on size/shape, weight, and fecundity using the allometric relationship ($Y = a \cdot X^b$), a standard strategy in this line of carcinologic studies (Hartnoll 2012, Goncalves et al. 2017, Rasheed et al. 2021, and others). Comparative inferences are then based on variables X and Y, where *b* is the allometric coefficient (slope or relatively constant between the variables), and *a* is a dimensional balance (±0) between X and Y, or the Y-intercept. Besides, converting raw values to log-linear is another approach used to improve the sensibility in comparative evaluations of parallelism or inclination of two or more *b* slopes, doing this through bivariate permutations in t-Student and covariance matrixes (Hartnoll 2012, Andrade & Estévez-Pérez 2014, Rasheed et al. 2021). Accordingly,



	TL	CW	TW
CW	*0.852856*		
TW	*0.912425*	*0.934026*	
F	*0.948550*	*0.935565*	*0.986864*

Spearman R values ($P < 0.01$)

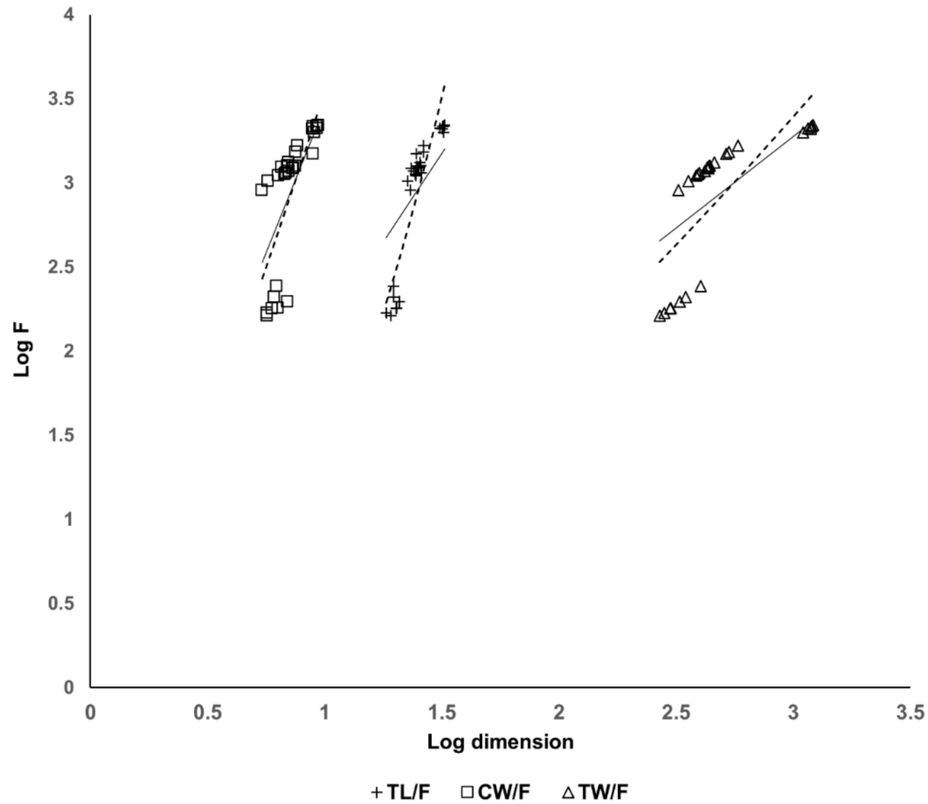
	TL	CW	TW
CW	*0.6711*		
TW	*0.7725*	*0.7979*	
F	*0.8148*	*0.8047*	*0.9471*

Kendall *T* values ($P < 0.05$)

Figure 2. Matrix distributions by fecundity (F), carapace length (TL, mm) and width (CW, mm), and body weight (TW, g) with statistical output of Spearman (r_s) correlation and Kendall (τ) concordance for *Stenorhynchus debilis* ovigerous females (28). Numbers in italics denote high correlation levels ($P < 0.01$) of the triple mode trend, while some overlap from TW and/or CW resulted in lower concordance, still into significant levels ($P < 0.05$).

$b > 1$ stands for positive allometry (one variable increases faster than the other), and $b = 1$ indicate isometry (same rate on both variables), $b < 1$ is negative allometry (one variable is slower than the other), and $b < 0$ is enaniometry (negative relation between the two variables, which may result in situations of sexual dimorphism).

Because exploratory histograms and median box-whisker plots had underlined triple-modal distributions relating the variables (low/moderate/high F, small/ medium/large carapace size -TL and CW, and light/ middle/heavy TW), non-parametric inferences were chosen to keep the real values, necessary at this stage of the analyses (Zar 1999). A combination of Spearman r_s correlation and Kendall τ concordance seemed adequate to identify rank order arrays (1 to 28) based on assumptions of dimensional F patterns onto the isosceles carapace. The results reinstated high positive correlations by the sequence of modes found in the variables (Spearman r_s between 0.85 and 0.99, $P < 0.01$). However, the Kendall τ lower range coefficient (between 0.67 and 0.95, $P < 0.05$) may indicate tendencies to rank overlaps in CW and TW. Principally due to some heavy medium-size and light large-size OFs that had moderate F (Fig. 2). Conversely, TL and F were significant discriminants in categorizing data distribution by size-weight. Consequently, regressions performed on the log-linear subset yielded positive allometry ($b > 1$) of F by TL (or TL/F) and CW (CW/F), although the alignment of the latter was poor ($R^2 = 0.47$, $P = 0.4$) (Fig. 3). The t-Student detected significant parallelism between TL/F and CW/F ($P < 0.005$) alluding the positive allometric rate associated to F ($b > 1$) where CW seems to increase slightly faster than TL, while the isometric TW ($b \sim 1$) implies that F increases at a slower rate about TW (Fig. 3).



CODE	$Y = a X^b$	R^2	Log Y = Log a + b Log X		R^2
TL/F	$F = 1.282\ TL^{2.485}$	0.783	F = - 3.858 + 4.881 TL	***a***	0.810
CW/F	$F = 3.545\ CW^{1.216}$	0.521	F = - 0.446 + 3.969 CW	***a***	0.522
TW/F	$F = 0.735\ TW^{1.393}$	0.533	F = - 0.781 + 1.381 TW	***b***	0.542

t-Student on slopes	**Log F / Log TL**	**Log F / Log CW**
Log F / Log CW	0.207, $P = 0.834$	
Log F / Log TW	0.210, $P = 0.837$	1.15, $P = 0.256$

Figure 3. Results of t-Student tests on 3×3 bivariate combinations of allometric relationships by fecundity (F) and body dimensions (total carapace length, TL, mm; carapace width, CW, mm; weight, TW, g) for *Stenorhynchus debilis* ovigerous females, showing the original power function and the corresponding Log-transformed equations of the relative fecundity constant (see text). Different letters (a, b) denote different slopes ($P < 0.005$).

At this point, it is plausible that the real F of *S. debilis* may be higher than reported before (Table 1), bearing in mind that spider crabs are known to have fewer and larger eggs among brachyurans in general (Hernández-Reyes et al. 2001, Davie et al. 2015). The relative fecundity likely describes a step-wise growth pattern through consecutive molts-intermolt phases that become longer as the reproductive lifespan progresses toward ending (Brylawski & Miller 2006, Hartnoll 2012). Similar studies developed in commercial crabs advocate this implicit trend (e.g. Joseeline 2013, Crowley et al. 2019, Epifanio 2019, Rasheed et al. 2021). Meaning that F increments in body complexion will be proportionally less in corollary to subsequent molt cycles until growth reaches the asymptotic level. This level is related to species-dependent trade-off at the pre-terminal ecdysis (Verísimo et al. 2011, Davie et al. 2015, Goncalves et al. 2017, Rasheed et al. 2021) and to size/age limits, naturally. This study revealed that *S. debilis* attains maturity within 3-4 months after the first crab instar, similar to other crabs observed in mariculture devices, like rock crabs *Pilumnus towsendi* and *Eriphia squamata*, and the pink swimming crab *Portunus xanthusi*, among others (Monteforte 2005). In our subject species, three reproductive cycles related to increasing F value were significantly consistent with three ascendant categorizations by size and weight (Fig. 2). Likewise, three grades of RF were consistent with corresponding categorizations by size-weight relationships on body complexion. The guideline points to significant size-based differences among small, medium, and large OFs as a function of RF. Reasoning thereby that the triple-mode sequence (low, median, and high) is congruent with the increase of carapace size (TL and CW) due to step-wise growth tagged to TL rather than CW. At the same time, TW would be associated with individual body complexion, assuming a continuous increase across intermolt phases. In resume, RF/TL varied from 8 to 68 eggs mm^{-1} ($\bar{x}$ = 43 ± 21 eggs mm^{-1}), RF/CW from 27.46 to 234.82 eggs mm^{-1} ($\bar{x}$ =159.39 ± 72 eggs mm^{-1}), and RF/TW from 599 to 2881 egg g^{-1} ($\bar{x}$ =1740 ±1100 eggs g^{-1}), which emphasizes the influence of CW, probably assigned to storage capacity.

However, in *S. debilis*, the sequence of modes suggests that the gain in body complexion is less from the first mode to the second than from this one to the third (Fig. 2, inlay table). Since the medium-sized OFs were numerically dominant, the overlaps were concentrated in the low and medium RF ranges due to CW -which seems to allude to the storage capacity- and especially to TW, which tagged the first and second modes with the smallest significance level (Figs. 2-3, and inlay tables). Highlights for *S. debilis* in this study were related to the recollection method, which established the occurrence of puberty molt and first reproductive molt very soon after benthic settlement (megalopa-first crab), as well as indications of two additional reproductive molts (Figs. 2-3). Based on the maximum adult size (>200 mm of leg span, equivalent to TL of 64-65 mm and CW of 18-19 mm, a male) (Monteforte et al. 2018), it is not possible to tell at this moment how many molts might follow until the terminal ecdysis, or at what size/age. This study might not apply to management or conservation as the representativity of data from non-dedicated devices could not reflect the dynamics of wild populations. Nevertheless, recruiting targeted species is effective, meaning that a natural stock, probably abundant, lives in the area. Finally, this work adds another mosaic to the knowledge of ornamental marine crabs.

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