Morphometric variation in pink shrimp populations at Rio de Janeiro coast (SE Brazil): are they really similar in closer areas?

CÁSSIA DE CARVALHO[1], KARINA A. KEUNECKE[2] and HELENA P. LAVRADO[1]

[1]Programa de Pós-Graduação em Zoologia do Museu Nacional, Universidade Federal do Rio de Janeiro (PPGZoo/MN-UFRJ), Departamento de Biologia Marinha, Instituto de Biologia, Av. Pau-Brasil, 211, Prédio do CCS - Bloco A, Ilha do Fundão, 21949-900 Rio de Janeiro, RJ, Brazil
[2]Departamento de Biologia Animal, Instituto de Ciências Biológicas e da Saúde, Universidade Federal Rural do Rio de Janeiro, Rodovia BR 465, Km 7, 23897-000 Seropédica, RJ, Brazil

Abstract: *Farfantepenaeus brasiliensis* and *F. paulensis* are the most exploited shrimps of SE-S Brazilian coast. Our aim was to verify if adjacent nursery areas with different environmental condition (Sepetiba and Guanabara bays, SE Brazil) influence on shrimp populations (eg, CPUE) and body shapes. Samplings were carried out during 12 months in those bays ca. 85 Km far from each other. Carapace length (CL), total body length (TL), wet weight, abdomen size and TL/CL ratio were used to analyze variations in shape through regressions. In general, *F. brasiliensis* was 4 to 6 times more abundant than *F. paulensis*. The sex ratio differed from 1:1 in *F. brasiliensis* in both bays, with dominance of females, largest catches occur in autumn. However, differences in size and morphology were found between bays, mainly regarding the TL/CL ratio. Shrimps in Sepetiba Bay have higher TL/CL showing a more "elongated shape" (larger abdomen) when compared to those from Guanabara Bay. Results suggest the existence of an estuary vs shrimp morphology relationship which results in differences in body shape even in spatially close areas. TL/CL ratio has proven useful for assessing shrimp populations differences and might be tested for tracking the origin of adult shrimps stocks at the coast.

Key words: *Farfantepenaeus brasiliensis*, *Farfantepenaeus paulensis*, Guanabara Bay, morphometry, pink shrimps, Sepetiba Bay.

INTRODUCTION

Morphometric studies are considered one of the simplest, most commonly and cost-effective used tools to identify and characterize stocks or populations of fishes and crustaceans (Cadrin and Silva 2005, Bissaro et al. 2012). These studies can potentially contribute to aquaculture purposes, management and conservation strategies for a population and lead to a better understanding of species ecology, behavioral traits and stock assessment (Chu et al. 1995, Cadrin and Silva 2005, Silva et al. 2009).

Morphological variability reflects both environmental and genetic influences. Some studies about populations of decapod crustaceans

Correspondence to: Cássia de Carvalho
E-mail: carvalho.c89@gmail.com
ORCid: https://orcid.org/0000-0003-4405-6789

suggested these differences as possible adaptive responses to the environment (Chow and Sandifer 1991, Silva et al. 2009, Dumont and D'Incao 2010, Bissaro et al. 2012). This condition is common in species with wide geographical distribution, like some penaeids, and it is called phenotypic plasticity.

The penaeids shrimps *Farfantepenaeus brasiliensis* (Latreille 1817) and *Farfantepenaeus paulensis* (Pérez-Farfante 1967), commonly known as pink shrimps, are native to western Atlantic Ocean and are the most exploited shrimp species of Brazil (Valentini et al. 2012). *Farfantepenaeus paulensis* is found from 12ºS (Bahia, Brazil) to 38ºS (Mar del Plata, Argentina), while *F. brasiliensis* exhibits a wider geographical distribution from 35ºN (North Carolina, USA) to 29ºS (Rio Grande do Sul, Brazil). Their geographical distributions present an overlapping in the Southeast and South of Brazil, from 12ºS to 29ºS (Pérez-Farfante 1967, D'Incao 1991, Costa et al. 2003).

For these species, estuaries are essential to complete their life cycle (type II lifecycle, Dall et al. 1990). It includes an estuarine phase, when post-larvae enter the mouth of the estuaries, disperse into the inner reaches, settle and become juveniles, grow and subsequently migrate to the sea as sub-adults (Garcia and Le Reste 1981). The estuarine phase is characterized by rapid growth and continuous migration, thus generating a short residence time within estuaries (4 to 6 months, Garcia and Le Reste 1981, D'Incao 1991).

Guanabara and Sepetiba bays are important nursery grounds for pink shrimps at Rio de Janeiro State, SE Brazil (Dias Neto 2011). Those bays also support artisanal pink shrimp fisheries (Vianna 2009). They are close geographically (ca. 85 km) but are different in terms of environmental conditions, including chlorophyll (higher at Guanabara Bay, Fiori et al. 2013) and water transparency (higher at Sepetiba Bay, Araújo et al. 2006). Both bays have suffered considerably from intense input of various sources of pollution and other human impacts as embankments and dredging. The main environmental issue in Guanabara Bay is the input of domestic sewage without treatment, while in Sepetiba Bay is the waste of heavy metals from industrial activities (Fiori et al. 2013). However, the bays still exhibit characteristics of typical tropical estuaries, such as high primary productivity and favourable conditions for growth and reproduction of many estuarine and marine species (Araújo et al. 2006, Gomes et al. 2013, Da Silva et al. 2016, Moraes and Lavrado 2017).

It has been reported that *F. brasiliensis* and *F. paulensis* shrimps present considerable intraspecific and interspecific variability (Teodoro et al. 2016). The morphometry of pink shrimps have already been investigated in continental shelf of the Southeast-South of Brazil (eg, Neto 1985, Leite Jr and Petrere Jr 2006) and in estuarine systems (eg, Branco and Verani 1998a, 1998b, Albertoni et al. 2003, Freitas Jr et al. 2011), but none of them with a comparative approach between geographically close areas. Most of the studies investigated differences in their spatial distribution and abundance without regarding morphological differences (eg, Costa et al. 2008, 2016, Lüchmann et al. 2008).

In this context, the aim of this work was to characterize and compare the population structure, size and morphological shape of *F. brasiliensis* and *F. paulensis* that coexist in two geographically close bays at SE Brazilian coast (Sepetiba Bay and Guanabara Bay). Although these bays are environmentally different, they do not seem to have any physical, geological and oceanographic barriers that may prevent dispersion. Our hypothesis is that adjacent nursery areas geographically close but environmentally different can influence on shrimp population structure and their body shapes. We also provide morphometric and population structure information which can be useful for shrimp stock identification purposes and for future shrimp management and monitoring programs in SE Brazilian coast.

MATERIALS AND METHODS

STUDY AREA

The climate of the Rio de Janeiro State is classified as tropical wet with a relatively dry winter and intense rainfall in the summer (Kjerfve et al. 1997, SEMADS 2001). The dry period occurs from May to October while the rainy season occurs from November to April according to historical monthly rainfall data (Geo-Rio 2013). Some physical and hydrological characteristics of Guanabara Bay and Sepetiba Bay (Figure 1) are summarized in Table I.

Guanabara Bay is a highly eutrophic estuary located in the center of the metropolitan region of Rio de Janeiro city, southeastern Brazil (Figure 1) and is the second largest Brazilian bay in terms of area. Approximately 12 million inhabitants live within the Guanabara Bay drainage basin (Soares-Gomes et al. 2016). This bay is strategically located adjacent to one of the most industrialized regions of the country and under the influence of numerous fishing and commercial port facilities, in addition to shipyards and oil refineries (Da Silva et al. 2016). Hydrological conditions are heterogeneous within the bay, depending on circulation patterns and pollution *foci* (Da Silva et al. 2016). During the summer, water column stratification is observed, forming a pycnocline. In winter, water conditions are more homogeneous (Ribeiro and Kjerfve 2002, Soares-Gomes et al. 2016).

Sepetiba Bay is a sedimentary embayment located ca. 85 km to the west of Guanabara Bay (Figure 1). Fifteen cities surround the bay (~2 million people). One of the largest port and industrial complexes of Brazil are located at its drainage area, and this complex continues arising at the present days (Fiori et al. 2013). It presents a circulation pattern resulting in great mixing in the water column and a low or nonexistent stratification (SEMADS 2001).

TABLE I
Main physical and hydrological characteristics of Guanabara Bay and Sepetiba Bay.

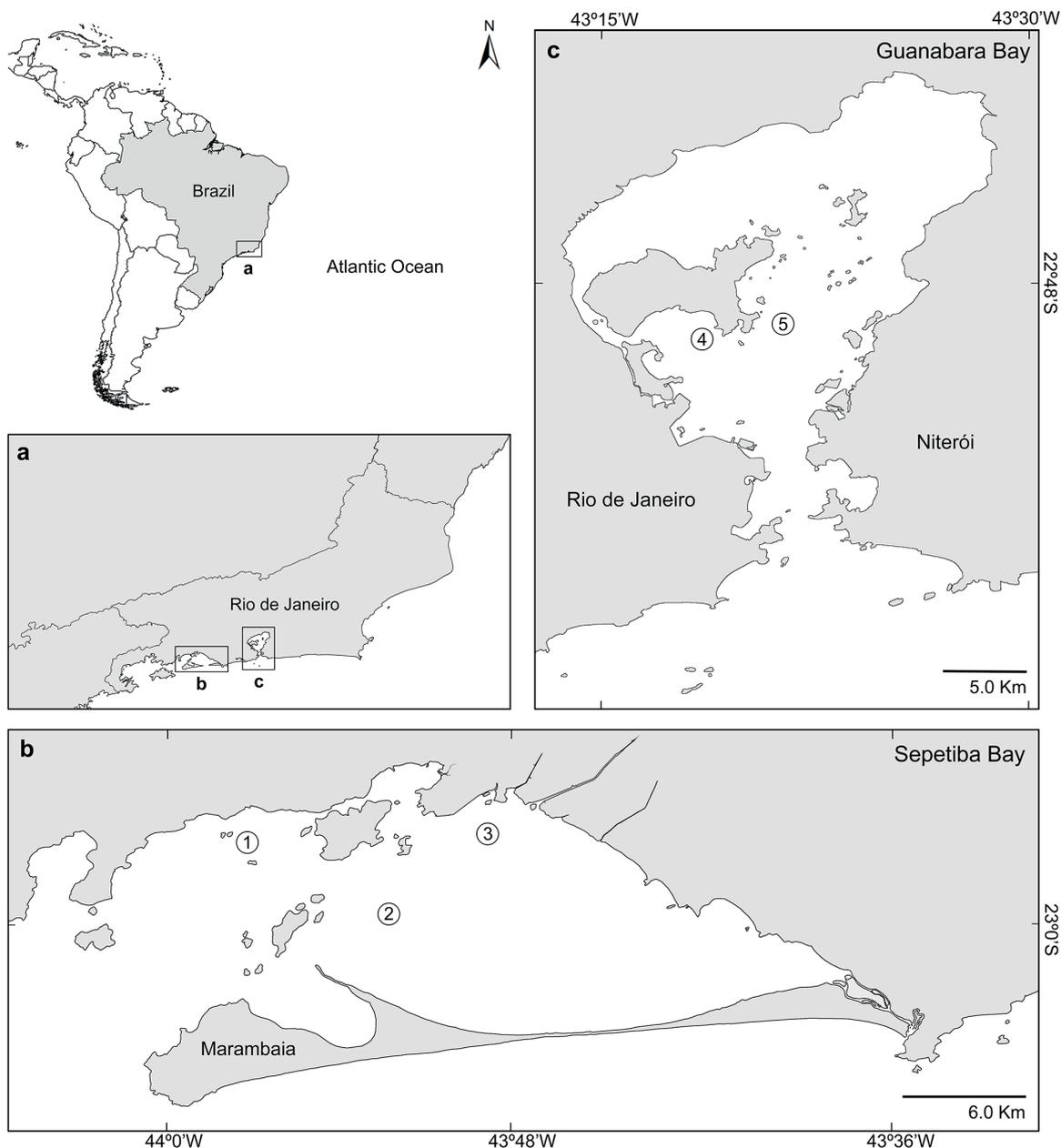|	Guanabara Bay	Sepetiba Bay
Coordinates	22°44'–22°57'S, 42°33'–43°19'W	22°53'–23°04'S, 43°34'– 44°10'W
Area	380 km^2 (Soares-Gomes et al. 2016).	305 km^2 (SEMADS 2001).
Salinity	13 (inner areas) to 34 (central channel) (Soares-Gomes et al. 2016).	20 (inner areas) to 34 (near Restinga da Marambaia) (SEMADS 2001).
Depth	The average depth is 5.7 m (maximum value – 58 m near the central channel) (Kjerve et al. 1997, Costa 1998).	From two to 31 m (near Itaguaí harbor), but ~ 50% of its area is less than 6 m (SEMADS 2001).
Tide mode	Semi-diurnal tide – 0.7 m tide range on average (Da Silva et al. 2016).	Semi-diurnal tide – 0.8 m tide range on average (SEMADS 2001).
Sediments	Bay mouth is mainly sandy; inner areas (south-north) are mainly muddy (Soares-Gomes et al. 1997).	Outer areas are mainly sandy; inner areas (west-east) are mainly muddy (SEMADS 2001).
Water stratification	Stratification mainly in summer period (Ribeiro and Kjerfve 2002).	No evident stratification (SEMADS 2001).
Chlorophyll-a (µg/L)	20.00 (Fiori et al. 2013).	4.22 (Fiori et al. 2013).
Mean Water transparency (m)	Inner area - 0.9 (0.3) Middle area - 1.3 (0.8) Outer area - 2.4 (1.0) (Santi and Tavares 2009)	Inner area - 1.7 (0.1) Middle area - 2.9 (0.1) Outer area - 3.6 (0.2) (Araújo et al. 2006)

Figure 1 - (**a**) Rio de Janeiro State, Brazil. Sampling areas in (**b**) Sepetiba Bay: 1: outer; 2: central; 3: inner areas, and (**c**) Guanabara Bay: 4: Fundão; 5: central channel.

SHRIMP SAMPLINGS AND LAB ANALYSIS

Samplings were carried out during 12 consecutive months (August 2011 to July 2012). A typical 10-m long boat from the artisanal shrimp fleet was used, equipped with an 11-m long shrimp trawl net and a 20-mm mesh size at the cod end. Six experimental hauls (30 min per haul) were conducted per month in each bay, in zones with depths varying from 4 to 27 m in Guanabara Bay (near Fundão Island and central channel areas, Figure 1) and from 4 to 17 m in Sepetiba Bay (outer, central, inner areas, Figure 1). In laboratory, shrimps were kept frozen before analysis. The specimens were sexed and identified following Costa et al. (2003). The carapace length

(distance from the postorbital margin to the mid-dorsal posterior edge of the carapace, CL) and total body length (distance from the tip of the rostrum to the tip of the telson, TL) were taken using a digital caliper (±0.01 mm). Analytical balance with accuracy of 0.01 g was used to record body wet weight (W). The abdomen size (ABD, mm) was estimated by the difference between the total length and the carapace length including the rostrum.

Juvenile shrimps were those with ≤ 25 mm carapace length, while adult shrimps were those with ≥ 35 mm carapace length due to observation of developing gonads and Gomes et al. (2013).

DATA ANALYSES

The proportion of *F. brasiliensis* by *F. paulensis* was compared between bays using a Chi-square test (χ^2). The deviation from the theoretical sex ratio (1:1) for each species was also evaluated using χ^2 (Zar 1999).

The CPUE average (individuals per haul) was calculated *per* season, bay, and species. A one-way Analysis of Variance (ANOVA) was used to compare CPUE by species between seasons in each bay. The CPUE data were log(x+1) transformed when necessary in order to achieve the ANOVA assumptions of normality and homoscedasticity. *A posteriori* Tukey's test was used to make pair wise comparisons (Zar 1999).

The means, standard deviations, maximum-minimum values and coefficient of variation (CV %) of all measurements (CL, TL, ABD, W) and TL/CL ratio were recorded for each sex, species and bay. All variables were compared between bays, sexes or species using a Student t test (Zar 1999).

Linear (TL=a+b.CL) and nonlinear regressions (W=a.TL^b) were used to evaluate the length-length and length-weight relationships. A Student t test was applied to evaluate the isometric nature of the length-weight relationships (b=3). The same test was also applied to compare the slope (b) of the length-length regressions between sexes or bays. As very large samples may allow for an easier rejection of the null hypothesis even if there are small differences, the effect size of Cohen (Cohen 1988) was calculated *a posteriori.* Cohen's d values of less than 0.19 indicate a very small effect size which means that the magnitude of the differences between groups are biologically irrelevant even it is statistically significant. Cohen's U_3 was also calculated as a measure of non-overlap, i.e., the percentage of population A that will be above the mean of the population B.

All statistical analyses were performed using Statistica 7 for Windows and R software with a 5% significance level.

RESULTS

A total of 7,243 *F. brasiliensis* and 1,518 *F. paulensis* specimens were examined. From those, 4,267 shrimps were sampled in Guanabara Bay (GB) and 4,494 in Sepetiba Bay (SB) during the study period. The total abundances of each species was similar in both bays (Table II), but the ratio of *F. brasiliensis/F. paulensis* was significantly different between bays (GB=3.91:1, SB=5.91:1, χ^2=48.17, p<0.05). The ratio in SB is ca.1.5 times higher than that found in GB. In general, females are more abundant than males for both species in both bays, but the sex ratio was significantly different from 1:1 only for *F. brasiliensis* in both bays (Table II).

The species CPUE values were statistically different among seasons only in SB (Table III) with larger catches recorded in autumn: April-June (F=4.71, p=0.005 and F=8.10, p=0.0001 for *F. paulensis* and *F. brasiliensis*, respectively). A similar trend was found for *F. paulensis* in GB (F=2.66, p=0.06, Table III), but the same did not occur with *F. brasiliensis* (F=0.48, p=0.70) probably due to CPUE variation between seasons (standard deviation values, Table III).

TABLE II
Total abundance and sex ratio for each species (*F. brasiliensis* and *F. paulensis*) and bay. P-values in bold indicate significant departure from the 1:1 sex ratio (Chi-square test, p < 0.05).

Species	Bay	Females (n)	Males (n)	Sex ratio F:M	χ^2	p-value
F. brasiliensis	Sepetiba	1,998	1,846	1.08	**6.01**	**0.013**
	Guanabara	1,802	1,597	1.13	**12.36**	**0.001**
F. paulensis	Sepetiba	332	318	1.04	0.006	0.610
	Guanabara	437	431	1.01	0.041	0.860

TABLE III
Comparison of CPUE average (nº ind/30-min haul) of pink shrimp species (*F. brasiliensis* and *F. paulensis*) per season.

Bay	Species	Season			
		Spring	Summer	Autumn	Winter
GB	*F. brasiliensis*	9.7±8.4[a]	34.3±40.1[a]	105.9±184.8[a]	36.5±40.3[a]
	F. paulensis	0.6±0.9[a]	3.6±7.7[a]	35.1±81.6[a]	8.3±14.3[a]
SB	*F. brasiliensis*	12.8±9.2[ab]	61.3±56.7[bc]	88.8±58.0[c]	50.3±89.1[a]
	F. paulensis	2.1±3.1[a]	7.4±11.0[ab]	18.3±17.6[b]	8.4±18.3[a]

GB = Guanabara Bay; SB = Sepetiba Bay; spring = Sep-Nov/2011; summer = Dec/11-Feb/12; autumn = Mar-May/12; winter = Aug/11 and Jun-Jul/12. Different letters indicate significant differences (one-way ANOVA, p < 0.05), considering by species and bay, n = 18 (hauls per season).

More than 97% of the shrimp sampled in the bays were juveniles or subadults (carapace length >25 mm and < 35 mm). Considering the biometric variables, the abdomen (ABD) and total length (TL) was significantly greater for Sepetiba Bay individuals (exception for TL in males of *F. paulensis*, Table IV). For both species, the individuals from SB also showed greater TL/CL ratios. The mean value of TL/CL ratio was 4.6 in SB, being higher than GB (4.1 to 4.3, Table IV). That ratio showed to be very stable within each population (CV less than 10%) considering the CL-size range of the collected shrimps (10-45 mm for *F. brasiliensis* and 8-50 mm for *F. paulensis*) and it distinguishes individuals between bays. The high values of Cohen's d and Cohen's U_3 indicate that the statistical differences are biologically relevant (Table III). For example, a Cohen's d of 1.99 (for differences of *F. brasiliensis* males TL/CL averages between bays) means that 97.7% of individuals from Sepetiba have TL/CL ratio above the average

ratio value of males from Guanabara Bay (Table IV). The differences in TL/CL ratios were larger for *F. brasiliensis* than those for *F. paulensis* (t-values and Cohen's d).

The TL-CL relationships were also significantly different between bays for both species and different between sexes (exception for *F. brasiliensis* in GB, Tables V and VI, Figure 2). But Cohen's d values > 1.15 were detected only when comparing the bays, which means that the TL growth variation was more related to areas rather than to sex (Table VII). The abdomen size increases faster than the carapace for Sepetiba individuals as the shrimp grows in length. The differences in TL-CL relationships were larger also for *F. brasiliensis* than *F. paulensis*.

The pink shrimps from Sepetiba Bay presented a negative allometry (b<3, W-TL relationship) while those from Guanabara Bay presented a positive allometry, b>3, with the exception of *F. brasiliensis* males (Table VII), indicating the increase in length was greater than weight in individuals of SB, the
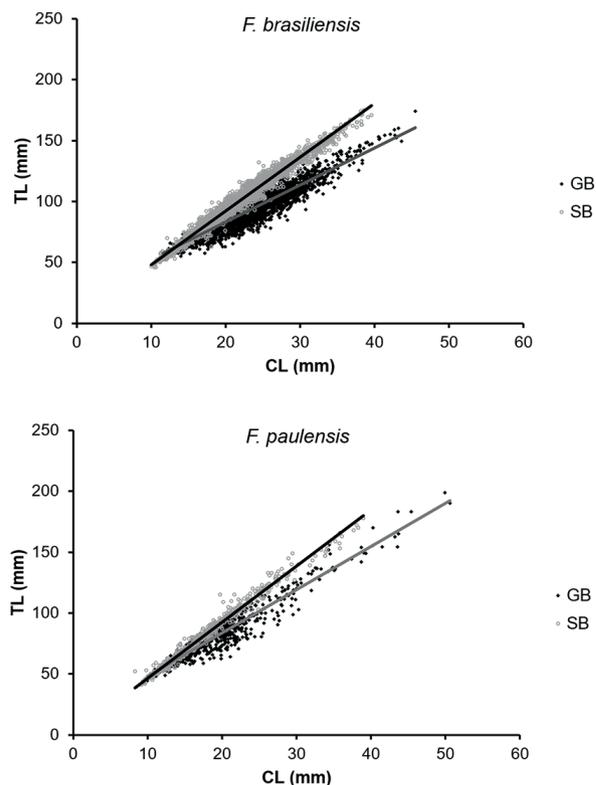
Figure 2 - Linear regressions (total length-carapace length relationship) for *F. brasiliensis* and *F. paulensis.* Black crosses = Guanabara Bay shrimps; Grey circles = Sepetiba Bay shrimps. TL = total length (mm); CL = carapace length (mm); GB = Guanabara Bay; SB = Sepetiba Bay.

opposite occurring in GB. The *b* coefficient was also different between bays with very large or large size effect for *F. paulensis* (Table VIII). However, when comparing females and males in each bay, the *b* value was significantly different for the two species only in Sepetiba Bay (Table VIII).

DISCUSSION

The dominance of *F. brasiliensis* over *F. paulensis*, observed in this study, is common in lower latitudes in the Southern hemisphere (12ºS), while the presence of *F. brasiliensis* in latitudes further south (close to its southern limit of distribution) is occasional according D'Incao et al. (2002). However, this tendency is not an ecological pattern (Table IX) because no evident latitudinal variation

of the *F. brasiliensis* / *F. paulensis* ratio (Fb/Fp) was observed. The dominance of *F. brasiliensis* occurred in shallow coastal areas (bays, lagoons) and continental shelf in Brazilian tropical and subtropical areas (Table IX). On the other hand, the dominance of *F. paulensis* can be observed only in very shallow estuarine areas from 27º30'S (Table IX). Freitas et al. (2011) also found a large variation of the Fb/Fp ratio (1.39-7.70) during the study period (1997-2006) in Saco dos Limões, Southern Bay, Santa Catarina, Brazil (Table IX). The authors suggested that this variation was associated with interannual mortality and recruitment variability of *F. brasiliensis*, since *F. paulensis* populations remained stable over time. But the increase of anthropogenic influence (effluent discharge and dredging activities have been increasing since 1995 in the region) may represent an important driving factor for the observed changes in the ratio of these species. In Imboassica lagoon, on the northeast coast of the Rio de Janeiro state, the variation of Fb/Fp ratio was 0.50-6.10 (Albertoni et al. 2003, average value in Table IX). This lagoon is characterized by presenting events of "man-made openings" throughout the year. Albertoni et al. (2003) reported that the changes in environmental conditions of Imboassica lagoon reflected negatively on the relative condition factor and growth rates of *F. brasiliensis* and *F. paulensis* species. The observed variation of Fb/Fp ratio along their distribution range suggests the existence of a habitat partition between the species caused by recruitment and mortality events as well as anthropogenic action rather than by latitudinal gradients.

We found a clear change in the Fb/Fp ratio in Sepetiba Bay after almost 30 years (Table IX). The species *F. brasiliensis* and *F. paulensis* occurred at approximately 0.51-1.37 Fb/Fp ratio of shrimp catches in Sepetiba Bay almost three decades ago (Oshiro and Araújo 1987). On the other hand, after a 10-year period, little variation in this ratio was found in Guanabara Bay compared to that found

TABLE IV

Comparison of the biometric variables (CL, TL, TL/CL, ABD, W) of females (F) and males (M) of *F. brasiliensis* and *F. paulensis* between two bays (Guanabara Bay = GB, Sepetiba Bay = SB).

Species	Sex	Variable	Sepetiba Bay				Guanabara Bay				t value	p value	Cohen's d	Size effect	Cohen's U₃ (%)
			N	Mean	SD	CV %	N	Mean	SD	CV %					
F. brasiliensis	F	CL	1,994	22.7	5.7	25.1	1,781	22.9	5.3	23.3	0.8	0.42	0.03	non-sign.	54.0
		TL	1,994	103.5	25.1	24.3	1,781	91.6	16.9	18.4	**16.9**	<0.0001	0.55	medium	72.6
		TL/CL	1,994	4.6	0.2	4.3	1,781	4.1	0.4	8.5	**58.4**	<0.0001	1.78	very large	96.4
		ABD	1,994	66.9	16.1	24.1	1,781	54.7	9.4	17.2	**28.0**	<0.0001	0.91	large	81.6
		W	1,994	10.5	7.3	70.0	1,801	7.3	5.0	68.9	**15.4**	<0.0001	0.50	medium	69.2
	M	CL	1,844	21.1	4.5	21.2	1,579	22.0	4.3	19.7	**6.0**	<0.0001	0.20	small	58.0
		TL	1,844	97.6	20.6	21.1	1,579	89.5	14.5	16.2	**12.9**	<0.0001	0.44	small	65.5
		TL/CL	1,844	4.6	0.2	4.3	1,579	4.1	0.3	7.3	**59.0**	<0.0001	1.99	very large	97.7
		ABD	1,844	63.5	13.5	21.3	1,579	54.0	8.7	16.1	**23.9**	<0.0001	0.82	large	78.8
		W	1,597	8.4	4.8	57.5	1,579	6.4	3.4	53.9	**13.9**	<0.0001	0.48	small	69.2
F. paulensis	F	CL	330	18.0	5.8	32.2	433	18.7	5.6	29.8	1.6	0.11	0.11	non-sign.	54.0
		TL	330	82.9	26.2	31.6	433	79.0	19.8	25.1	**2.3**	0.02	0.17	non-sign.	58.0
		TL/CL	330	4.6	0.2	4.3	433	4.3	0.3	7.0	**17.2**	<0.0001	1.15	very large	88.5
		ABD	330	52.9	16.6	31.4	433	48.0	11.1	23.1	**4.9**	<0.0001	0.36	small	65.5
		W	332	6.1	7.0	115.7	437	4.8	6.6	137.5	**2.6**	0.01	0.19	non-sign.	58.0
	M	CL	312	16.9	4.7	27.9	427	18.9	5.3	28.1	**5.3**	<0.0001	0.40	small	65.5
		TL	312	78.8	23.3	29.6	427	79.5	20.4	25.7	0.4	0.66	0.03	non-sign.	54.0
		TL/CL	312	4.6	0.2	4.3	427	4.2	0.4	9.5	**18.9**	<0.0001	1.21	very large	88.5
		ABD	312	50.1	15.5	30.9	427	48.0	12.3	25.6	**2.6**	0.01	0.15	non-sign.	58.0
		W	314	4.9	4.2	85.8	431	4.9	5.7	116.6	0.1	0.95	0.00	non-sign.	54.0

CL = carapace length (mm); TL = total length (mm); ABD = abdomen (mm); W = wet weight (g); SD = standard deviation; CV = coefficient of variation. Values in bold indicate p < 0.05, according to Student t-test (t). non-sign. = non-significant.

TABLE V
Parameter values of the equation TL=a+b.CL for each sex, species (*F. brasiliensis* and *F. paulensis*) and bay.

Species	Bay	Sex	N	a±SE	b±SE	r^2
F. brasiliensis	Sepetiba	F	1,994	4.57±0.33	4.36±0.01	0.98
		M	1,844	1.82±0.38	4.53±0.02	0.97
		Grouped sexes	3,838	3.90±0.25	4.41±0.01	0.98
	Guanabara	F	1,781	22.63±0.62	3.02±0.03	0.94
		M	1,579	22.07±0.78	3.06±0.03	0.83
		Grouped sexes	3,360	22.52±0.48	3.03±0.02	0.93
F. paulensis	Sepetiba	F	330	3.04±0.66	4.44±0.03	0.98
		M	312	-4.05±0.54	4.90±0.03	0.99
		Grouped sexes	642	0.45±0.46	4.61±0.03	0.98
	Guanabara	F	433	14.50±0.80	3.46±0.04	0.94
		M	427	10.54±1.16	3.64±0.06	0.90
		Grouped sexes	860	12.65±0.70	3.55±0.04	0.96

TL = total length (mm); CL = carapace length (mm); F = females; M = males; SE = standard error.

TABLE VI
Comparisons of *b* values (TL=a+b.CL) for each sex, species (*F. brasiliensis* and *F. paulensis*) and bay.

Species	Sex	Bays	t-value	Cohen's d	Size effect	Cohen's U_3 (%)
F. brasiliensis	F	SB x GB	**33.04**	1.50	very large	93.3
	M	SB x GB	**28.22**	1.35	very large	91.9
	Grouped sexes	SB x GB	**42.99**	1.42	very large	91.9
	F x M	SB	**5.40**	0.25	small	61.8
	F x M	GB	0.66	0.03	non-sig.	<54.0
F. paulensis	F	SB x GB	**12.77**	1.27	large	90.3
	M	SB x GB	**13.99**	1.27	large	90.3
	Grouped sexes	SB x GB	**17.38**	1.18	large	88.5
	F x M	SB	**7.00**	0.78	medium	78.8
	F x M	GB	**1.83**	0.17	non-sig.	57.9

TL = total length (mm); CL = carapace length (mm) between sexes or bays. Values in bold indicate p<0.05 according to Student t-test (t). F = females; M = males; SB = Sepetiba Bay; GB = Guanabara Bay; non-sig. = non-significant.

by P.M. Golodne (unpublished data, Table IX). Our results suggest a demographic change of pink shrimp populations in Sepetiba Bay not related to large-scale environmental changes (hundreds of km). In both bays, pink shrimps are the most abundant shrimp species (Oshiro and Araujo, 1987, Lavrado et al. 2000), but there are no studies about long-term temporal changes regarding other shrimp species that could be used for comparisons. Future studies are needed to follow up these populations in these bays to clarify which are the local environmental drivers of those temporal changes.

Sexual ratio is a feature that reflects population balance (Fisher 1930) and the ratio of 1:1 in penaeids shrimps is very common (Dall et al. 1990). However, the sex ratio differs from the

TABLE VII
Parameter values of the equation W=a.TL^b for each sex, species (*F. brasiliensis* and *F. paulensis*) and bay.

Species	Bay	Sex	N	a(x10^{-5})	b±SE	t-value	r^2
F. brasiliensis	Sepetiba	Females	1,681	1.00	2.96±0.01	**2.87**	0.97
		Males	1,541	1.50	2.86±0.02	**7.89**	0.96
		Grouped sexes	3,222	1.00	2.96±0.01	**3.75**	0.97
	Guanabara	Females	1,696	0.70	3.05±0.01	**3.98**	0.96
		Males	1,517	0.70	3.02±0.02	1.26	0.94
		Grouped sexes	3,213	0.60	3.06±0.01	**5.78**	0.91
F. paulensis	Sepetiba	Females	267	1.20	2.91±0.02	**4.33**	0.99
		Males	252	2.90	2.71±0.03	**10.00**	0.98
		Grouped sexes	519	1.20	2.92±0.02	**4.94**	0.98
	Guanabara	Females	399	0.50	3.10±0.01	**7.02**	0.99
		Males	403	0.40	3.13±0.02	**7.41**	0.99
		Grouped sexes	802	0.50	3.11±0.01	**10.11**	0.99

W = wet weight (g); TL = total length (mm); SE = standard error. Values in bold indicate p<0.05, (b≠3), according to Student t-test (t).

TABLE VIII
Comparisons of *b* values (W=a.TL^b) for each sex, species (*F. brasiliensis* and *F. paulensis*) and bay.

Species	Sex	Bays	t	Cohen's d	Size effect	Cohen's U$_3$ (%)
F. brasiliensis	Females	SB x GB	**3.40**	0.32	small	61.8
F. brasiliensis	Males	SB x GB	**4.51**	0.33	small	61.8
F. brasiliensis	Grouped sexes	SB x GB	**4.69**	0.26	small	61.8
F. brasiliensis	Females x Males	SB	**3.21**	0.27	small	61.8
F. brasiliensis	Females x Males	GB	0.88	0.05	non-sig.	54.0
F. paulensis	Females	SB x GB	**5.45**	2.02	very large	97.7
F. paulensis	Males	SB x GB	**9.04**	2.73	very large	99.7
F. paulensis	Grouped sexes	SB x GB	**6.95**	1.64	very large	94.5
F. paulensis	Females x Males	SB	**4.11**	1.26	large	90.3
F. paulensis	Females x Males	GB	0.79	0.72	medium	75.8

W = wet weight (g); TL = total length (mm) between sexes and/or between bays .Values in bold indicate p < 0.05, (b≠3), according to Student t-test (t). SB = Sepetiba Bay; GB = Guanabara Bay; non-sig. = non-significant.

expected ratio of 1:1 for *F. brasiliensis* in both bays in the present study. Possible causes for that difference are the existence of a segregated distribution (spatial partition between males and females) and/or differential mortality associated to dimorphism in growth between sexes, where males usually have larger constant k, and consequently, higher mortality rates (Garcia and Le Reste 1986,

Dall et al. 1990). Besides, the sexual dimorphism in size (females being bigger than males) might result in higher mesh size selection during trawling, leading to the biased proportion toward females (Kevrekidis and Thessalou-Legaki 2006).

According to Geisel (1972), populations that are physiologically and behaviorally homeostatic and occupy relatively constant environments tend

to show the sexual ratio of 1:1 or a slightly increased ratio in the number of males. On the other hand, populations inhabiting variable environments will show an increase in the number of females in order to maximize the evolutionary potential due to unequal selection between the sexes. Guanabara Bay (GB) and Sepetiba Bay (SB) have been both suffering from anthropic impacts for decades, mainly as a result of urbanization and disordered industrial development causing significant changes in these ecosystems and making them more variable. In turn, this may be reflecting on the balance of these populations, especially *F. brasiliensis*, increasing the number of females over time. Previous studies at Guanabara Bay (P.M. Golodne, unpublished data, Table IX) and Sepetiba Bay (L.M.Y. Oshiro et al., unpublished data, Table IX) did not reveal a significant difference in *F. brasiliensis* sex ratio a decade ago (2005-2007 in GB and 2004-2005 in SB) which suggests an increase in male mortality due to environmental changes on a regional scale (tens to hundreds of km) such as coastal circulation or rainfall variation.

These large-scale factors could also explain the annual variation of CPUE of the species in the two bays (Table III). Although the seasonal variation was significantly different only in SB, it followed the same trend in GB with a peak in autumn followed by a decrease in winter. The main cues for the migration of juveniles to offshore areas involve intrinsic factors (eg, shrimp size) but also extrinsic factors (eg, rainfall and temperature, Dall et al. 1990, Costa et al. 2008). Rainfall and temperature presented similar oscillations in the study region. Thus, the migration of pink shrimps from nursery areas to offshore areas appeared to follow the same environmental cues.

In general, differences in size and morphology between bays were observed in all analyses in the present study. Even using few morphometric variables, our results point out relevant morphological differences of both species in two

geographically close bays, which may indicate different subpopulations or phenotypic variability. Some attempts have already been made to identify differences in morphometric traits and correlate such traits with geographic location for some penaeids shrimp species for fishing management or genetic resources (Barcia et al. 2005, Paramo and Saint-Paul 2010, Carvalho-Batista et al. 2014). However, other authors showed that natural populations of penaeids shrimps do not appear to be finely subdivided (Chow and Sandifer 1991, Gusmão et al. 2005, Teodoro et al. 2015). A genetic homogeneity among shrimps on the Brazilian coast have been reported for *Artemesia longinaris* Bate 1888 (Carvalho-Batista et al. 2014), *F. brasiliensis* (Gusmão et al. 2005), *L. schmitti* (Burkenroad 1936) (Gusmão et al. 2005) and *F. paulensis* (Teodoro et al. 2015). The populations homogeneity was justified by the larval dispersal period (around 12 to 21 days) characterized by larval development up to the first post-larval stage (settlement) (Dall et al. 1990). Swimming capacity and migratory movements of sub-adult and adult individuals may also contribute to mixing the gene pool of populations. The fisheries effort in shrimp populations were also indicated as a factor of population homogenization (Barcia et al. 2005, Gusmão et al. 2005, Teodoro et al. 2015). Considering the fishing pressure on the penaeids shrimps stocks for several decades, a reduction in the genetic diversity of these organisms is to be expected. In Brazil, pink shrimp industrial fisheries has been taking place for more than five decades and by the end of 1970's a reduction in stocks has already been detected (D'Incao et al. 2002, Valentini et al. 2012).

Considering that most individuals are juveniles or sub adults of both bays and genetically similar, this leads us to infer that differences in environmental conditions influence on the shrimp metabolism and growth (k parameter, for example) causing the observed differences in their body shapes. Similar results were found for *F. brasiliensis*

TABLE IX

F. brasiliensis/F. paulensis ratio (Fb/Fp) in tropical and subtropical coastal areas of S-SE Brazil (22°S-29°S). In ascending order of latitude.

Local	Coordinates	Depth (m)	Fishing gear	Study period	Ratio (Fb/Fp)	Study
Imboassica Lagoon, RJ	22°25'S, 41°42''W	0.1-1.5*	Trawl net and casting net (no mesh size data)	Jun/1995-Sep/1997	3.12	Albertoni et al. (2003)
Guanabara Bay, RJ	22°41'-22°56'S, 43°02'-43°18''W	2.7-15.2**	Trawl net (20-mm mesh size at the codend)	Jul/2005-Jun/2007	4.04- 5.55	P.M. Golodne (unpub data)
Guanabara Bay, RJ	22°41'-22°56'S, 43°02'-43°18''W	4.6-26.0*	Trawl net (20-mm mesh size at the codend)	Aug/2011-Jul/2012	3.91	**Present study**
Sepetiba Bay, RJ	22°54'-23°04'S, 43°34'-44°10'W	0.1-1.5 m*	Beach seining (7 mm mesh size)	Jun/1983-Jun/1984	0.51-1.37	Oshiro and Araujo (1987)
Sepetiba Bay, RJ	22°54'-23°04'S, 43°34'-44°10'W	7.0 -14.0*	Trawl net (20-mm mesh size at the codend)	Aug/2011-Jul/2012	5.91	**Present study**
Continental shelf, RJ	23°-25°S	?	Industrial fishing landing. (Double trawl net)	Jul/2000-Feb/2001	1.46	Paiva and Fonteles-Filho (2004)
Ubatuba region, SP	23°20'15''S-23°31'43''S, 44°53'39''-45°12'54''W	5.0-20.0*	Double trawl net (20-mm mesh size at the codend)	Jan/1998-Dec/1999	2.13-2.22	Costa et al. (2016)
Ubatuba and Caraguatatuba, SP	23°26'27''- 23°36'09''S 45°03'18''- 45°20'25''W	4.3-36.1**	Double trawl net (20-mm mesh size at the codend)	Jul/2001-Jun/2003	7.25	Castilho et al. (2008)
Continental shelf, SC	26°-28° S	25.0-70.0*	Industrial fishing landing. (Double trawl net)	Aug/1983-Jun/1985	2.67	Neto (1985)
Conceição Lagoon, SC	27°30' - 27°36'15''S, 48°25' - 48°30'W	0.3-1.5**	Handy shrimp trap net ("bernunça") (5 mm- mesh size)	May/1992-Apr/1993	0.22	Branco and Verani (1998a, 1998b)
Conceição Lagoon, SC	27°34'S - 48°27' W	0.5-1.0**	Casting net (10-mm mesh size)	Sep/2003-Aug/2004	1.66	Luchman et al. (2008)
Saco dos Limões, Sul Bay, SC	27°36' - 27°39'S, 48°33'-48°31'W	2.0-8.0**	Double trawl net (20-mm mesh size at the codend)	1997, 2000 -2006	1.39-7.70	Freitas et al. (2011)
Lagoa Ibiraquera, SC	28°06'18'' 28°10'16''S 48°37'44''- 48°41'53''W	0.2-2.0**	Casting net (27-mm mesh size)	Feb/2004-Feb/2005	0.03	Ferreira and Freire (2009)

RJ = Rio de Janeiro state; SC = Santa Catarina state; SP = São Paulo state. (*) depth variation (min-max). (**) variation of depth averages in different areas. (?) data not found. unpub data = unpublished data.

on the northeast coast of Brazil (5º11''56'-6º22'10''S and 35º00''- 35º25'W – A.P. Pinheiro, unpublished data). That author found significant morphometric differences (CL, TL, ABD and W) for *F. brasiliensis* between sites, mainly when the sexes were grouped. Females of *F. brasiliensis* were more different between sites than males but F_{st} values did not show genetic structuring.

There is a consensus on the influence of environmental conditions on morphological variability of certain body structures such as size and shape of carapace, rostrum and abdomen. For *Penaeus monodon* Fabricius 1798 populations in Indian Ocean, the extensive morphometric variability found was mainly due to variation in carapace length and width, with males presenting more evident phenotypic differences among areas (Sun et al. 2014). The phenotypic plasticity of size and shape of the chelae also occur in some brachyurans, being related to responses to environmental cues such as food availability (diet) and temperature (Smith 2004, Baldridge and Smith 2008, Silva et al. 2009). In addition, variation of one structure may be more evident than another, as reported by Brian et al. (2006) for *Carcinus maenas* (Linnaeus 1758), where the variation in chelae shape was more conspicuous than the variation in carapace shape.

In the present study, the TL/CL ratio variation between bays was more evident than carapace length (CL) and total length (TL). Sepetiba Bay shrimps had a more "elongated shape" (greater TL/CL ratios) while shrimps from the Guanabara Bay had a "shorter shape". The differences mainly lie in the size of abdomen, which is larger in SB individuals. Those differences in shape may also be related to differences in shrimp diets between bays. The isotopic composition of shrimps (C. Carvalho, unpublished data) showed that SB individuals have higher nitrogen isotope levels (δ^{15}N, mean value = 12.3‰) than those from Guanabara Bay (mean value = 7.5 ‰). This suggests that SB shrimps may

occupy a higher trophic position, ingesting different preys which in turn can influence on the weight and abdomen size during growth. It has been already known that *F. paulensis* and *F. brasiliensis* increase in weight when they are submitted to a protein-rich diet (Ballester et al. 2010). On the other hand, the stress due to organic pollution may also interfere on shrimp growth. Guanabara Bay is more eutrophic than Sepetiba Bay and has a lower water quality level and a higher ecological risk for the marine biota (Fiori et al. 2013). In that case, the high energy costs associated to a poor quality food could reduce the abdomen growth in length even if total weight remains higher for GB individuals as a function of higher food availability.

Differences in ratio (TL/CL) were observed in both sexes. Larger abdomen in female prawns of the infraorder Caridea is common because they carry their eggs in the pleopod until hatching, but this reproductive behavior does not occur with penaeids. The ontogenetic variation in the abdomen size exists in some Decapoda (eg, Astacidea, Caridea) (Arnott et al. 1998). Astacidea juveniles present a larger abdomen compared to adults in response to predators by tail-flipping, while adults use their claws against predators (Arnott et al. 1998). So, a larger abdomen in juveniles may favor the escape from visual predators, such as fishes, squids and cetaceans. That feature can represent an advantage for the pink shrimps on Sepetiba Bay, where waters are less turbid than those from Guanabara Bay (Araújo et al. 2006, Table I).

It is known that interactive effects of environment, natural selection, and genotype variation on individual ontogeny produce morphometric differences within a species and between different geographic areas (Cadrin 2000). Thus, the existence of estuary *vs* shrimp life cycle (types I, II or III, Dall et al. 1990) relationship can result in differences of population structure in spatially close areas even when those areas are not separated by evident physical, geological and

oceanographic barriers. This variation usually is a result of differences in development rates of each species where morphometric discrimination is probably the result of different feeding strategies, reproductive rates and growth, for example (Cadrin 2000). Variations in parameters such as body size, sexual maturity and longevity are influenced by habitat conditions correlated with latitude (eg, water temperature and food/nutrient supply) (Castilho et al. 2007). Considering that a 30-mm CL pink shrimps are at least 9-11 months old in both bays (using growth equations found in D'Incao 1991) and that post-larvae usually penetrate an estuary by the age of one month, pink shrimps remain inside the bays time enough to have their morphology and growth be affected by habitat conditions.

Although morphometric differences are found in *F. brasiliensis* and *F. paulensis* in the present study, this cannot be generalized for the whole genus *Farfantepenaeus* Burukovsky, 1997. The morphometrics of *F. notialis* Pérez-Farfante, 1967 in four different geographical regions along the Colombian Caribbean Sea, for instance, showed great homogeneity indicating the existence of a single population (Paramo and Saint-Paul 2010). In that case, authors suggested that the environmental conditions could not induce different morphologies in individuals of those four localities.

The TL/CL ratio proved to be a good indicator of phenotypic plasticity among subpopulations of pink shrimp in those two geographically close bays. The measurements of total length and carapace length are commonly and easily measured which makes the use of TL/CL ratio easy and suitable for other penaeids species. Considering the commercial importance of pink shrimps, further studies are needed in order to detect other morphometric differences (eg, rostrum length, width and height of abdomen, width and height of carapace) that could be used for tracking the presence of subpopulations or even the estuarine origin of the coastal shrimp stocks especially in

geographically close areas. Stocks are often defined using body morphometrics or life history traits from juveniles or adults captured at different areas. The phenotypic variability has been used in fish stocks identification (Burke et al. 2000, O'Neill et al. 2012). Differences in fish size, development, growth or even fin ray counts of juveniles between different nursery grounds were proposed as a useful tool for fish stock identification. Recently, morphological differences were successfully used for deep-sea shrimp populations identification (Purushothaman et al. 2017) reinforcing the use of morphometrics also for shrimp stock identification.

Our results indicate a clear phenotypic variability of the pink shrimp populations in SE Brazilian coast despite the absence of a significant genetic variability (reported to date). Thus, the same genotype may be associated with different phenotypes under different environmental conditions even at geographically closer areas (tens to hundreds of kilometers). This phenotypic plasticity contributes for the species acclimation in dynamic and stressful habitats, such as estuaries, and it could be also used as a clue for tracking the estuarine origin of pink shrimp stocks during fishing resources management actions along the coast.

AUTHOR CONTRIBUTIONS

Helena P. Lavrado and Karina A. Keunecke are responsible for the study conception and sampling design, supervision of the project and also contributed to the data analysis and to the writing of the manuscript. Cássia de Carvalho contributed to the study conception, carried out the field and labworks, performed data analysis and wrote the manuscript with input from the other authors.

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