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# Morphological differentiation of southern pink shrimp *Farfantepenaeus notialis* in Colombian Caribbean Sea

Jorge Paramo[1,2,a] and Ulrich Saint-Paul[1]

[1] Universität Bremen, Leibniz-Zentrum für Marine Tropenökologie (ZMT), Fahrenheitstr. 6, 28359 Bremen, Germany
[2] Universidad del Magdalena, Grupo de Investigación Ciencia y Tecnología Pesquera Tropical (CITEPT), Cra. 32 No. 22-08 Avenida del Ferrocarril, Santa Marta, Colombia

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**Abstract –** *Farfantepenaeus notialis* (Crustacea, Decapoda) constitutes about 70% of the total shrimp catch in the Colombian Caribbean. In this study, we examined morphological characteristics of *F. notialis* to investigate stock differentiation, provided biological data such as size at 50% sexual maturity and discussed the importance of this information to fisheries management. The study was conducted in the Colombian Caribbean Sea from June to December of 2004 in four locations: Uraba gulf, Morrosquillo gulf, Amansaguapos, and La Vela cape. Individual shrimp were measured according to ten body segments and sex determined. We used discriminant function analysis (DFA) of size-adjusted data to generate two-dimensional plots of the morphometric indices to test for geographic variation in morphometry by mean of canonical dimensions. The length-frequency distributions showed statistically significant differences between the measurements of both sexes, males were smaller than female in all measures. In females, size range was 16 to 46 mm cephalothorax length (*CL*) and size at sexual maturity ($CL_{50\%}$) was 30.6 mm. Size range was 19 to 32 mm (*CL*) for males. The DFA of morphological differences between individuals (female/male) showed strong overlapping and no clear separation between regions. We did not find morphometric variability between regions, which indicates a single population of *F. notialis* from the morphometric point of view.

**Key words:** Morphometrics / Sexual dimorphism / Stock identification / Shrimp / Penaeidae / Colombia

## 1 Introduction

Penaeid shrimps inhabit tropical and subtropical shallow waters on the continental shelf (May-Kú et al. 2006), and constitute an important resource for fisheries near to the equatorial region (King 2007; Guillett 2008). The one to two year life cycle of a typical penaeid species is complex (Dall et al. 1990), involving the spawning of adults off the sea and larvae migration into the nursery regions which include coastal lagoons, mangroves, and estuaries (García and Le Reste 1987). The nursery regions provide food (Lee 1999; Loneragan and Bunn 1999) and refuge against predators (Minello and Zimmerman 1991). The migration comprises an estuarine phase when the post-larvae populations enter the mouths of the rivers, remain until the juvenile stage and then migrate toward the sea as sub-adults, and is a period characterized by quick growth and continuous migration (Dall et al. 1990). The pink shrimp *Farfantepenaeus notialis* (Pérez Farfante 1967) is found in the Caribbean Sea from Quintana Roo Mexico to Río de Janeiro Brazil, and the west coast of Africa, from Mauritania to Angola (Carpenter 2002). The shrimp fishery in the Colombian Caribbean provides the most important source of economic activity in the continental shelf, significant employment and revenue is generated. The target species of this fishery are *Farfantepenaeus notialis* (Pérez Farfante 1967), *Farfantepenaeus brasiliensis* (Latreille 1817), *Farfantepenaeus subtilis* (Pérez Farfante 1967) and *Litopenaeus schmitii* (Burkenroad 1936), with *Farfantepenaeus notialis* constituting ~70% of the total shrimp catch. The landings for the shrimp fishery in this region can be described as a typical unmanaged fishery (Hilborn and Walters 1992; King 2007). The development of this commercial shrimp fishery may be described in stages (Hilborn and Walters 1992; Jennings et al. 2001; King 2007) (Fig. 1). Commercial exploitation of shrimp starts in the beginning of the 1970s, growth stage, fishing effort (days of fishing) was less active but the catch (landings in tons) larger, thus the catch per unit effort (CPUE) was significantly higher. As fishing effort increased in the beginning of the 1980's during the fully exploited stage, catches fluctuated and the CPUE showed a small decrease. An over-exploited stage was reached about the mid '1980s when fishing effort and catch rate increased and during the first five years of the '1990s when CPUE, fishing effort and catch fluctuated. In 1990 fishing effort fell drastically, but was again increased in 1991 and the CPUE fell. In the collapse stage,

[a] Corresponding author: jparamo@unimagdalena.edu.co

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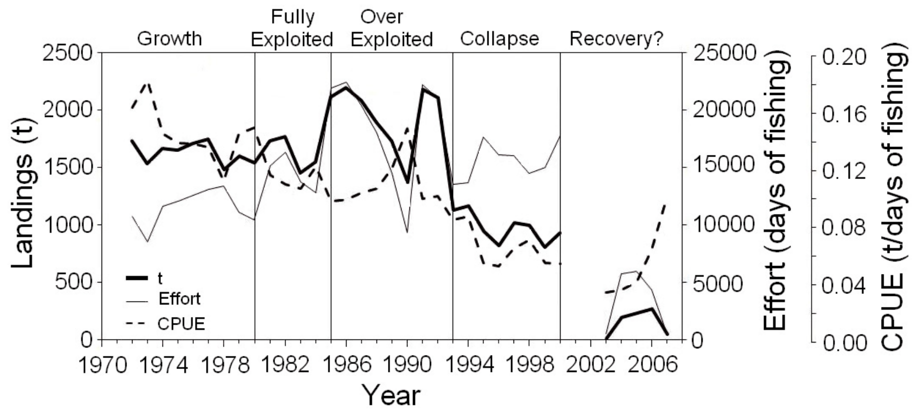


**Fig. 1.** Development of shrimp fishery in Colombian Caribbean in stages (source: INDERENA, INPA and INCODER Colombian fisheries management institutes).

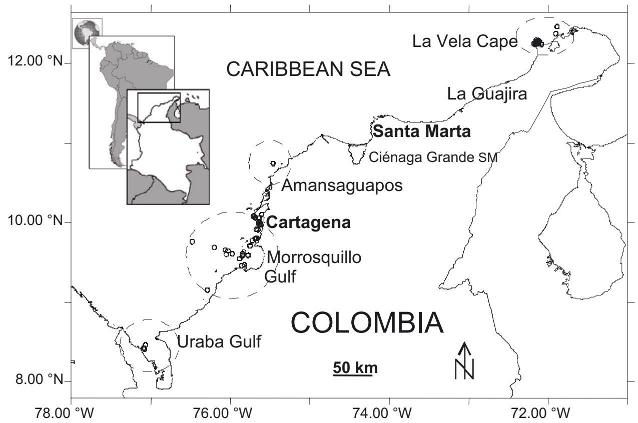


**Fig. 2.** Locations in Colombian Caribbean Sea where pink shrimp (*F. notialis*) samples were obtained: Uraba gulf (U), Morrosquillo gulf (M), Amansaguapos (AG) and La Vela cape (VC).

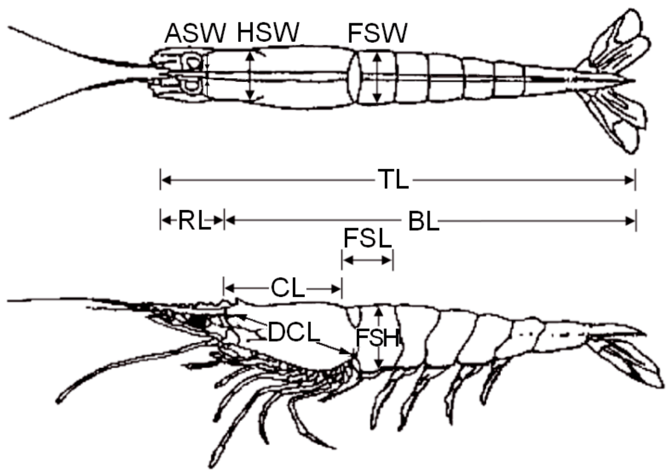


**Fig. 3.** Diagram of a pink shrimp showing the body segments measured (Tzeng et al. 2001).Total length (TL), body length (BL), rostrum length (RL), first abdominal segment length (FSL), cephalothorax length (CL), diagonal cephalothorax length (DCL), first abdominal segment height (FSH), antennal spine width (ASW), hepatic spine width (HSW) and first abdominal segment width (FSW).

catch rates fell drastically, but fishing stabilized by the end of 1990s and the CPUE decreased drastically. In the beginning of 2000 the fishing decreased as commercial fishers left the fishery activity, catches rates were significantly lower and the CPUE showed a small increase. Despite the importance of the shrimp fishery in the Colombian Caribbean, there is a lack of necessary information on the population dynamics in this region. For example, in order to design sustainable management strategies (Cadrin et al. 2000), fishery managers in Colombia need to know whether they are dealing with single or multiple populations of *F. notialis*. In fact, stock identification is a prerequisite for the correct application of stock assessment and population dynamics models, which assume that the group of individuals has homogeneous vital rates and closed life cycle (Hilborn and Walters 1992; Quinn and Deriso 1999; Jennings et al. 2001; Cadrin et al. 2000; King 2007). In this study, we examine the morphological variability of pink shrimp *F. notialis* with regard to stock differentiation and provide biological data such as size at 50% sexual maturity which is vital to efficient fishery management.

## 2 Materials and methods

The morphometric study of pink shrimp (*F. notialis*) was conducted in the Colombian Caribbean Sea (Fig. 2) from June to December of 2004 in four sample locations: Uraba gulf (U), Morrosquillo gulf (M), Amansaguapos (AG) and La Vela cape (VC).

The pink shrimp were measured using ten segments of the body to the nearest 0.1 mm, total wet weight (*W*) to the nearest 0.01 g and sexes were determined (Fig. 3): total length (*TL*), body length (*BL*), rostrum length (*RL*), first abdominal segment length (*FSL*), cephalothorax length (*CL*), diagonal cephalothorax length (*DCL*), first abdominal segment height (*FSH*), antennal spine width (*ASW*), hepatic spine width (*HSW*) and first abdominal segment width (*FSW*) (Tzeng et al. 2001; Tzeng and Yeh 2002).

Five macroscopic maturity stages were determined visually: I) Immature, translucent ovaries, II) In development, opaque ovaries, III) Almost mature, ovaries yellow orange color, IV) Mature, very enlarged ovaries olive color sometimes brown, and V) Spawned, empty ovaries. For estimation of the maturity at length we considered stages I and II as immature and stages III, IV and V as mature. Size at sexual maturity ($L_{50\%}$) was modeled by fitting the logistic function of a mature specimen proportion with 1 mm of size interval of CL. The curve was fitted by applying the maximum likelihood and uncertainty by Monte Carlo resampling (Manly 2006) to obtain the estimated parameters and the confidence intervals (Roa et al. 1999; Quiroz et al. 2007).

$$P(L) = \frac{1}{1 + (a + b \times CL)}.$$

Where $P(L)$ is the mature female proportion, $a$ and b are the parameters estimated by resampling and $CL$ the cephalothorax length. The size at 50% maturity is $CL_{50\%} = -(a/b)$ (King 2007). The ANOVA one-way was used to establish significant differences among sex (female and male) of each measurement, once the normality and homogeneity variance assumption were verified with the log-transformed data. We used the Student's*t*-test for differences between means of $CL$ by region for both females and males (Gotelli and Ellison 2004; Manly 2004). Measurements of the body were standardized using BL, which normalizes the individuals to the overall mean standard length to correct for correlation with body size (Tudela 1999; Salini et al. 2004; Pinheiro et al. 2005; Kristoffersen and Magoulas 2008). The measurement was adjusted by the following allometric equation $\hat{Y} = aX^b$, such that the standardized value of this variable of an individual of size $Xi$ is given by,

$$M_c = M_x \left[ \frac{\overline{BL}}{BL_i} \right]^b$$

where $\overline{BL}$ is the overall mean body length, $b$ is the slope, within areas, on logarithms of $M_x$ and $BL$. This standardization normalizes the individuals in a sample to a single, arbitrary size, common to all samples, and maintains the individual variation (Tudela 1999). Morphometric characteristics were analyzed using multivariate analysis. Principal components analysis (PCA) of log-transformed data was performed to explore patterns of variation among female and male and stages of maturity in female. PCA was used on the correlation matrix of analyzed parameters. Stepwise linear discriminant function analysis (DFA) of size-adjusted data was used to generate two-dimensional plots of the morphometric indices to test for geographic variation in morphometry by mean of canonical dimensions.

## 3 Results

A total of 1094 specimens of *F. notialis* were measured between June and December of 2004: 44 individuals from Uraba gulf (28 female, 16 male), Morrosquillo gulf 385 individuals (159 female, 226 male), Amansaguapos 160 individuals (97 female, 63 male) and La Vela cape 505 individuals (283 female, 222 male). The length-frequency distributions for each morphometric measurement are illustrated separately for each sex (Fig. 4). Statistically significant differences (ANOVA test) between the measurements of both sexes were found (Fig. 4), revealing sexual dimorphism ($p = 0$) in all morphometric characters, the males were smaller than females in all measurements.

**Table 1.** Student's t-test for differences between means of cephalothorax length (CL) by region according to sex for *F. notialis*. * $p \leqslant 0.001$; **$0.01 < p \leqslant 0.05$. U: Uraba gulf, M: Morrosquillo gulf, AG: Amansaguapos, VC: La Vela cape.

| Group | CL Female | CL Male |
|---|---|---|
| U-Mo | 0.384 | 0.106 |
| U - AG | 0.024** | 0* |
| U - VC | 0.039** | 0* |
| M - AG | 0.038** | 0* |
| M - VC | 0.006** | 0* |
| AG -VC | 0.673 | 0* |

The CL showed an increase in size with a decrease of latitude (Fig. 5), the larger individuals were found mainly in the south of the study area (Uraba gulf, Morrosquillo gulf and Amansaguapos) and otherwise smaller individuals were located more towards the north of the Colombian Caribbean (La Vela cape in La Guajira region). The CL of females differs significantly among Uraba gulf, Amansaguapos and La Vela cape regions, Morrosquillo gulf with Amansaguapos and La Vela Cape, but does not differ significantly for Uraba gulf with Morrosquillo gulf and Amansaguapos with La Vela Cape (Table 1). For males, just does not differ significantly among Uraba gulf and Morrosquillo gulf regions.

A total of 570 females were analyzed to determine different maturity stages, where 43%, correspond to immature shrimps. The size at sexual maturity ($CL$ 50%) in females (Fig. 6) was 30.6 mm $CL$ (95% confidence interval, $CI$, 29.5 to 32.6 mm), the parameters $a = 11.56$ ($CI$, 8.82 to 12.75) and $b = -0.38$ ($CI$, –0.43 to –0.27).

Principal components analysis (PCA) on the morphometric indices of *F. notialis* for female and male indicate that the first two components explain 94.3% of total variance and shows strong sexual dimorphism, which suggest to make the analysis separated by sex (Fig. 7 left). PCA for *F. notialis* females illustrates variability in stages of maturity and depicts differences in levels of maturity by morphometric measurements (Fig. 7 right). We extracted the first two components which explained 77.9% of total variance. The plot shows that all maturity groups are similar, which means that there is no difference between maturity stages. This analysis demonstrates that maturity stages of females did not confound the morphometric differentiation in *F. notialis*.

The DFA of morphological differences between the male and female individuals shows a strong overlapping and no clear separation between the regions (Fig. 8): Uraba gulf (U), Morrosquillo gulf (M), Amansaguapos (AG) and la Vela cape (VC). The first two canonical functions carry the analysis through the 97.0% and 94.5% for female and male, respectively (Table 2). The Wilk's lambda for female indicate that

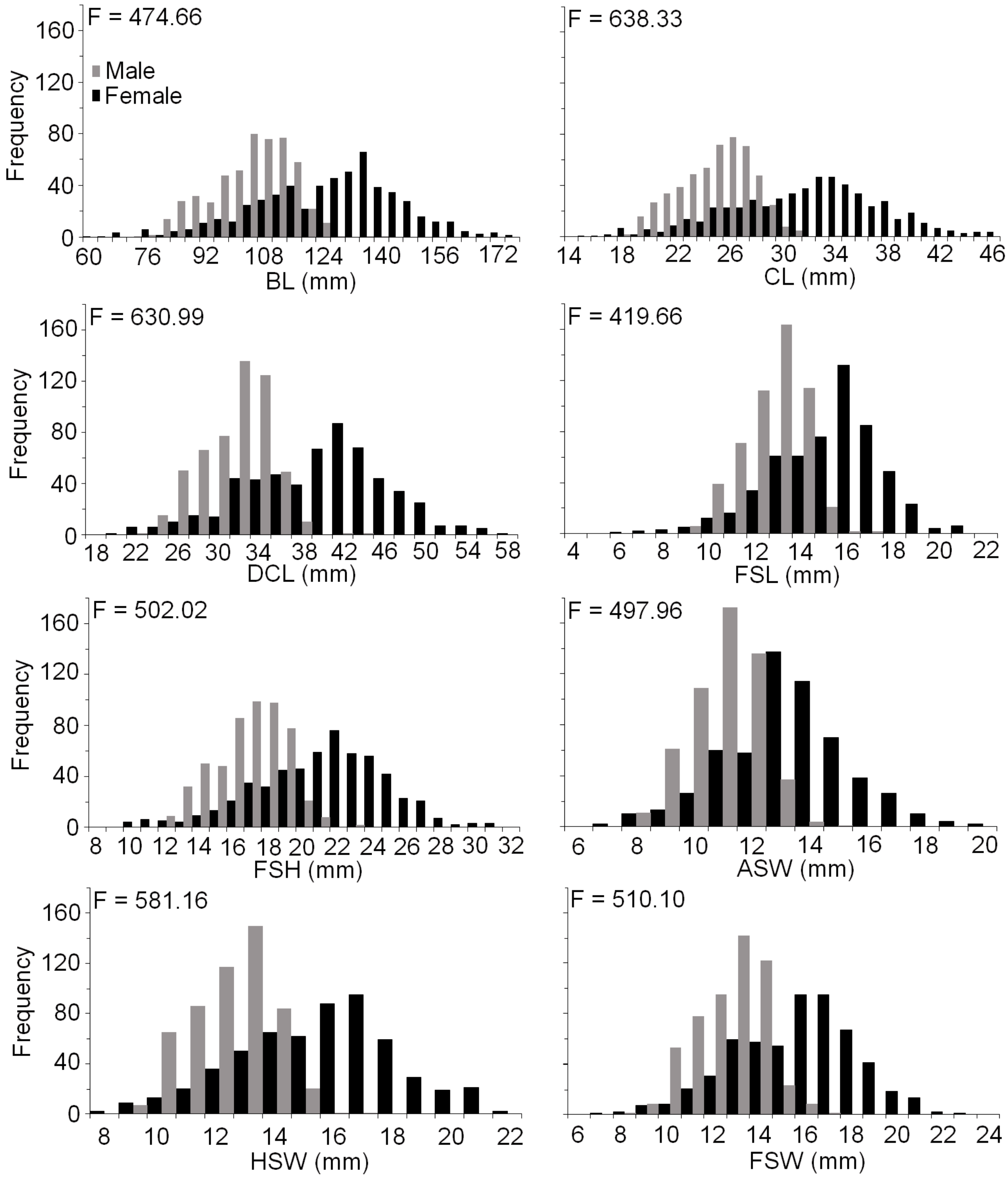


**Fig. 4.** Histogram of the morphometric body parts measured (mm) by sex for *F. notialis*. One way ANOVA test ($F$ value and $p = 0$) for differences between the two sexes for each measurement (see Fig. 3).

variable ASW contributes most to discriminate between different stocks, followed by FSL and CL (Table 3). The Wilk's lambda for male show that TL is the variable that allows to discriminate between different stock, followed by BL and ASW (Table 3). The means of canonical variables in female and male (Table 4) shows that the first two discriminant functions not discriminates between regions, because the canonical mean are not different between the other groups.

## 4 Discussion

Knowledge of stock structures of a species is very important for effective and successful management of a fishery as well as to be able to implement rebuilding programs in collapsed fisheries (Begg et al. 1999; King 2007). A stock is considered to be a group of individuals with unique phenotypic attributes, but sexual dimorphism, timing of sampling, allometric growth, and the state of maturity may confound the morphological relationships (Tzeng et al. 2001). The samples analyzed in this study showed different stages of maturity for females. However, in this case the maturity does not seem to have affected the patterns of similarity between the samples in the PCA analysis. The analysis demonstrates that the morphometric indices are not affected by the particular stage of maturity of the female. Regional environmental factors (i.e. upwelling) tend to influence the phenotypic characteristics (Swain and Foote 1999; Begg and Waldman 1999; Kristoffersen and Magoulas 2008). Different regions

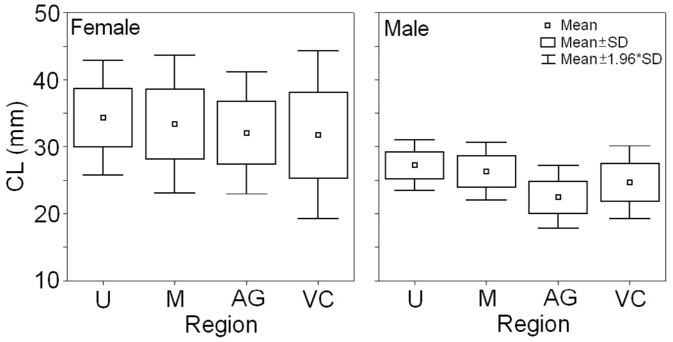


**Fig. 5.** Box plot of the cephalothorax length (CL) discriminated by regions for female and male of *F. notialis*. Uraba gulf (U, $n$ = 44 specimens), Morrosquillo gulf (M, $n$ = 385), Amansaguapos (AG, $n$ = 160), La Vela cape (VC, $n$ = 505).

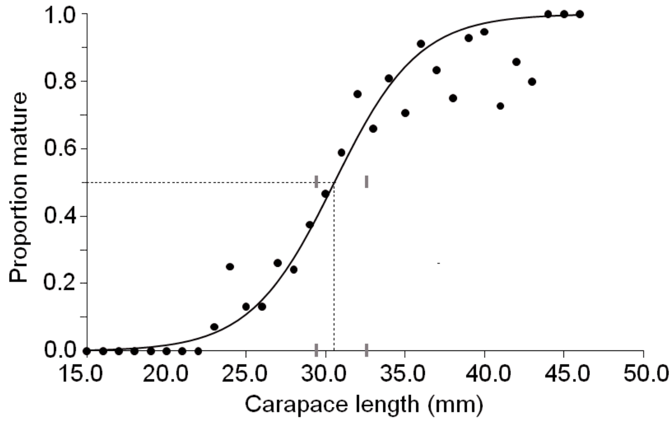


**Fig. 6.** Size at 50% sexual maturity for females of *F. notialis*, cephalothorax length ($CL$) = 30.6 mm; i.e. total length ($TL$) = 136.7 mm; abdomen length (tail length) = 88.2 mm.

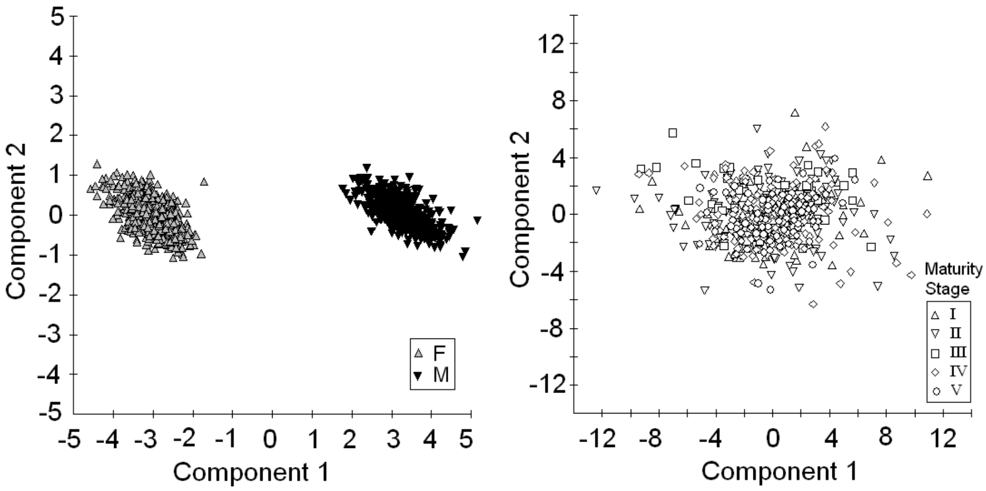


**Fig. 7.** Factor loadings plot of PCA on the morphometric indices of *F. notialis*, grouped for patterns of variation according to female and male (left) and stages of maturity for females (right).

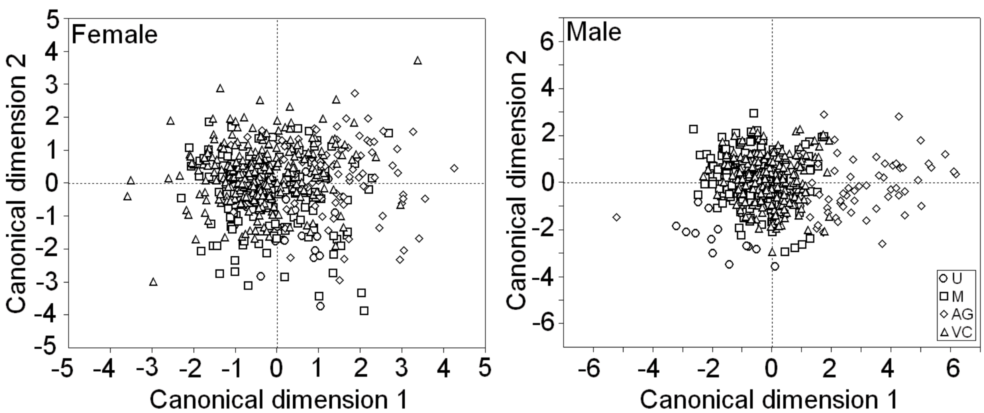


**Fig. 8.** Canonical discriminant functions 1 and 2 on the morphometric indices of *F. notialis*, grouped according to localities for female and male. Uraba gulf (U), Morrosquillo gulf (M), Amansaguapos (AG) and La Vela cape (VC).

**Table 2.** Summary of the first two canonical discriminant functions of the morphometric indices for female and male.

| Sex | Function | Eingen value | Cumulative percent | Canonical correlation | Wilk's lambda | Chi squared | *df* | *p* |
|---|---|---|---|---|---|---|---|---|
| Female | 1 | 0.406 | 73.806 | 0.537 | 0.621 | 266.989 | 27 | 0 |
| | 2 | 0.127 | 97.000 | 0.336 | 0.872 | 76.360 | 16 | 0 |
| Male | 1 | 1.211 | 84.718 | 0.740 | 0.368 | 520.028 | 24 | 0 |
| | 2 | 0.140 | 94.503 | 0.350 | 0.813 | 107.415 | 14 | 0 |

**Table 3.** Summary of the stepwise discriminant function analysis for morphometric characters in female and male (see body segments on Fig. 3).

| Female | | | | Male | | | |
|---|---|---|---|---|---|---|---|
| Step no. | Variable entered | Wilk's lambda | *p*-level | Step no. | Variable entered | Wilk's lambda | *p*-level |
| 1 | ASW | 0.706 | 0 | 1 | FSL | 0.407 | 0 |
| 2 | FSL | 0.687 | 0 | 2 | FSW | 0.380 | 0.001 |
| 3 | FSH | 0.642 | 0 | 3 | ASW | 0.412 | 0 |
| 4 | HSW | 0.628 | 0.099 | 4 | HSW | 0.390 | 0 |
| 5 | FSW | 0.634 | 0.007 | 5 | DCL | 0.380 | 0.001 |
| 6 | DCL | 0.629 | 0.050 | 6 | FSH | 0.385 | 0 |
| 7 | CL | 0.645 | 0 | 7 | TL | 0.583 | 0 |
| - | - | - | - | 8 | BL | 0.581 | 0 |

**Table 4.** Means of canonical variables for female and male. U: Uraba Gulf, M: Morrosquillo Gulf, AG: Amansaguapos, VC: La Vela Cape.

| Group | Female | | Male | |
|---|---|---|---|---|
| | Dimension | | Dimension | |
| | 1 | 2 | 1 | 2 |
| U | 0.313 | –1.052 | –1.349 | –0.149 |
| M | –0.199 | –0.360 | –0.667 | 0.267 |
| AG | 1.354 | 0.184 | 2.827 | 0.197 |
| VC | –0.383 | 0.243 | –0.026 | –0.317 |

show different sizes, the northern shrimps of *F. notialis* are smaller than from the south, and this characteristic is possibly influenced by the increase of temperature southward of the study area. This occurrence of a North-South gradient of sizes could be a strong indication that there may be a single stock, the smaller shrimps coming from the north. However, the Colombian Caribbean Sea has several mangroves areas, which could be serve as nursery habitats for *F. notialis* (i.e. Ciénaga Grande de Santa Marta, Morrosquillo gulf, and Uraba gulf). At this point it is not possible to distinguish between these two alternatives and is necessary further research about currents, larval dispersion and spawning areas for *F. notialis*. Thus, the morphometric similarity of individuals of *F. notialis* along the Colombian Caribbean Sea seems to indicate that environmental conditions did not induce different morphologies in individuals of different localities. Morphometric data of *F. notialis* showed a great homogeneity between different geographical regions, indicating the existence of a single population along the Colombian Caribbean Sea from the morphometric point of view. With this work we provide the first complete view, to this date, of the pink shrimp *F. notialis* stock structure and fishery dynamics, based on morphometric, historic landings and biologic data in the Colombian Caribbean Sea. The identification and knowledge of shrimp stock must be based on more than a single methodology and should comprise other stock identification approaches such as life-history (rate growth, recruitment, etc.) and genetic analysis (Begg and Waldman 1999; Cadrin 2000; Robainas-Barcia et al. 2002; Robainas-Barcia et al. 2008). The shrimp fishery in the Colombian Caribbean is a typical case in which high exploitation, combined with non-existent fisheries management, have resulted in the significant depletion of shrimp stock. It has been seriously negatively impacted by overfishing, where spawning stock could have been reduced to a level in which the number of recruits produced is insufficient to maintain the population. Additionally, due to the possible low levels of spawning stock, reproduction and survival is reduced (Allee effect) by the inability to find mates, to resist predators or to withstand environmental fluctuations (King 2007). However, because the short life cycle, the shrimp fishery when is an overfishing stage, can be quickly recovered (Guillet 2008). Finally, to aid in the recovery of this shrimp fishery, the task to be carried out in the near future is a direct stock assessment and fishing management should be directed towards maintain fishing effort until spawning populations show signs of full recovery.

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