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RESEARCH ARTICLE

Geographic variation in *Prionotus punctatus* (Bloch) (Teleostei, Scorpaeniformes, Triglidae): a geometric morphometric analysis

Variação geográfica em *Prionotus punctatus* (Bloch) (Teleostei, Scorpaeniformes, Triglidae): uma análise morfométrico-geométrica

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Resumo Padrões de variação geográfica na forma do corpo foram analisadas em nove amostras de populações da cabrinha *Prionotus punctatus* (Bloch) da costa nordeste, sudeste e sul do Brasil, usando técnicas de morfometria geométrica. As nove amostras foram ordenadas pela análise de variáveis canônicas em três grupos correspondendo às regiões norte e sul da isoterma de 23°C. As diferenças de forma representam um contraste entre um aumento da altura do corpo nos exemplares do litoral nordeste e um alongamento do corpo nos exemplares das outras amostras. Estes resultados sugerem que existe extensa variação geográfica em *P. punctatus* no litoral brasileiro. Os padrões de variação geográfica na forma do corpo são aparentemente relacionados ao decréscimo na temperatura da água na direção sul ao longo da costa.

Palavras-Chave: *Prionotus*, América do Sul, morfometria geométrica, variação geográfica.

Abstract Patterns of geographic variation in body shape were analyzed in nine population samples of the searobin *Prionotus punctatus* (Bloch) from the northeastern, southeastern, and south Brazilian coast, using geometric morphometrics techniques. The nine samples were ordinated by canonical variate analysis into three groups corresponding to regions north and south of the 23°C isotherm. The shape differences represent a contrast between an increase in body depth in the specimens of the northeastern coast and an elongation of the body in the remaining samples. These results suggest that there is extensive geographic variation in *P. punctatus* along the Brazilian coast. The patterns of geographic variation in body shape are apparently related to decreasing water temperature southward along the coast.

Keywords: *Prionotus*, South America, geometric morphometrics, geographic variation.

Introduction

The searobin, *Prionotus punctatus* (Bloch) is a medium-sized benthic fish found in shallow to moderate depths feeding mainly on crustaceans and molluscs. It ranges from the coast of Central America (Belize) to Argentina (Ginsburg 1950). In Brazil, *P. punctatus* has been recorded from Pernambuco to Rio Grande do Sul (Figueiredo & Menezes 1980). Although not considered to be a species of commercial importance, *P. punctatus* is a large component of demersal fisheries in the southeastern Brazilian coast, and provides local fishermen with a source of income when catches of other species are reduced (Andrade 2004). Therefore, detailed knowledge of its distribution is important for the management of this species as a potential economic resource. However, despite its wide distribution, little is known about the patterns of geographic variation in this species. Ginsburg (1950) pointed out the existence of differences in meristic and morphometric characters among local population of *P. punctatus* from the Caribbean and the South American coast, but because of the small size of the samples available to him, this author could not draw definite conclusions regarding the taxonomic significance of these differences. He concluded, however, that the differences seemed to be in the range of those usually detected among the local populations of species with a wide geographic range. Over the last two decades, several studies have documented the widespread occurrence of extensive geographic variation in both benthic and demersal marine fish species along the coasts of South America and Africa in the South Atlantic Ocean (see Cavalcanti & Lopes 1998 for a short review). These studies offer abundant support to the emerging paradigm of populations of marine species as closed systems, only very loosely, if at all, by the gene flow promoted by ocean currents (Cowen *et al.* 2000, Hellberg *et al.* 2002).

Despite its potential to detect patterns of size and shape changes at both the inter- and intraspecific levels, geometric morphometrics (Bookstein 1991) methods have been infrequently applied to the study of geographic variation in local populations of marine fishes. Corti & Crosetti (1996) were the first to report the application of geometric morphometrics to the analysis of patterns of geographic variation in size and shape of a marine fish. More recently, Valentin *et al.* (2002), Medina *et al.* (2008), Oliveira *et al.* (2009), Luceño *et al.* (2013), Luceño *et al.* (2014)and Cabasan *et al.* (2017)also applied similar techniques to analyze geographic variation in marine fish species.

The objective of this work was to analyze geographic variation in body shape in *P. punctatus* along the Brazilian coast, applying geometric morphometrics and multivariate statistical methods.

Materials and Methods

The specimens of *P. punctatus* examined in this study are housed in the collections of Universidade Estadual de Feira de Santana, Bahia (UEFS), Universidade do Estado do Rio de Janeiro (UERJ), and Pontifícia Universidade Católica do Rio Grande do Sul (PUCRS). A total of 56 individuals from 9 localities were measured. Localities, geographic coordinates and sample sizes are listed in Table 1.

Table 1. Locality, geographic coordinates, location relative to the 23°C isotherm, region, and sample size of the nine populations of *Prionotus punctatus* examined in the present study.

Number	Locality	Latitude	Longitude	Location relative to 23°C isotherm	Region	Sample size
1	Baía de Todos os Santos	12° 48' S	38° 36' W	North	NE	28
2	Baía de Guanabara	22° 48' S	43° 08' W	South	SE	7
3	Baía da Ilha Grande	23° 09' S	44° 30' W	South	SE	5
4	Caraguatatuba	23° 40' S	45° 20' W	South	SE	5
5	Porto Belo	27° 07' S	48° 34' W	South	S	3
6	Florianópolis	27° 35' S	48° 34' W	South	S	3
7	Garopaba	28° 04' S	48° 40' W	South	S	1
8	Torres	29° 21' S	49° 44' W	South	S	2
9	Mostardas	31° 05' S	50° 57' W	South	S	2

Because the number of specimens from some samples was inadequate for statistical analyses, the localities were pooled into three non-contiguous regions,located respectively to the north and to the south of the 23° C isotherm: (1) the sample from the northeastern coast of Brazil (NE); (2) the samples from the southeastern coast (SE); and (2) the samples from the southern coast (S) (Fig. 1). This division was done on the basis of the proposal by Palacio (1982) that the 23° C isotherm (the line of constant mean annual temperature, located approximately at the 21° S latitude) defines the limit between two distinct biogeographic regions in the Brazilian coast. A previous study by Cavalcanti & Lopes (1998) provided evidence of geographic variation in quantitative characters in the batfish *Ogcocephalus vespertilio* corresponding to the regions north and south of the 23° C isotherm.

Measurements were made using a truss network protocol (Strauss & Bookstein 1982; McGlade & Boulding 1986), anchored at 10 homologous anatomical landmarks (Fig. 2). Landmarks refer to: (1) anterior tip of the snout on the upper jaw; (2) most posterior aspect of the neurocranium (beginning of scaled nape); (3) origin of pelvic fin; (4) origin of spinous dorsal fin; (5) origin of anal fin; (6) origin of soft dorsal fin; (7) insertion of anal fin; (8) insertion of second dorsal fin; (9) insertion of first ventral caudal fin ray; (10) insertion of first dorsal caudal fin ray. All measurements were taken with an electronic caliper to the nearest 0.05 mm.

The 21 interlandmark distances obtained from the truss network were converted to Cartesian coordinates by means of a simplified multidimensional scaling algorithm (Carpenter *et al*. 1996), using the UNFOLD program written by H. J. S. Sommer.

The raw coordinates of all specimens were aligned (i.e. translated, rotated, and scaled to match one another) using the Procrustes generalized orthogonal least-squares (GLS) superimposition method, which fits one configuration over another by minimizing the squared distances between homologous landmarks (Rohlf & Slice 1990). The average configuration of landmarks resulting from this procedure served as the "reference" or tangent configuration (defining the point of tangency between the non-linear shape space and the approximating tangent space, see Rohlf, 1996) in the subsequent computations.

Canonical variate analysis and multivariate analysis of variance were used to evaluate the patterns of variation and discrimination among the population samples of *P. punctatus.* Canonical analysis provided weighted combinations of characters, termed canonical variates, maximizing among-sample variation with respect to the within-sample variation. Each canonical variate represented an identifiable fraction of the total variation in the data. This has been one of the most widely used ordination technique for studying geographic variation (Gould & Johnston 1972; Thorpe, 1976). Shape changes associated with the canonical variate axes were depicted as deformation grids generated by regressing the partial-warp scores onto each canonical axis (Rohlf *et al*., 1996). All computations were performed using the software MorphoJ v.1.0.6d (Klingenberg 2011).

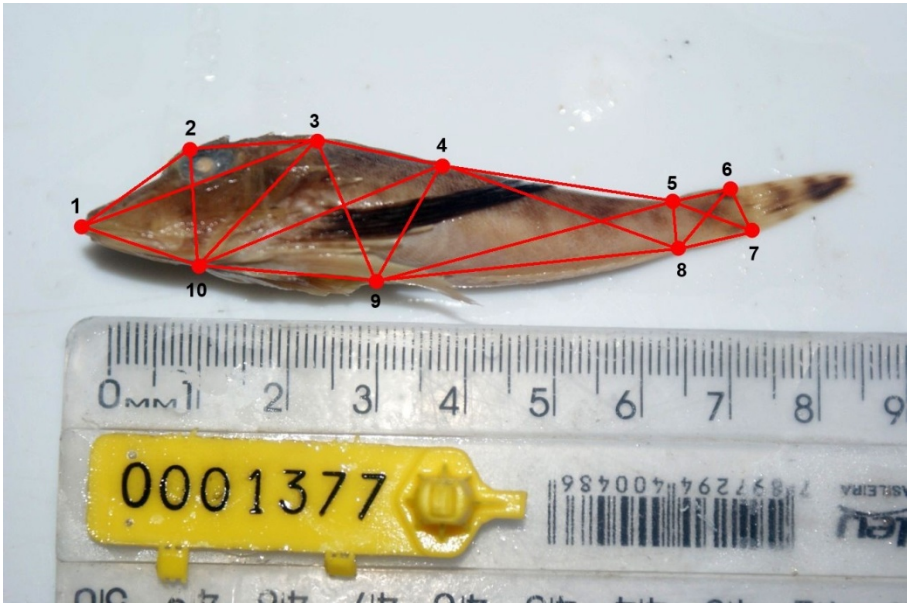

Figure 1. Locations of the 10 anatomical landmarks (numbered points) and morphometric distance measurements recorded on each specimen of *Prionotus punctatus*.

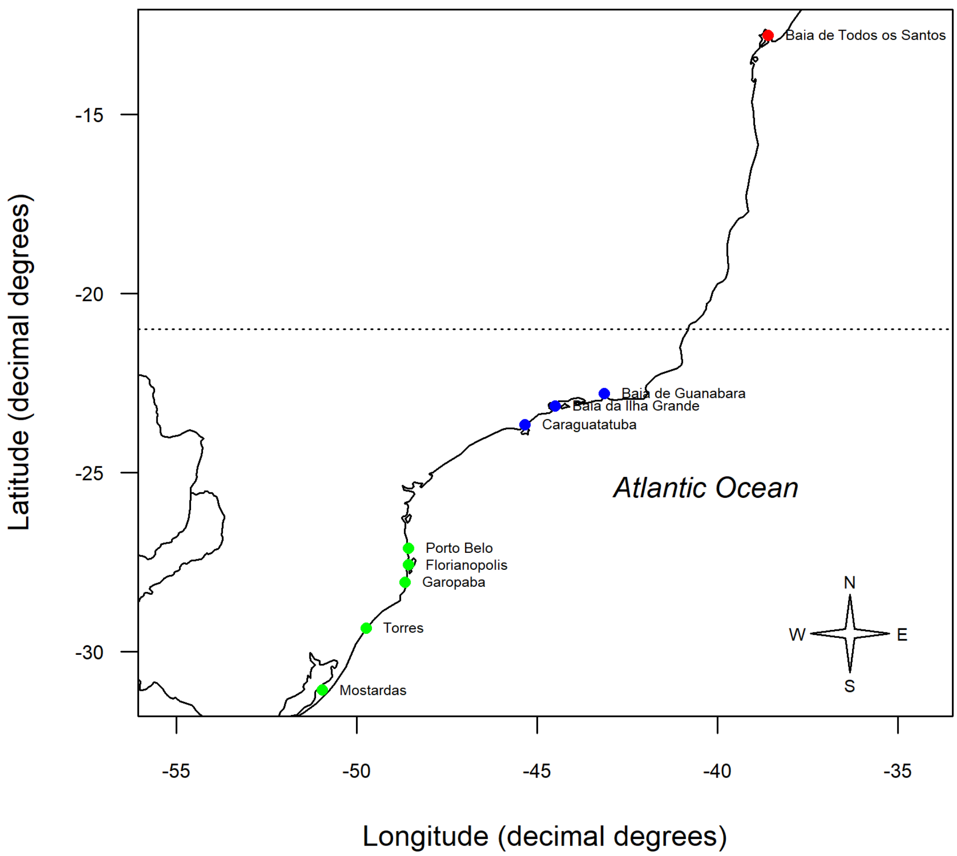

Figure 2. Distribution map of the nine population samples of *P. punctatus* analyzed in this study.

Results

The canonical analysis of body shape variation showed that the Mahalanobis distances among the nine populations of *P. punctatus* differed significantly between the Northeastern and Southeastern or Southern populations (Wilks' lambda, P < 0.0001), but not between the Southeastern and Southern populations (P = 0.2005). Two canonical vectors accounted for 100% of the total among-group variation, with the first and second canonical vectors explaining, respectively, 81.8% and 18.2% of the total variation. The space defined by these two canonical vectors disclosed three groups of populations, one formed by the Northeastern Brazil population, a second representing the Southeastern Brazil population and a third composed of the Southern Brazil populations (Fig. 3). The Baía de Todos os Santos (Northeastern Brazil) population is discriminated from the other populations along the first canonical vector, whereas the group formed by the populations of Baía de Guanabara, Ilha Grande, and Caraguatatuba (Southeastern Brazil) is separated from the Southern Brazil (Porto Belo, Florianópolis, Garopaba, Torres, Mostardas) populations along the second canonical vector. A few individuals from the Southeastern and Southern populations overlap partially in the space of the second canonical vectors, indicating that these individuals are morphometrically similar.

The shape changes depicted along the canonical variates (Fig. 4) indicate a relative increase in body depth in the specimens from Baía de Todos os Santos, as well as an elongation of the caudal region in the specimens of the remaining populations, leading to a more bulky shape in the populations of Northwestern Brazil and a more slender shape in the populations of Southeastern and Southern Brazil.

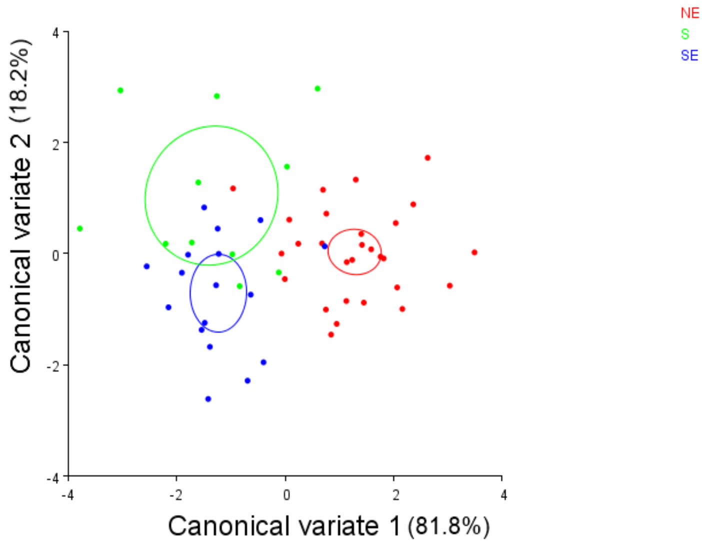

Figure 3. Outlines of scatterplots of individual scores from the canonical variates analysis of the population samples of *P. punctatus*, with 95% confidence interval around group means (NE = Northeastern; SE = Southeastern; S = Southern).

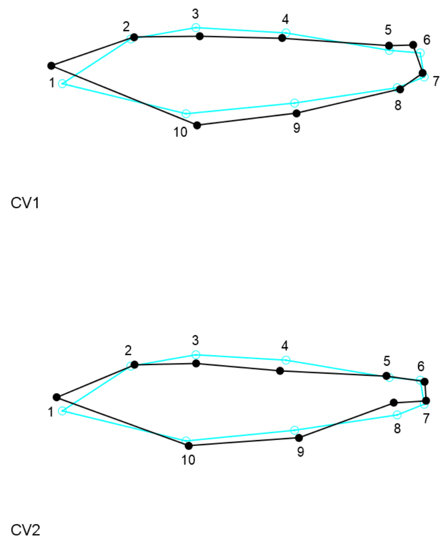

Figure 4. Shape changes in *P. punctatus* in relation to the reference specimen (in light blue) along the first (top) and second (bottom) canonical variates (in black).

Discussion

The results presented in this paper point to extensive variation in shape in the populations of *P. punctatus* studied. Geographic variation in marine fishes has been regarded as the consequence of different environmental conditions, such as water temperature, salinity, and dissolved oxygen (Barlow, 1961; Gunther, 1961), acting on groups of geographically isolated populations and leading to adaptive genetic changes (Palumbi, 1994).

The waters of the coast of Cabo Frio, near Arraial do Cabo, are influenced by an important coastal upwelling phenomenon, characterized by lower salinity and temperature and richness of nutrients. To the north, coastal waters are under the influence of the tropical waters of the Brazil Current, of higher salinity and temperature, and with a reduced nutrient content (Valentin 2001). This may act as an important factor in the differentiation of marine populations and has already been shown to influence patterns of geographic differentiation in several species of demersal fishes occurring along that stretch of the Brazilian coast (Vazzoler, 1971; Vargas, 1976; Yamaguti, 1979; Paiva Filho & Cergole, 1988; Cavalcanti & Lopes, 1998; Oliveira *et al.*, 2009). In a study of age and growth of *P. punctatus* in the southern coast of Brazil, on the basis of increments in the sagittal otolith, Andrade (2004) suggested that water temperature may in fact be one of the most important environmental factors affecting the growth patterns in this species.

A major potential limitation of the present study are the small sample sizes available for some localities, that while not being atypical of most systematic studies, could disturb the results of statistical analyses. Nonetheless, in the present study these small sample sizes might be expected to obscure patterns of differentiation rather than create them. Further studies, including the collection of specimens from the intervening areas, will be necessary in order to provide a more complete understanding of the underlying causes of geographic variation in *P. punctatus* along the Brazilian coast.

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