

Population Structure and Distribution of Deep-Water Cardinal Fish *Epigonus occidentalis* (Epigonidae) and *Epigonus pandionis* (Epigonidae) in the Colombian Caribbean Sea¹

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Abstract—Cardinal fish are commercially valuable species. In the Colombian Caribbean Sea *E. occidentalis* and *E. pandionis* occurred in 37 and 35% of tows during a research trawl survey (>200 m), respectively and the biology of these vulnerable species is unknown. The aim of this work is to describe the spatial distribution patterns of biomass, size structure and morphometric relationships of *E. occidentalis* and *E. pandionis* in deep waters of the Colombian Caribbean Sea. The samples were collected by trawling in depths between 200 and 550 m. No statistical differences were found in size by sexes in both species. In female and male *E. occidentalis* the growth was isometric, while in female and male *E. pandionis* it was positive allometric. *E. occidentalis* occurred mainly in the northern zone of Colombian Caribbean Sea, with highest aggregations off Santa Marta and Riohacha. *E. pandionis* was distributed in the northern area between Santa Marta and Riohacha and in the southern area between Cartagena and Morrosquillo Gulf. However, before the exploitation of these species is considered, further research is required to determine basic life history traits, such as growth, reproduction, recruitment, and mortality.

Keywords: *Epigonus occidentalis*, *Epigonus pandionis*, spatial distribution, size structure, Colombian Caribbean Sea

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INTRODUCTION

Fish belonging to the family Epigonidae are epibenthic and are found on continental and insular slopes and seamounts in the Atlantic, Indian and Pacific oceans at depths from 75 to 3700 m (Carpenter, 2002; McEachran and Feckhelm, 2005; Nelson, 2006). A deep-sea cardinal fish, *Epigonus telescopus* is commercially caught by trawl in the Exclusive Economic Zone of New Zealand and Australia (Zintzen et al., 2011) and by longline in northeast Atlantic near the Portuguese archipelago of the Azores and Madeira islands (Menezes et al., 2009). These species form large reproductive and feeding aggregations on seamounts and have been heavily exploited in several oceans (Clark et al., 2004; Tracey et al., 2004). In the deep-water crustacean fishery off Chile, *E. craissoni* was caught as by-catch in a demersal fishery for fishes and crustaceans with a frequency of occurrence of 80% (Queirolo et al., 2011), but currently this fishery is closed (Ojeda et al., 2010; Wiff et al., 2005).

E. occidentalis is distributed in the west central Atlantic Ocean, the Gulf of Mexico and Caribbean Sea (Abramov, 1992), while *E. pandionis* is distributed in the western Atlantic Ocean between New Jersey (United States) (Abramov, 1992) and the northern of Gulf of Mexico to northeastern South America (Cervigón, 1993) and in the eastern Atlantic from the Guinea Gulf to Agulhas Bank (Abramov, 1992). In the Colombian Caribbean Sea, *E. occidentalis* and *E. pandionis* had a frequency of occurrence in research trawl catches in November and December 2009 (>200 m) of 37.04 and 35.19%, respectively, and in another study they occurred in 5.21% and 8.33% of the catches, respectively (Polanco et al., 2010). The biology of these vulnerable species is poorly known (Paramo et al. 2012). Species that inhabit deep-sea ecosystems (>200 m depth) (Clark et al., 2010; Mengerink et al., 2014) are vulnerable to exploitation due to distinctive characteristics of their strategies of life cycle, such as late sexual maturity, long life expectancy, low growth rate, low rate of natural mortality, intermittent recruitment and sporadic spawning, making them especially

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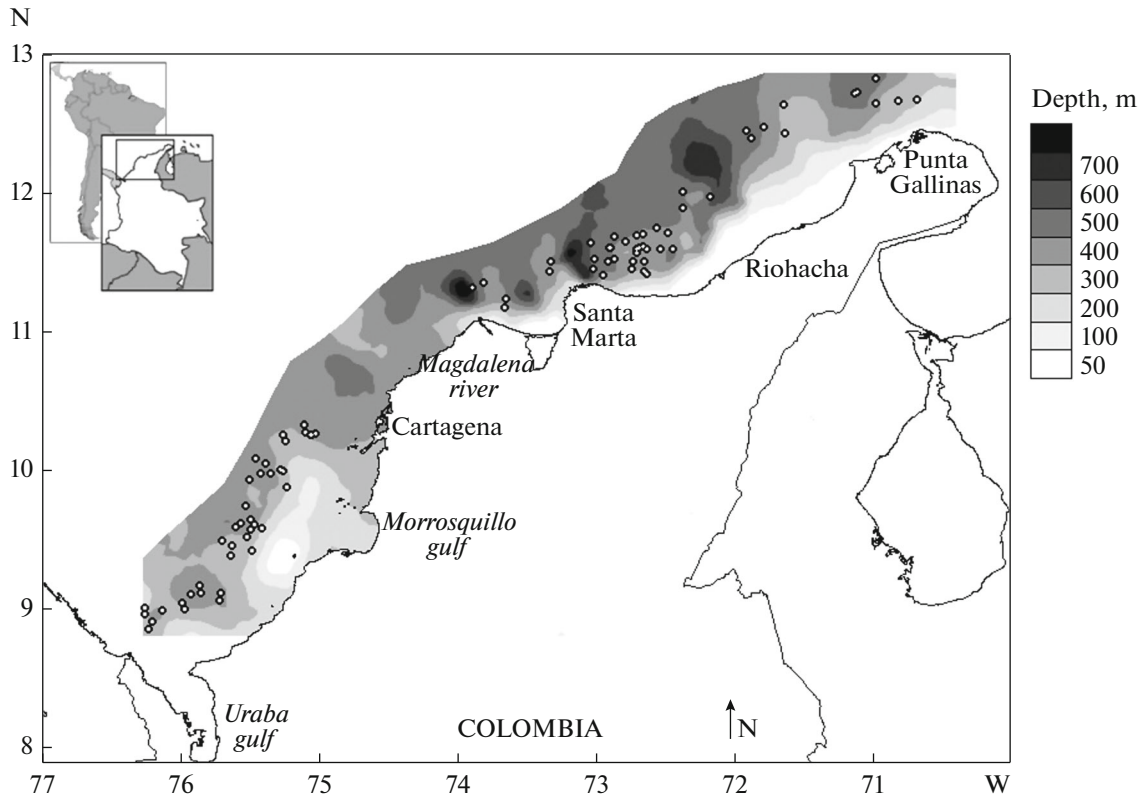


Fig. 1. Study area in the Colombian Caribbean Sea. Circles indicate the sampled stations.

vulnerable to fishing exploitation (Koslow et al., 2000; Morato et al., 2006; Drazen and Haedrich, 2012). The sustainable exploitation of such deep water species, therefore, involve conservative fishery management strategies based on a knowledge of the status of resources in deep waters of the Colombian Caribbean, where a deep-sea fishery has not yet been developed, and the environment can be considered as still unfished. (Paramo et al., 2012). Thus, it is necessary to know biological attributes such as distribution, size structure, and length-weight relationships of the possible commercial species to determine measures for sustainable management based on an ecosystem approach to fisheries. The aim of this work is to describe the spatial distribution patterns of biomass, size structure and morphometric relationships of *E. occidentalis* and *E. pandionis* in deep waters of the Colombian Caribbean Sea.

MATERIALS AND METODS

Study Area

Trawl sampling was conducted in the Colombian Caribbean Sea in August and December 2009, and March and May 2010. Sampling was stratified by depth ranging from 200 to 550 m (based on 100 m stratum intervals). The actual location of trawl depended on the presence of trawlable bottom, determined by

using a commercial echosounder (FURUNO FCV 1150 with a transducer at a frequency of 28 kHz) on a grid of 87 stations, with at least two hauls per 100 m depth stratum (Fig. 1). Samples were collected by the commercial shrimp trawler “Tee Claude” using a trawl with a cod-end mesh size of 44.5 mm from knot to knot. No trawling was done between Cartagena and Magdalena River due to the irregular depth profile in this zone. The haul duration was 30 min and the distance travelled by the net was estimated by a GPS (Garmin MAP 76CSx). The deep-sea fish catch from each haul was analyzed for total abundance (N/km²) and biomass (kg/km²). The swept area was estimated from the wing spread of the net (11.58 m) and the speed of the vessel measured with GPS (average 2.5 knots) (Gunderson, 1993; King, 2007).

Size Structure

The total weight, sex and number of individuals of *Epigonus occidentalis* and *Epigonus pandionis* from each station were recorded. All the specimens were recorded total weight (*W*) to the nearest 0.1 g, and the total length (*TL*) was measured to the nearest 0.1 cm using a calipers. In addition, the standard length (*SL*), the body height (*BH*), the head length (*HL*) and eye diameter (*ED*) were measured. Differences in the length and weight distributions among females and

Table 1. Descriptive statistics of size structure (Total length) and total weight in female (F) and male (M) *E. occidentalis* and *E. pandionis*

Species	Sex	Total length, cm							Total weight, g					
		<i>n</i>	mean	median	min	max	standard deviation	<i>p</i> -value	mean	median	min	max	standard deviation	<i>p</i> -value
<i>E. occidentalis</i>	F	32	18.5	188.0	13.0	24.2	2.7	0.068	64.7	64.5	20.7	134.5	25.8	0.171
	M	48	19.8	201.5	14.4	25.8	2.2		76.2	76.6	31.1	149.0	25.2	
<i>E. pandionis</i>	F	18	18.2	19.7	11.2	23.5	4.3	0.162	94.1	107.2	13.5	172.3	55.7	0.443
	M	23	17.4	17.8	13.1	20.4	2.0		68.5	67.3	22.9	118.0	26.9	

males were assessed using a non-parametric Kruskal–Wallis test (Gotelli and Ellison, 2004).

Morphometric Relationships

The length-weight relation was determined by adjusting the log-transformed power function $W = aTL^b$ by $\text{Ln}W = \text{Ln}a + b\text{Ln}TL$ where W is the total weight in g, TL is the total length in cm, a is the intercept and b is the allometry coefficient. As a measure of goodness of fit, the determination coefficient (R^2) was used. The 95% confidence interval for b was computed and a t -student test was conducted to determine the presence of isometric growth ($H_0: b = 3, a = 0.05$). The morphometric relationships TL vs SL , TL vs BH , TL vs ED and TL vs HL were estimated linear model between variables. To evaluate differences in linear relationships between the sexes, an analysis of covariance was performed (ANCOVA) (Zar, 2009).

Spatial Distribution

The spatial distribution of the biomass was modeled using a geostatistical approach (Rivoirard et al., 2000, Paramo and Roa, 2003), with the regionalized variable being the biomass by station of *E. occidentalis* and *E. pandionis* (kg/km²). The experimental variogram is defined as the variance of difference between values that are h units apart.

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} [z(x_i) - z(x_i + \mathbf{h})]^2,$$

where $\hat{\gamma}(\mathbf{h})$ is semivariance, h is a vector of distance and direction, $N(\mathbf{h})$ is the number of pairs of observations at distance h and given direction, $z(x_i)$ is the fish density (kg/km²) of *Epigonus occidentalis* and *Epigonus pandionis* for the i th data point.

Spherical, Gaussian and exponential variogram were fitted and selected according to the weighted least-square criterion (Cressie, 1993). Finally, ordinary point kriging was used to reproduce the stochastic processes across the region of interest, i.e. the mean

density inside the spatial distribution area (Isaaks and Srivastava, 1989). To estimate the variance of the mean fish density, the intrinsic geostatistical method was applied, in which the variance is dependent on the geometry in the area of spatial distribution, the sampling design, and the variogram structure (Petitgas and Prampart, 1995; Rivoirard et al., 2000). The spatial analyses were carried out in the R-project software (geoR library) (Ribeiro and Diggle, 2001).

RESULTS

For both species, no statistical differences were found in size by sexes (Fig. 2, Table 1) ($p > 0.05$). Female of *E. occidentalis* ranged between 13.0 and 24.2 cm TL (mean 18.5 ± 2.7 cm) and males between 14.4 and 25.8 cm TL (mean 19.8 ± 2.2 cm) (Table 1). Female of *E. pandionis* ranged between 11.2 and 23.5 cm TL (mean 18.2 ± 4.3 cm) and males between 13.1 and 20.4 cm TL (mean 17.4 ± 2.0 cm) (Table 1). No significant differences were found in the weight (g) of females and males of *E. occidentalis* and *E. pandionis* (Table 1, Fig. 2).

The length-weight regressions (Fig. 3) in both males and females *E. occidentalis* and *E. pandionis* were significant ($p < 0.001$) and about 90% of weight variability is explained for both sexes (Table 2). In female and male *E. occidentalis* the growth was isometric (t -test > 0.05), while in female and male *E. pandionis* the growth was positive allometric (t -test < 0.05) (Table 2).

The morphometric relationships between TL vs SL , BH , ED and HL of *E. occidentalis* and *E. pandionis* showed high coefficients of determination (>0.70) (Table 3). ANCOVA showed no significant differences in regression slopes between females and males in all morphometric relationships (Fig. 4, Table 3).

The spatial distribution of biomass was best fitted using the Gaussian variogram model for *E. occidentalis* and the spherical model for *E. pandionis* (Fig. 5). For *E. occidentalis*, the Gaussian model showed a spatial structure with 20.17% of non-explained variance by sampling design (nugget) and the correlation range

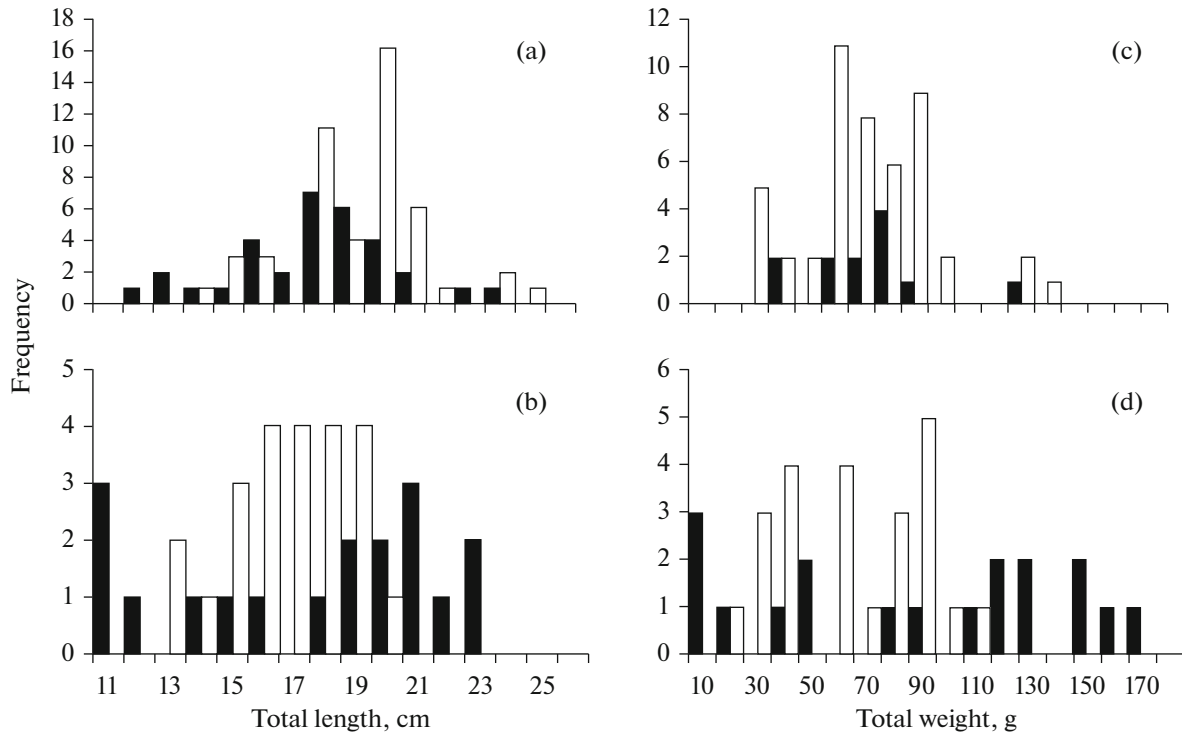


Fig. 2. Frequency distributions of total length (TL, cm) and total weight of female (■) and male (□) *E. occidentalis* (a, c) and *E. pandionis* (b, d) in the Colombian Caribbean Sea.

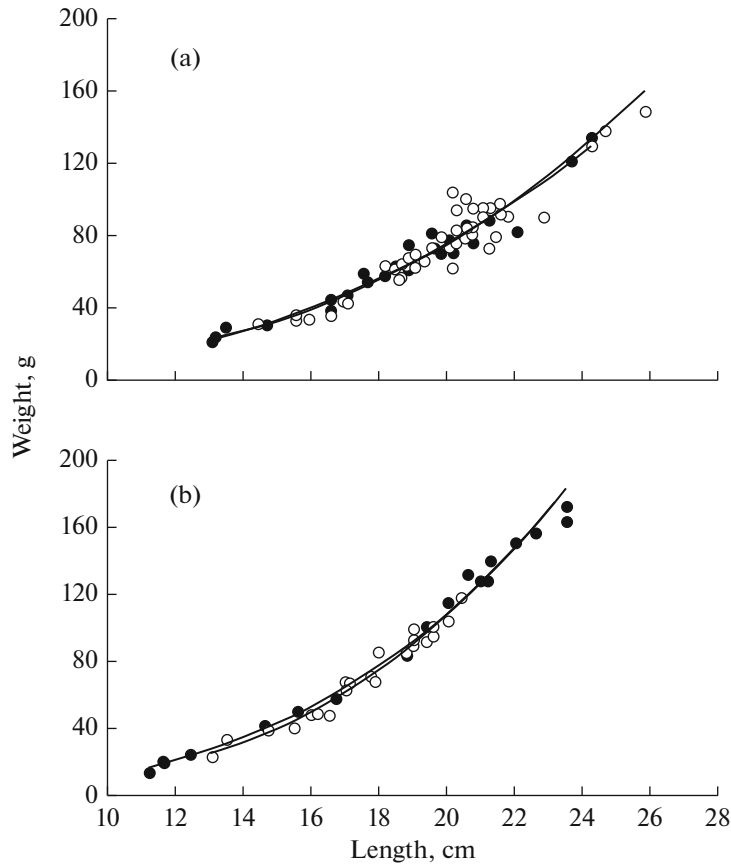


Fig. 3. Length–weight relationships for female (●) and male (○) *E. occidentalis* (a) and *E. pandionis* (b).

Table 2. Parameters of the length–weight relationship ($WT = aTL^b$) for female and male *E. occidentalis* and *E. pandionis*

Species	Sex	<i>n</i>	<i>a</i>	<i>a</i> (C.I.95%)	<i>b</i>	<i>b</i> (C.I. 95%)	<i>R</i> ²	<i>t</i> -test (<i>H</i> ₀ : <i>b</i> = 3)	F (ANCOVA)	<i>p</i> -value (ANCOVA)
<i>E. occidentalis</i>	F	31	0	0–0	2.811	2.600–3.021	0.961	0.076	0.136	0.714
	M	47	0	0–0	2.944	2.676–3.211	0.914	0.672		
<i>E. pandionis</i>	F	17	0	0–0	3.250	3.094–3.405	0.992	0.003	1.958	0.170
	M	22	0	0–0	3.407	3.109–3.704	0.964	0.010		

F—female, M—male.

Table 3. Parameters of morphometric relations for female (F) and male (M) *E. occidentalis* and *E. pandionis*

Species	Relation	Sex	<i>a</i>	<i>a</i> (C.I. 95%)	<i>b</i>	<i>b</i> (C.I. 95%)	<i>R</i> ²	F (ANCOVA)	<i>p</i> -value (ANCOVA)
<i>E. occidentalis</i>	$LT = a \times bSL$	F	−16.531	−30.886 to −2.177	1.381	1.284 to 1.478	0.964	0.365	0.547
		M	6.762	−8.441 to 21.965	1.221	1.125 to 1.318	0.932		
<i>E. pandionis</i>		F	3.079	−7.259 to 13.417	1.170	1.105 to 1.236	0.991	0.153	0.698
		M	9.296	−0.015 to 18.606	1.137	1.073 to 1.202	0.990		
<i>E. occidentalis</i>	$LT = a \times bHL$	F	17.456	2.577 to 32.335	3.403	3.113 to 3.693	0.961	0.005	0.945
		M	15.968	−0.672 to 32.609	3.430	3.121 to 3.738	0.927		
<i>E. pandionis</i>		F	−8.349	−33.071 to 16.373	3.473	3.034 to 3.911	0.958	0.025	0.877
		M	40.745	20.752 to 60.737	2.556	2.175 to 2.937	0.932		
<i>E. occidentalis</i>	$LT = a \times bBH$	F	35.448	13.942 to 56.953	4.039	3.485 to 4.594	0.904	0.090	0.765
		M	39.397	16.175 to 62.618	3.922	3.359 to 4.485	0.832		
<i>E. pandionis</i>		F	39.688	4.327 to 75.050	3.577	2.726 to 4.428	0.864	0.003	0.959
		M	39.644	7.762 to 71.526	3.584	2.738 to 4.430	0.845		
<i>E. occidentalis</i>	$LT = a \times bED$	F	15.091	−28.478 to 58.660	10.989	8.277 to 13.701	0.743	0.194	0.661
		M	16.217	−18.165 to 50.599	10.835	8.819 to 12.852	0.745		
<i>E. pandionis</i>		F	9.137	−34.621 to 52.894	7.528	5.681 to 9.375	0.857	0.874	0.358
		M	52.771	18.422 to 87.121	5.399	3.886 to 6.911	0.807		

was 26.28 km. For *E. pandionis* the spherical model showed just 3.24% of non–explained variance and the correlation range was 18.85 km (Table 4).

The spatial distribution showed that *E. occidentalis* was found mainly in the northern zone of Colombian Caribbean Sea and the highest aggregations were found off Santa Marta and Riohacha. In the southern area, a concentration of lower biomass was found off Morrosquillo Gulf (Fig. 6). The mean density for *E. occidentalis* in the northern zone was higher (14.11 kg/km²) than in the southern zone (3.95 kg/km²),

Table 4. Parameters of isotropic variogram models of *E. occidentalis* and *E. pandionis*

Parameters	Species	
	<i>E. occidentalis</i>	<i>E. pandionis</i>
	Gaussian	spherical
Nugget	50.13	5.17
Sill	198.46	154.37
Range, km	26.28	18.85
%sill	20.17	3.24

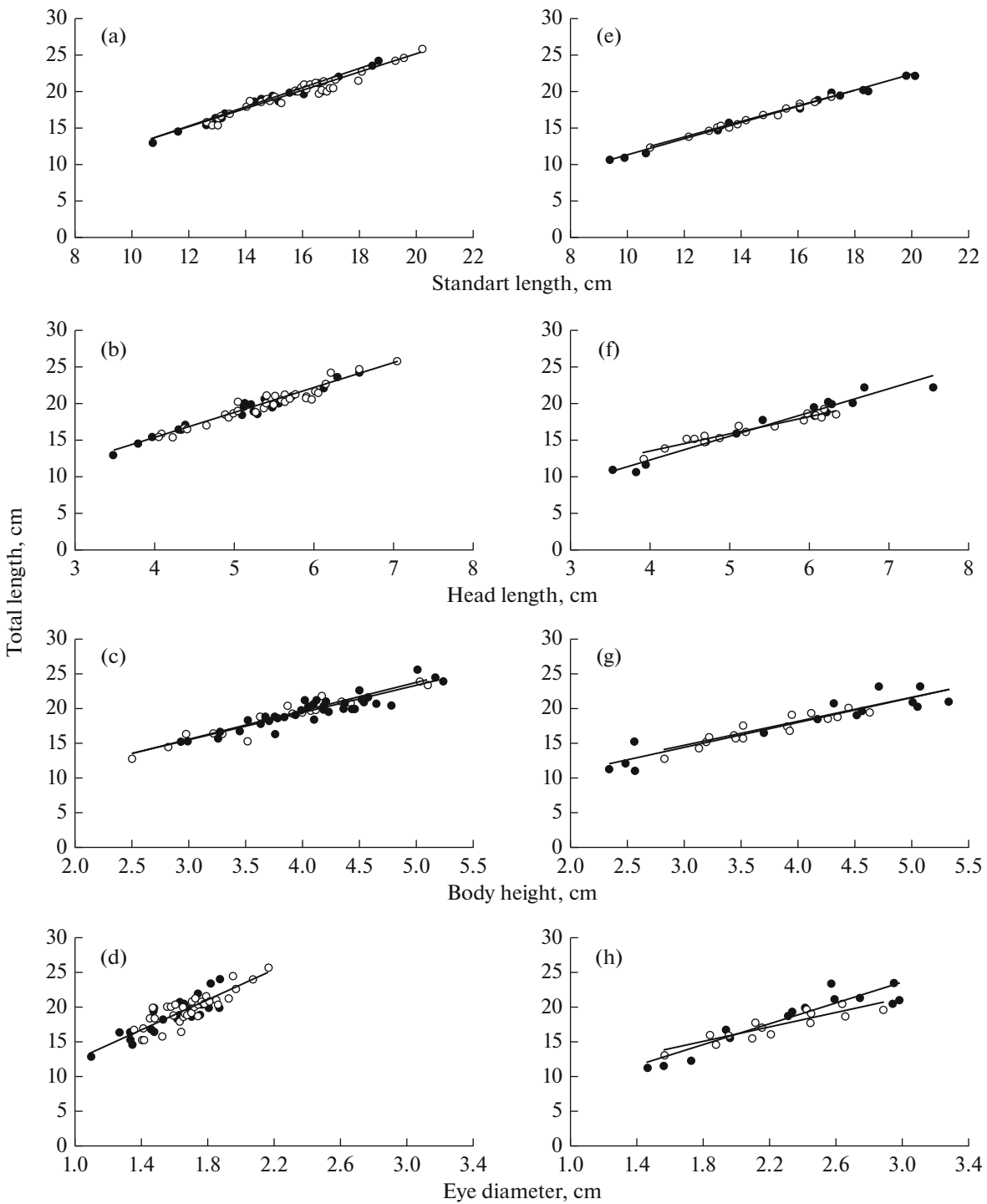


Fig. 4. Linear relationships between morphometric characters in female (●) and male (○) *E. occidentalis* (a–d) and *E. pandionis* (e–h).

resulting in biomasses estimates of 97561 kg (CV = 18.21) in the northern area and 3831 kg (CV = 21.24) in the south. *E. pandionis* was distributed in the north between Santa Marta and Riohacha, and in the south

was found between Cartagena and Morrosquillo Gulf (Fig. 6). The mean density for *E. pandionis* in the northern zone was very similar (8.65 kg/km²) to that in the southern zone (8.92 kg/km²), resulting in biomass

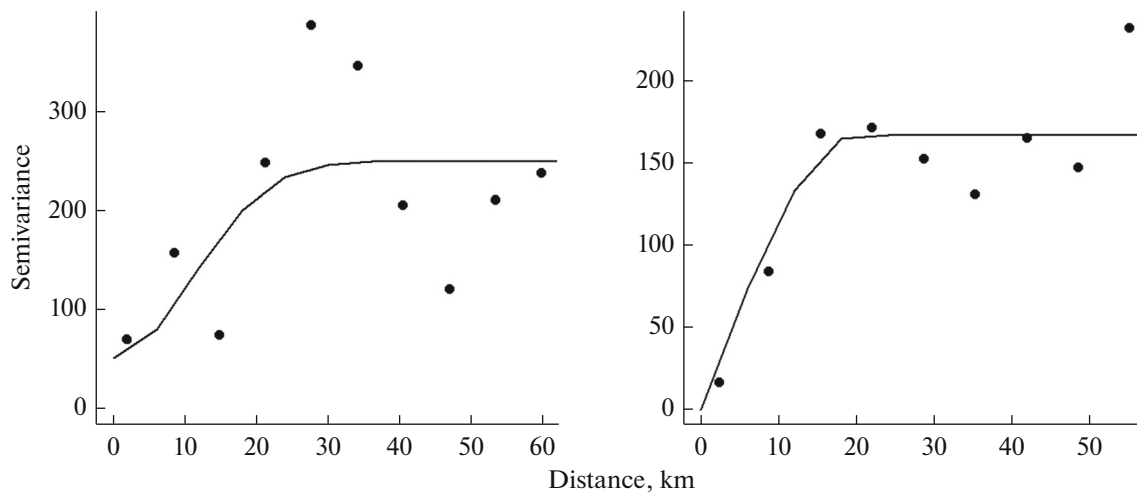


Fig. 5. Isotropic variogram fitted to Gaussian and spherical models for *E. occidentalis* (a) and *E. pandionis* (b), respectively.

estimates of 27501 kg (CV = 26.13) in the north and 18070 kg (CV = 26.92) in the south.

DISCUSSION

Cardinal fish *E. occidentalis* and *E. pandionis* are present across a wide depth gradient, demonstrating their ability to migrate vertically, i.e., they are eurybathic species (Paramo et al., 2012). Similar species in the northwestern Mediterranean Sea (e.g. *E. denticulatus*) are distributed at the top of continental slope between 200 and 700 m (Fernández-Arcaya et al., 2013). *E. telescopus* is found in depths of 75 to 1200 m, but more commonly between 300 and 800 m (Tortonese, 1986; Abramov, 1992; Field et al., 1997). In Chile the bathymetric distribution of *E. crassicaudus* shows large catches between 300 and 400 m (Leal et al., 2009). In general, species of *Epigonus* perform diurnal vertical migrations between midwater and benthos (Abramov and Lipskaya, 1989), migratory habits which corroborate with a diet of euphausiids, small pelagic fish (myctophids) and benthic organisms (Leal et al., 2009). Therefore, juveniles are associated with nepheloid layers with large amount of suspended sediment, which provide a large supply of food for fish larvae and juveniles, and interact with continental margins, indicating that these deep strata act as nursery areas for deep-sea fish which later complete an ontogenetic migration to deeper waters (Fernández-Arcaya et al., 2013). In the Colombian Caribbean Sea, *E. occidentalis* exhibits isometric growth, while for *E. pandionis* the growth was positive allometric. However, *E. crassicaudu* in Chile shows that the observed maximum size of females (17–46 cm) is larger than males (17–43 cm), with a negative allometric growth in both females and males (Gálvez and Rebolledo, 2001). In addition, species of *Epigonus* can be very long-lived, e.g., the estimated maximum age of *E. tele-*

scopus females is 39 years and 34 years for males, with Linf of 76.3 cm and 83.3 cm, respectively (Vieira et al., 2013). Cardinal fish (*E. crassicaudus*) in Chile has a lifespan of 15 years (Galvez et al., 2000), although other studies indicate age as high as 54 years (Ojeda et al., 2010).

The northern area of the Colombian Caribbean Sea is influenced by the northeast trade winds, which causes an Ekman transport off the coast flowing in the direction to south-west, almost parallel to the coast (Paramo et al., 2012). The trade winds are responsible for upwelling that increases productivity in the Guajira area (Andrade et al., 2003; Paramo et al., 2003, 2009, 2011). This is likely the reason that the largest aggregations of *E. occidentalis* and *E. pandionis* were found in the northern part of the Colombian Caribbean, where local oceanography is modulated by seasonal upwelling with high productivity (Paramo et al., 2009, 2011).

Cardinal fish *E. occidentalis* and *E. pandionis* have the potential to be a sustainable fishery owing to their high frequency of occurrence among deep-sea fish in the Colombian Caribbean Sea. However, further research is required to determine their life history traits such as growth, reproduction, recruitment, mortality, spawning season and nursery areas. The precautionary approach in FAO guidelines should be adopted, regarding the exploitation of these deep-sea species, because life history traits make them especially vulnerable to fishing exploitation (Koslow et al., 2000; Morato et al., 2006; Follesa et al., 2011).

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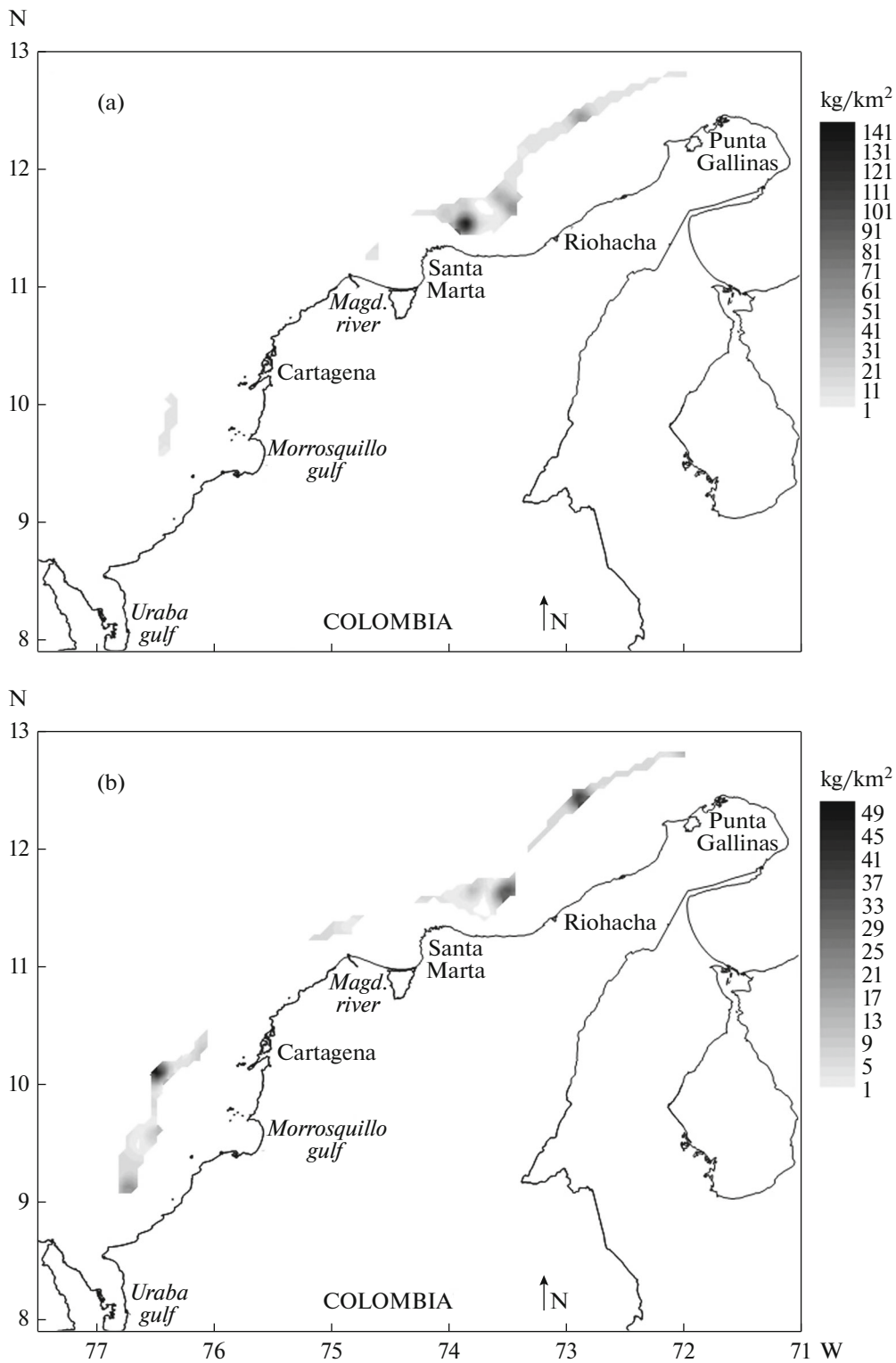


Fig. 6. Spatial distribution of biomass (kg/km²) of *E. occidentalis* (a) and *E. pandionis* (b) in the Colombian Caribbean.

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