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Article

Catch composition of deep-sea resources of commercial importance in the Colombian Caribbean

Composición de las capturas de los recursos de aguas profundas de importancia comercial en el Caribe colombiano

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Resumen.- Recientes estudios en el Caribe colombiano describen el potencial para una nueva pesquería de crustáceos entre 200 a 550 m de profundidad. Con el fin de soportar planes de manejo apropiados para su utilización sostenible, el objetivo del presente estudio fue identificar la composición de la captura y detectar tendencias generales en la distribución batimétrica de las cuatro principales categorías biológicas (crustáceos, teleósteos, condrictios y moluscos), en relación con el estrato de profundidad. Una captura por unidad de área total de 8.759 ind. km^{-2} y 226 kg km^{-2} fue reportada y la mayor contribución fue soportada por los peces teleósteos (89 especies; 62% abundancia y 73% de biomasa total), dominando el estrato de profundidad de 200-300 m, seguido por los crustáceos (36 y 22%, respectivamente), para aguas más profundas (>500 m). Las especies más importantes fueron los peces *Coelorinchus caelorhincus* (20,2 ind. km^{-2}; 16,7 kg km^{-2}) y los crustáceos *Penaeopsis serrata* (579 ind. km^{-2}, 7% de la abundancia total) y *Pleoticus robustus* (12,6 kg km^{-2}, 6% de la biomasa total). La información obtenida es parte de la línea de base requerida para describir el potencial efecto de las pesquerías de aguas profundas en el ecosistema y soportan futuras decisiones acerca del uso, manejo y conservación de los recursos de aguas profundas de esta región.

Palabras clave: Aguas profundas, pesquería, crustáceos, Colombia, Caribe

Abstract.- Recent studies in the Colombian Caribbean Sea describe the potential for a new deep-sea crustacean fishery between 200 a 550 m depth. In order to support appropriate management plans for their sustainable utilization, the goal of the present study was to identify the catch composition and to detect general trends in the bathymetric distribution of the main four biological categories (crustaceans, teleostean, chondrichthyes and molluscs), in relation to depth strata. A total catch per unit area of 8,759 ind. km^{-2} and 226 kg km^{-2} was reported and the major contribution was supported by teleostean fish (89 species; 62% abundance and 73% of total biomass), dominating the depth stratum 200-300 m, followed by crustaceans (36 and 22%, respectively) for deeper waters (> 500 m). Most important species were the fish *Coelorinchus caelorhincus* (20.2 ind. km^{-2}; 16.7 kg km^{-2}) and the crustaceans *Penaeopsis serrata* (579 ind. km^{-2}, 7% of the total abundance) and *Pleoticus robustus* (12.6 kg km^{-2}, 6% of the total biomass). The information obtained is part of a base line required to describing the potential effects of deep-sea fisheries on the ecosystem and supporting future decisions about use, management and conservation of deep resources for this region.

Key words: Deep-sea, fishery, crustaceans, Colombia, Caribbean

Introduction

The by-catch is a major concern worldwide, it has been estimated in 7.3 million ton mean per year and most of the contribution is from by-catch landings of shrimp fisheries (27%) (Kelleher 2005). By-catch and discards are the most important topics in fishery management (Paighambari & Moslem 2012). Recent studies in the Colombian Caribbean Sea revealed several areas of high concentration of commercially important deep-sea decapod crustaceans (*i.e., Aristaeomorpha foliacea*, *Pleoticus robustus*, *Penaeopsis serrata*, *Metanephrops binghami*) representing a potential new deep fishery resource (Paramo & Saint-Paul 2012a,b,c). These potential fisheries have great economic importance in the emergent development of deep-sea fisheries particularly in Latin America (Arana *et al*. 2009), where crustaceans, as opposed to fishes, have a noticeable commercial interest (Wehrtmann & Echeverría 2007, Wehrtmann *et al*. 2012, Pérez *et al*. 2013). However, it is well known that deep-sea resources are highly vulnerable to over-exploitation due to their life-history characteristics that include long longevity, slow growth rate, late maturity and low fecundity (Morato *et al*. 2006, Follesa *et al*. 2011). Therefore, deep sea stocks are depleted more easily, and recovery will be much slower than for species in shallow waters (Roberts 2002).

Despite its importance, the deep-sea demersal fauna from the continental margin of the Colombian Caribbean is relatively unknown (Paramo *et al*. 2012). There is an increasing interest in the exploitation of deep-water (defined here as >200 m; Cavanagh & Kyne 2006) resources in this area. Available studies from deeper waters of the Colombian Caribbean have focused on length-weight relationships for selected species (Díaz *et al*. 2000), technical reports for potential commercial fisheries (Álvarez-León & Rey-Carrasco 2003), species reports (Roa-Varón *et al*. 2003, Saavedra *et al*. 2004) and deep fish inventories (Polanco *et al*. 2010).

Different studies demonstrated that fishing activities could cause significant changes in deep- sea ecosystems (Bianchi *et al*. 2000, Labropoulou & Papaconstantinou 2005). Therefore, research about the by-catch associated to commercial species (shrimps) of the Colombian Caribbean Sea is crucial for describing the potential ecosystem effects of these fisheries and for supporting future decisions about policies and strategies for management and conservation of deep resources. Thus, the present study aimed to identify the catch composition and to detect general trends in the bathymetric distribution of the main biological categories (crustaceans, teleostean fish, chondrichthyes and molluscs), in relation to depth strata of a potentially new deep-sea resource in the Colombian Caribbean.

Materials and methods

Study area and sampling design

Experimental trawls during two surveys in November and December of 2009 were carried in depths ranging from 200 to 550 m in the Colombian Caribbean. Samples were collected by the commercial shrimp vessel "Tee Claude" using a trawl with a cod-end mesh size of 44.5 mm from knot to knot. The actual location of trawlable bottoms were found using a commercial echosounder FURUNO FCV 1150 with a transducer at a frequency of 28 kHz, with at least two hauls per 100 m depth stratum, on a grid of 60 stations (10 sampled stations between 200-300 m depth, 26 between 300-400 m, 18 between 400-500 m, and 6 at depth >500 m) (Fig. 1). No samples were collected between Cartagena and Magdalena River due to the irregular depth in this zone. The effective haul duration was 30 min and the tow distance by the net was estimated by means of a GPS Garmin MAP 76CSx. Total and relative (%) number and weight of individuals were recorded by categories of crustaceans (commercial and non-commercial), teleostean fish, chondrichthyes and molluscs. The deep-sea catch per unit of area (CPUA) was standardized by km^2 of sample area for total abundance (ind. km^{-2}) and biomass (kg km^{-2}). The swept area was estimated considering the spread of the net (11.58 m), using the vulnerability correction factor for shrimp trawls nets (0.7) (Sparre & Venema 1995) and the speed of the vessel (average 2.5 knots) (Gunderson 1993, King 2007). The catch composition by weight and number was standardized by depth strata; species regarded as pelagic and hard bottom associated were excluded from the analysis (D'Onghia *et al*. 2004).

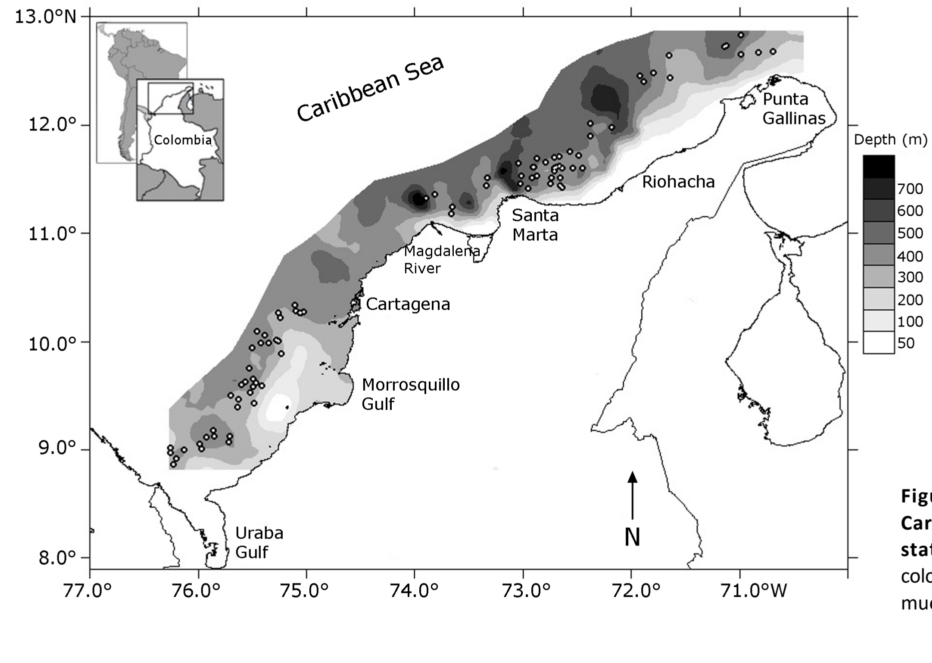

Figure 1. Study area in the Colombian Caribbean. Circles indicate the sampled stations / Área de estudio en el Caribe colombiano. Los círculos indican las estaciones muestreadas

Statistical analysis

The quantitative species composition for each 100 m stratum intervals was analyzed. In each interval the dominant species in terms of both abundance and biomass were determined. Due to the substantial marketability of four deep-sea crustaceans (*Aristaeomorpha foliacea*, *Pleoticus robustus*, *Penaeopsis serrata*, *Metanephrops binghami*) make them as a potential new economic resource in the Colombian Caribbean (Paramo & Saint-Paul 2012a,b,c), were labeled as commercial crustaceans (CC). Non-commercial crustacean species were named as NoCC and teleostean fish, chondrichthyans and molluscs, as total by-catch. The calculated indices from the biomass and abundance trawl data were 1) the ratio of by-catch to CC, 2) the ratio of chondrichthyans to CC, 3) the ratio of chondrichthyans to total catch (TC), 4) the ratio of teleosteans to CC and 5) the ratio of NonCC to CC. Changes with depth in the calculated indices were evaluated using Generalized Additive Models (GAM) (Hastie & Tibshirani 1990). The analysis was exploratory with the aim to describe the bathymetric distribution of the above-mentioned indexes. An additive model is an extension of a linear model, but allows linear functions of predictors (depth) to be replaced by smoothing functions (Agenbag *et al*. 2003), as follows:

$$y = \alpha + \sum_{i=1}^{n} \cdot fi(Xi) + \varepsilon$$

where, y is the response, Xi the predictor, α a constant and ε the error term. The function fi is estimated using smoothers. We used spline (s) smoothing with a Gaussian model (Burnham & Anderson 2002). Differences in CPUA values of abundance and biomass between depth stratum from crustacean, teleostean fish, chondrichthyes and molluscs, were evaluated using Kruskal-Wallis non-parametric test (Gotelli & Ellison 2004, Zar 2009).

Results

A total CPUA of 8,759 ind. km^{-2} and 226 kg km^{-2} were obtained for all sampled stations. Highest abundance (ind. km^{-2}) was represented by teleostean fish from the total calculated, followed by the crustaceans, chondrichthyes and molluscs. Fish and crustaceans accounted for most of the total catch in biomass (kg km^{-2}), followed by chondrichthyes and molluscs (Fig. 2).

Higher abundance and biomass for crustaceans were obtained for > 500 m stratum. Highest fish abundances occurred in the 200-300 m depth stratum and most of the fish biomass was collected in depths > 500 m. Between the fish category, deep-sea teleosteans represented most part of the total catch in terms of abundance and biomass. The fish abundance decreased with the increase in depth. However, the crustacean abundance increased with depth (Fig. 3). Nevertheless, a comparison of the CPUA in abundance and biomass using Kruskal-Wallis non-parametric test, showed no statistical differences ($P > 0.05$) in abundance and neither biomass between depth strata by group category.

Teleostean fish captures were represented by 48 teleostean families and 89 species, the orders Gadiformes (33 species), Perciformes (16 species), Zeiformes (7 species) and Scorpaeniformes (6 species), amounted to almost 62 species of the fish species inhabiting the deeper waters of the Colombian Caribbean. The families Macrouridae, Zeniontidae, Merluciidae, Trachichthyidae,

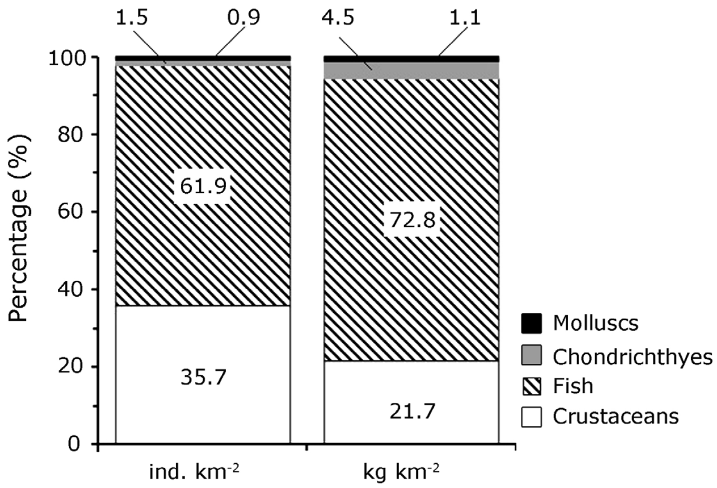

Figure 2. Abundance in terms of number (ind. km^{-2}) and weight (kg km^{-2}) of the four main categories of the catch of deep-sea Colombian Caribbean / Abundancia en términos de número (ind. km^{-2}) y peso (kg km^{-2}) de las cuatro categorías principales de la captura de aguas profundas en el Caribe colombiano

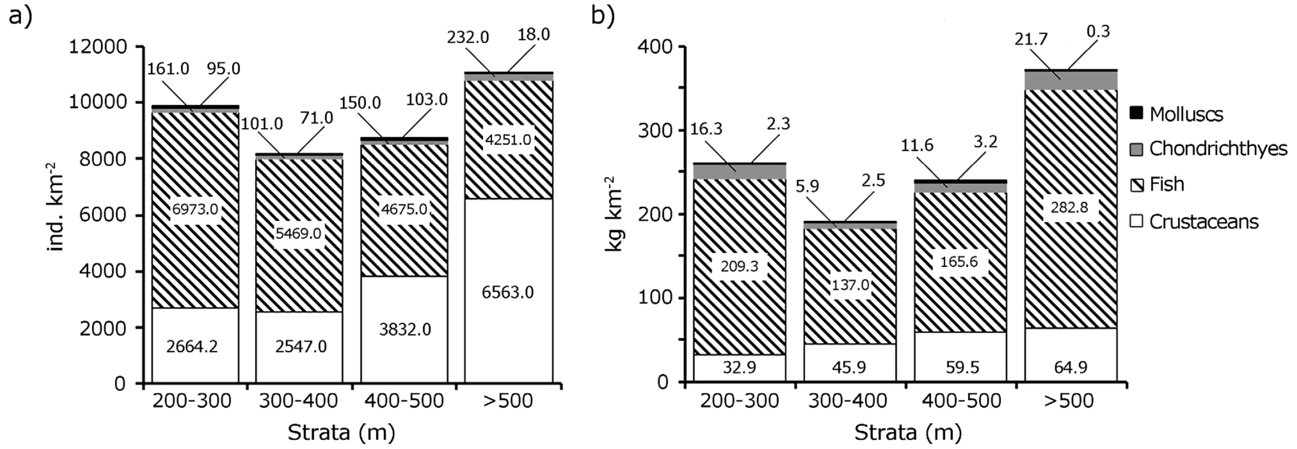

Figure 3. Deep-sea catch composition in terms of: a) abundance (ind. km^{-2}), b) biomass (kg km^{-2}) by depth stratum (m) in the Colombian Caribbean / Composición de la captura de aguas profundas en términos de: a) abundancia (ind. km^{-2}), b) biomasa (kg km^{-2}) por estrato de profundidad (m) en el Caribe colombiano

Chlorophthalmidae, Setarchidae and Epigonidae, accounted 55% of the total fish abundance, including teleosteans and chondrichthyans. The most abundant species were *Coelorinchus caelorhincus* (20.2 ind. km^{-2}; 16.7 kg km^{-2}), *Zenion hololepis* (13.4 ind. km^{-2}; 4.1 kg km^{-2}), *Steindachneria argentea* (4.5 ind. km^{-2}; 9.4 kg km^{-2}), *Chlorophthalmus agassizi* (2.0 ind. km^{-2}; 0.8 kg km^{-2}), *Poecilopsetta beanii* (2.4 ind. km^{-2}; 0.6 kg km^{-2}), *Chaunax suttkusi* (2.3 ind. km^{-2}; 2.5 kg km^{-2}), *Neobythites gilli* (2.3 ind. km^{-2}; 0.7 kg km^{-2}), *Bembrops anatirostris* (1.8 ind. km^{-2}; 2.3 kg km^{-2}), *Hymenocephalus* sp. (1.3 ind. km^{-2}; 2.7 kg km^{-2}) and *Cyttopsis rosea* (1.3 ind. km^{-2}; 0.7 kg km^{-2}).

Chondrichthyes proportion was always low among strata, ranging between 1.2-2.1% in abundance and 3.1-6.2% in biomass. A total of 9 chondrichthyan orders and 13 species occurred in 28% of the sampled stations. The most abundant chondrichthyan species were *Etmopterus perryi* (1.1 ind. km^{-2}; 1.0 kg km^{-2}), *Gurgesiella atlantica* (0.2 ind. km^{-2}; 0.6 kg km^{-2}), *Anacanthobatis americanus* (0.2 ind. km^{-2}; 0.6 kg km^{-2}), *Galeus cadenati* (0.2 ind. km^{-2}; 0.5 kg km^{-2}), *Squalus cubensis* (0.2 ind. km^{-2}; 0.4 kg km^{-2}), *Cruriraja rugosa* (0.1 ind. km^{-2}; 0.8 kg km^{-2}), *Hydrolagus alberti* (0.1 ind. km^{-2}; 0.4 kg km^{-2}), *Scyliorhinus boa* (0.1 ind. km^{-2}; 0.4 kg km^{-2}), *Squatina dumeril* (0.04 ind. km^{-2}; 0.8 kg km^{-2}), *Anacanthobatis* sp. (0.03 ind. km^{-2}; 0.04 kg km^{-2}), *Neoharriotta carri* (0.02 ind. km^{-2}; 0.10 kg km^{-2}), *Dactylobatus clarkii* (0.01 ind. km^{-2}; 0.23 kg km^{-2}) and *Centrophorus granulosus* (0.01 ind. km^{-2}; 0.09 kg km^{-2}). Molluscs constituted 0.2-1.2% of abundance and 0.1-1.3% of biomass among all depth strata (Fig. 3).

The most important commercial deep-sea crustacean in terms of individual number was *P. serrata* followed by *P. robustus*, *A. foliacea* and *B. binghami* and for the biomass *P. robustus* followed by *A. foliacea*, *M. binghami* and *P. serrata* (Table 1). *Penaeopsis serrata* was dominant in terms of abundance between the strata 200-300 m, 300-400 m and 400-500 m. For depths > 500 m the highest abundance was registered for *P. robustus* (Table 1). The highest biomass for *P. robustus* was recorded in the stratum > 500 m and 400-500, followed by *Metanephrops binghami* in 200-300 m and 300-400 m. *Metanephrops binhgami* was not captured in the >500 m stratum (Table 1).

Table 1. Commercial crustacean species catch composition on deep-sea grounds in terms of total and relative abundance (ind. km^{-2}) and biomass (kg km^{-2}). The percentage in parentheses is related to the total of catch per unit area / Composición de la captura de especies de crustáceos comerciales en regiones de aguas profundas en términos de abundancia total y relativa (ind. km^{-2}) y biomasa (kg km^{-2}). El porcentaje en paréntesis está relacionado al total de la captura por unidad de área

Strata (m)	CPUA (ind. km)			
	A. foliacea	*P. robustus*	*P. serrata*	*M. binghami*
Total	355 (4.0%)	378 (4.3%)	579 (6.6%)	223 (2.5%)
200 - 300	347 (3.5%)	128 (1.2%)	354 (3.5%)	314 (3.1%)
300 - 400	300 (3.6%)	184 (2.2%)	512 (6.2%)	303 (3.6%)
400 - 500	396 (4.5%)	703 (8.0%)	829 (9.4%)	107 (1.2%)
>500	616 (5.5%)	742 (6.7%)	196 (1.7%)	0 (0%)
Strata (m)	CPUA (kg km^{-2})			
	A. foliacea	*P. robustus*	*P. serrata*	*M. binghami*
Total	8.2 (3.6%)	13.1 (5.7%)	3.6 (1.5%)	6.7 (2.9%)
200 - 300	5.1 (1.9%)	3.5 (1.3%)	1.6 (0.6%)	6.6 (2.5%)
300 - 400	6.4 (3.3%)	8.1 (4.2%)	2.7 (1.4%)	9.6 (5.0%)
400 - 500	10.4 (4.3%)	22.3 (9.2%)	5.9 (2.4%)	3.5 (1.4%)
>500	20.9 (5.6%)	25.7 (6.9%)	2.0 (0.5%)	0 (0%)

The model fit was significant ($P < 0.01$) in explaining the variability of bathymetric distribution of the calculated indices. Higher ratios of by-catch to CC (10.1% of explained deviance) (Fig. 4a), Teleosteans to CC (6.1% of explained deviance) (Fig. 4b) and NonCC to CC (23.6% of explained deviance) (Fig. 4c) were found at shallower depths (200-300 m); the minimum values of these ratios showed a decrease from 350 m to 550 m. When the chondrichthyes were separated in the analysis, the ratios chondrichthyes to CC (26.5% of explained deviance) (Fig. 4d) and chondrichthyes to TC (23.9% of explained deviance) (Fig. 4e) showed a strong increment at shallower depths (270-300 m).

Discussion

Results of the present study for the total catch from the experimental trawling in the Colombian Caribbean showed that the abundance and biomass of fish catches were 1.7 and 3.3 times higher, respectively, than the crustacean contribution. The following groups were the chondrichthyes and the molluscs, both with a marked less proportion than the former groups. In Turkey (Iskenderun Bay) fish and shellfish represent the 97% of the landings by weight and 72% of the captures of economic value (Can *et al*. 2004). Additionally, the catch composition of the trawl fleet operating from Mallorca (Balearic Islands) reported the major proportion of fish in the total catch, with around 70% of the discarded biomass for mean depths between 300 and 616 m, resulting in overfishing over some target fish species (Moranta *et al*. 2000). For the Bushehr coastal waters (Persian Gulf) the 12.5% of the total catch was represented by target species of shrimp and 87.5% was by-catch. The reported by-catch for this region includes 114 species from 45 teleostei families (14.0%), 13 species from 7 elasmobranchs families (14.0%) and 13 species from 13 invertebrate families (13.9%), demonstrating that shrimp trawls produce large catches of fishes, including some demersal threatened species by catching the adults and immature individuals (Paighambari & Moslem 2012).

Despite differences in sampling designs, it is noticeable that for the present study the stratum > 500 m contributed to the highest abundance. Same results were described for the commercial red shrimps and the non-commercial species for depths between 500 and 700 m in the Eastern Ioninan Sea (Mytilineou *et al*. 2006), where also the contribution of the

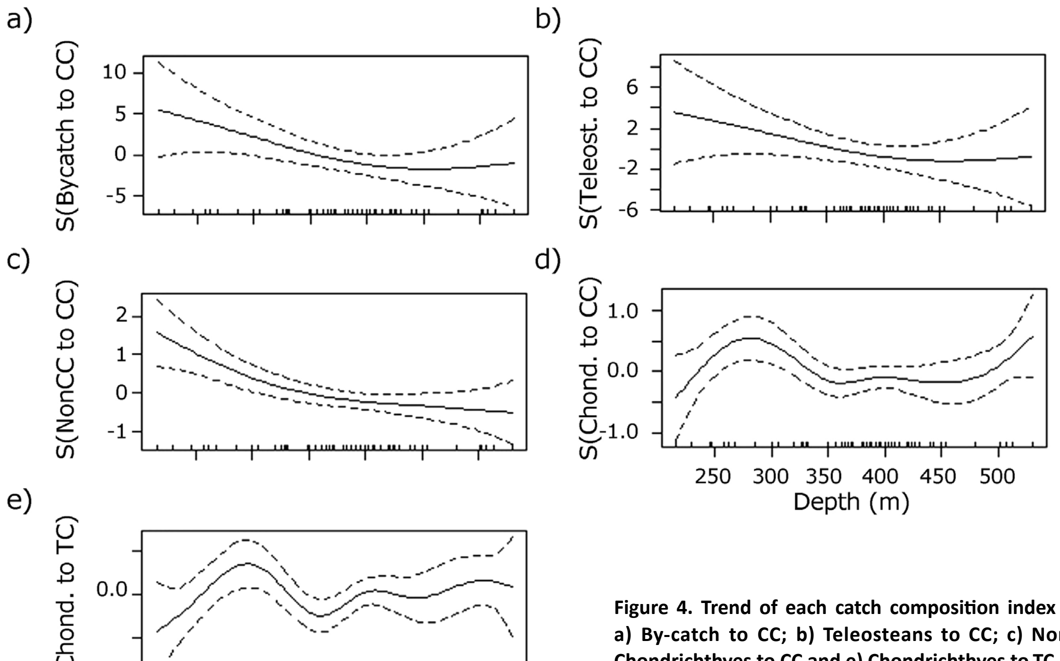

Figure 4. Trend of each catch composition index *versus* depth: a) By-catch to CC; b) Teleosteans to CC; c) NonCC to CC; d) Chondrichthyes to CC and e) Chondrichthyes to TC / Tendencia de cada índice de composición de captura *versus* la profundidad: a) By-catch a CC; b) Teleósteos a CC; c) NoCC a CC; d) Condrictios a CC y e) Condrictios a TC

molluscs was negligible, ranging between 0.1% and 1% of the total catch. Our results included the shrimp *A. foliacea,* the fish *C. agassizii* and the shark *C. granulosus* between the most important species, in terms of weight and number of individuals. The contribution of these species in the studied area agrees with the catch composition of the unmarketable fish present in the discards from the red shrimp *A. foliacea* in the western Mediterranean (Moranta *et. al*. 2000, Mytilineou 2006), especially in relation to the importance of the genera *Centrophorus*, *C. uyato* and *Etmopterus*, *E. spinax*. The contribution of the latter groups was also described for the Brazilian deep-sea trawling fisheries which includes as the most important species the deep-water sharks (Etmopteridae *Etmopterus lucifer* 1617 individuals) and the skate (Rajidae *Gurgesiella dorsalifera* 688 individuals) between the elasmobranch discards for the area (Pérez *et al*. 2013). The most important finfish belongs to two families: Neoscopelidae (Myctophiformes) and Macruridae (Gadiformes) and between the eight principal components of the deep-water shrimp fisheries appear the finfish *Coelorinchus marinii* and the red shrimp *A. foliacea* (Pérez *et al*. 2013). The abundance of the red shrimp *A. foliacea* in the Colombian Caribbean Sea increases with depth (Paramo & Saint-Paul 2012c); higher abundances were reported for deeper strata (400-500 and >500 m). These results agree with the maximum abundances reported for this species between 500 and 700 m worldwide (Mytilineou *et al*. 2006, Papaconstantinou & Kapiris 2001, Ragonesse *et al*. 2001, Politou *et al*. 2003, 2004). In many countries *A. foliacea* is a commercially valuable crustacean; however, unregulated trawling fishery has reduced its biomass into critical levels (Cau *et al*. 2002, Mytilineou *et al*. 2006, Pérez *et al.* 2013). For the Colombian Caribbean Sea *A. foliacea* reveals a potential for a new fishery (354.8 ind. km^{-2}) (Paramo & Saint-Paul 2012c) in comparison to the median densities calculated for this species in the Brazilian shrimp fishing during 2005-2006 (100-200 ind. km^{-2}), showing the most aggregately distributional pattern in the fishing area (Pérez *et al*. 2013). There is a clear evidence that fish groups from the Colombian Caribbean Sea appears to coexist with several areas of high concentration of commercially important deep-sea crustaceans (*i.e.*, *Aristaeomorpha foliacea*, *Pleoticus robustus*, *Penaeopsis serrata*, *Metanephrops binghami*) described in recent studies (Paramo *et al.* 2011, Paramo & Saint-Paul 2012a,b,c). The abundance of the mentioned crustacean species in deeper bottoms in the Colombian Caribbean could be explained due to benthic or benthopelagic distributional pattern exhibited by larger individuals (Aguzzi *et al*. 2007). Large size crustaceans do not migrate off bottom, but follow sloping seabed occupying upper slope (Aguzzi & Compani 2010, MacIsaac *et al*. 2014). The maximum biomass values were obtained in the present study at around depths >500 m, could reflect an individual size increment by depth (Paramo & Saint-Paul 2012a,b,c), rather than an overall increase in number. The presence of larger individuals in deeper waters is known as the bigger-deeper phenomenon (Haedrich & Rowe 1977, Pollini *et al.* 1979), which is explained as an ontogenic migration of individuals to deeper water (Stefanescu *et al*. 1992). This a common characteristic of deep-sea organisms where the adults benefit from a reduced metabolic rate and the life expectancy is increased due to the low habitat temperatures at deeper waters (Love 1970, 1980; Cushing 1983). Consequently, a bigger-deeper trend seems to appear on upper slope with middle and large-size species and individuals could reach their highest abundance in deeper waters and replace smaller species that dominate at shallower depths (Moranta *et al*. 1998). Nevertheless, future studies using size-based community metrics such as size spectrum should aim in that direction. The changes of the faunistic composition between different megafaunal assemblages are due to the substitution of the dominant and subdominant species, throughout the depth gradient, by a continuous faunistic turnover (Hecker 1990). The zonation pattern obtained in our study could be associated with different bathymetric strata and revealed higher teleost abundances between 200-300 m depth, and crustaceans dominating over the 400 m depth strata. Between the crustaceans, *P. serrata* was the most abundant (578.7 ind. km^{-2}) species caught at median depths (200-500 m) and was subdominant in deeper waters (>500 m) where is replaced by *P. robustus*. In addition, depth seems to control on the vertical zonation of all marine biota including the demersal crustaceans for the Colombian Caribbean Sea (Moranta *et al*. 1998, Paramo *et al*. 2012, MacIsaac *et al*. 2014). In addition to depth, is noticeable that the trophic relationships between the two dominant groups (crustaceans and teleosts) in the studied area would probably be based on a competitive exclusion due to the exploitation of similar food resources rather than on predator/prey relationships, as was described in different deep-sea communities (Cartes *et al*. 2001). Since, some of the mentioned fish species prey over supra-benthos but also infauna or planktonic preys, the abundance distribution pattern of fish and crustacean suggests the contribution of important sources of organic matter form the phytodetritus of the pelagic zone exported from upwelling productive areas to the deep-sea ecosystems (Rice *et al*. 1986). Furthemore, higher abundances of fish and crustaceans in the Colombian Caribbean seems to be modulated by the local oceanography specifically by the seasonal upwelling (Paramo *et al*. 2009), and river continental discharges (Manjarrés 2011) with effects on deeper horizons by export flux from surface to seafloor (Bakun 1996, Paramo & Saint-Paul 2010).

Fisheries continue to move towards deeper waters around the world (Simpfendorfer & Kyne 2009) but most of them are highly susceptible to overfishing (Relini & Orsi-Reliniv 1987, Stevens *et al*. 2000, Queirolo *et al.* 2011). Therefore, the virgin populations of the Colombian Caribbean must consider an ecosystem-based management and maintain their biomass sustainably with very low exploitation rates. Intensive exploitation of the fishing resources over the past decades, mainly on the continental shelves, has led to the progressively declining catches of many fish and crustacean stocks (Pauly *et al*. 2003). In response, new fishing areas in deeper and deeper waters are being developed, taking advantage of recent advances in capture technologies (Pauly *et al*. 2003). Nevertheless, deep-sea ecosystems and fisheries are not considered highly productive and are especially vulnerable to over-exploitation due to the life-history characteristics of deep-sea species, including extreme longevity, slow growth rate, late maturity and low fecundity (Morato *et al*. 2006, Follesa *et al*. 2011). The potential effects of the threats on deep-sea resources include the extensive restructuring of entire ecosystems, changes in the geographical ranges of many species, large-scale elimination of taxa, and a decline in biodiversity at all scales (Robison 2009). For this reason, the stocks of deep waters tend to collapse much more rapidly, and their recuperation is slower, in contrast with the shallow environments (Roberts 2002). Among the results of anthropogenic impact which affect these ecosystems are: i) the removal of predators by fishing and the removal of habitat-forming species (such as gorgonians and stony corals), ii) the modification of the food webs among species and as a response to the allochthonous contribution of the by-catch which is taken advantage of by various groups, iii) the accumulation of heavy metals and toxins, and iv) global climate changes that alter the quantity and quality of food that reaches the deep waters (WWF/IUCN 2004). Therefore, the sustainable use of new fisheries should include the life history of the target species, their ecology and bio-economic potential, as well as of the associated biodiversity in deep-sea ecosystems (FAO 2003, Munro 2011). Therefore, we suggest a deep and detailed analysis about the potential and irreversible impact of the fishing footprint over slope benthic environments in the Colombian Caribbean, before considering any kind of trawl fishery.

The implementation of spatial management, with zoning for different kinds of fishing activity and use of seasonal or temporary closures is one important measure that should be included in the ecosystem-based management of the deep-sea and resources in the Colombian Caribbean. This can be a useful tool for reducing discard rates and controlling effort exerted. Spatial management measures must be underpinned by a good knowledge of the biology, spatial distribution and abundance of both resource species and other species impacted by fisheries, including protected species (Bellido *et al*. 2011). Marine protected areas (MPA) have emerged as a tool for marine conservation and fisheries management following an ecosystem-based approach (Worm *et al*. 2006, Fraser *et al*. 2009, Paramo *et al*. 2009, Jackson & Jacquet 2011). The ecosystem-based management of the deep-sea and resources should be based on an ecosystem approach, that considers population dynamics and structure and function of the ecosystem, the optimum allocation of catches and effort, protection of nursery and spawning areas, the development of monitoring strategies and the care of ecosystems through the implementation of MPA. This holistic approach will allow an appropriate level of biodiversity and the habitat quality to be maintained, while accomplish sustainable fisheries.

In conclusion, experimental trawling catches from the Colombian Caribbean Sea were characterized by the dominance of finfish and crustaceans in all depth strata. Some of the dominant groups described for the Colombian Caribbean Sea were also important components of deep-sea assemblages in different regions worldwide. Finally, this study presents baseline information needed for understanding the potential ecosystem effects of trawling fishery and the implementation of an ecosystem approach to deep-sea fisheries management in the Colombian Caribbean Sea.

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