Multi-Year Density Variation of Queen Conch (*Aliger gigas*) on Serrana Bank, Seaflower Biosphere Reserve, Colombia: Implications for Fisheries Management

Néstor E. Ardila[1]*, Hernando Hernández[1], Astrid Muñoz-Ortiz[2], Óscar J. Ramos[2], Erick Castro[3], Nacor Bolaños[3], Anthony Rojas[4] and Juan A. Sánchez[5]

[1] *División de Biología Marina, ECOMAR Consultoría Ambiental, Bogotá, Colombia,* [2] *Departamento de Ciencias Básicas, Universidad de La Salle, Bogotá, Colombia,* [3] *Corporación para el Desarrollo Sostenible del Departamento Archipiélago de San Andrés Providencia y Santa Catalina, CORALINA, San Andrés, Colombia,* [4] *Secretaria de Agricultura y Pesca de la Gobernación del Departamento Archipiélago de San Andrés Providencia y Santa Catalina, San Andrés, Colombia,* [5] *Laboratorio de Biología Molecular Marina (BIOMMAR), Departamento de Ciencias Biológicas, Facultad de Ciencias, Universidad de los Andes, Bogotá, Colombia*

BACKGROUND

Queen conch *Aliger gigas* (Linnaeus, 1758), formerly known as *Strombus gigas*, constitute a valuable commercial and cultural resource for native communities since pre-Hispanic times (Baisre, 2010). Populations of this marine gastropod are registered for 36 countries in the Caribbean, extending from Florida to the northern coast of South America and live mainly on sandy bottoms, in clear waters down to a depth of 100 m (CITES, 2003). Mating and spawning usually take place during the warmer months of the year, although in some areas, mainly in the western Caribbean, the breeding activity is continuous at low reproduction levels throughout the year (Avila-Poveda and Baqueiro-Cardenas, 2009; Aldana-Aranda et al., 2014; Boman et al., 2018). Moreover, some populations migrate seasonally from open waters to shallower waters for spawning (Appeldoorn, 1993).

Over the past decades, intensive overfishing has led to population decline, collapse of stocks, and temporary closure of fisheries in different locations at Bermuda, Cuba, Colombia, Florida, Mexico, Netherlands Antilles, Virgin Islands and Venezuela (Stoner and Schwarte, 1994; Stoner et al., 2018). Studies indicate that most populations of *A. gigas* continue their decline despite having been listed in the CITES appendices for being threatened by local fisheries in countries like Belize, Colombia, Dominican Republic, Haiti, Honduras, Panama, Puerto Rico and the Virgin Islands, as well as the support by regional fisheries management agencies (Stoner et al., 2012; Prada et al., 2017; Tewfik et al., 2019).

In the Colombian Caribbean, *A. gigas* has been one of the most significant fishery resources for many years, being therefore subject to large-scale exploitation. Specifically, for the Seaflower Biosphere Reserve, which included the archipelago of San Andrés, Providencia and Santa Catalina, the landings reached a maximum of 813 tons in 1988, decreasing to 465 tons in 1993 and 81 tons in 2003 (Prada et al., 2009). Restricted access to this resource was enforced in this region between 2005–2007 and 2011–2013. The fishery was reopened between 2008 and 2010 in the areas of Serrana and Roncador banks, and in 2013 only for Serrana bank (Prada et al., 2009; Castro et al., 2011).

In terms of conservation activities, following the guidelines of FAO and CITES, efforts for the responsible management of the queen conch have been implemented in Colombia, which enforced

fishing management and regulations since 1977 (Castro et al., 2011). In recent years, studies have estimated densities and abundances of the queen conch throughout habitat and depth strata on different banks of the Seaflower Biosphere Reserve at least once every 3 years (Castro et al., 2011). With the new ecosystem-based management approach, the 8% control rule proposed by Medley (2008) was incorporated as a criterion of sustainability to regulate the intensity of fishing activity. This increased the restriction for fishing in small banks, taking into account the recruitment of juveniles, the zoning of the Marine Protected Areas (MPA's), and illegal fishing. With this model, it was possible to define the fishery closing and reopening cycles, which have shown positive effects on species recovery (Castro et al., 2011).

The combination of overfishing and the loss and disturbance of habitats are the main factors influencing the population decrease of the queen conch. The current study presents a multi-temporal analysis of *A. gigas* populations on Serrana bank, which is an atoll in the western Caribbean that is included into the Seaflower Biosphere Reserve. This reserve was declared a Marine Protected Area since 2005. The main objective was to release raw data from these valuable observations and assess whether the management tools in the MPA are having positive effects on the recovery and conservation of juvenile and adult populations of *A. gigas*.

DATA COLLECTION

Serrana bank is a triangular bank of 15.5 km in maximum length in the direction SW-NE, originated from an atoll partially dissected to leeward (Díaz et al., 2000). The bank platform has a volcanic form with a strong slope emerging from 1,500 m depth (Geister and Díaz, 2007). Despite its isolation from human populations, coral reef habitats have been declining in the last three decades on Serrana Bank following the Caribbean-wide trend (Sánchez et al., 2019). A total of 72 sampling sites were established on Serrana Bank, which were monitored five times over a period of 10 years (2003, 2007, 2010, 2011, and 2013), although only 69 sampling sites were monitored during 2003. Monitoring consisted in observations of the distribution and density of the queen conch during each season. Estimates of abundance and density of queen conch were made from diver-based visual surveys along 4 strip-transects of 30 × 8 m. Data collected during observations included georeferencing, depth, habitat type (seagrass habitat is not present on Serrana bank, probably replaced by the ruffled form of *Lobophora variegata*, see additional details in Sánchez et al., 2005, 2019), zoning regarding conservation, and density of adults and juveniles of the conch estimated as number of individuals per hectare (ind. ha^{-1}). All conch encountered were counted and lip thickness was measured (nearest 0.1 mm) with a caliper by placing it as far as possible onto the middle of the shell lip. Adults were defined as individuals with flared lips ≥5 mm thick (Brownell, 1977). This criterion was adopted since 2003 although more recently higher values have been proposed (e.g., ≥13 mm; Avila-Poveda and Baqueiro-Cardenas, 2006). The difference

in these criteria are due to the fact that the first reference of sexual maturity was based on the evaluation of external macroscopic characteristics and the second work was based on histological methods.
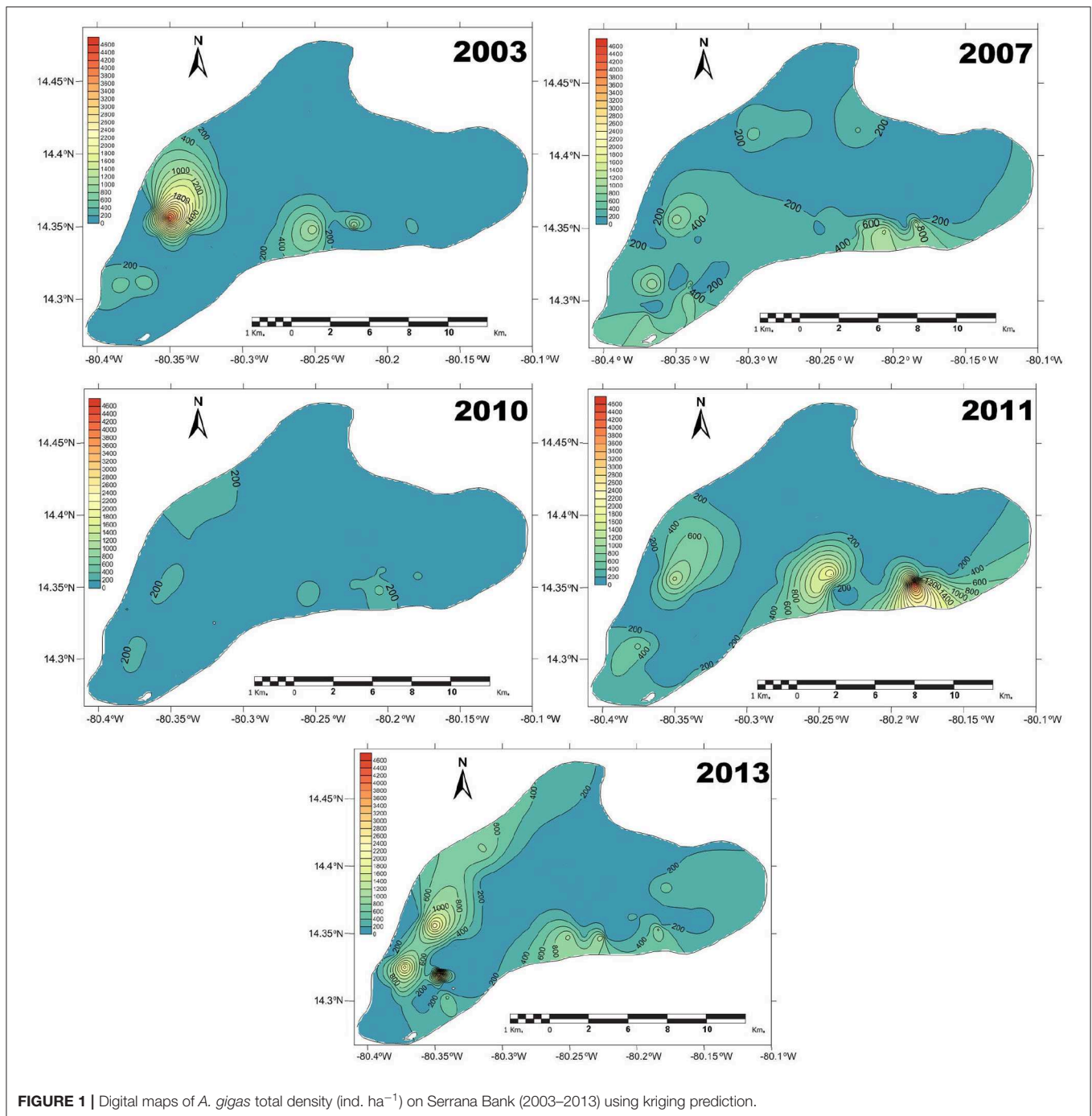
STATISTICAL ANALYSIS AND SPATIAL DESCRIPTION

To establish relationships between depth and adult and juvenile densities of the queen conch, Spearman rank correlations were calculated for the five different samplings given the lack of normality of the data (Shapiro Wilk test). Additionally, to describe and characterize changes in the conch density among habitat types, sampling periods and zoning with respect to conservation, a factorial analysis of variance was performed. The estimations were made using R (R Development Core Team, 2015) with statistical significance level considered for $p <$ 0.05. Based on the information obtained from the 72 sites, and using their respective georeference, densities (ind. ha^{-1}) were mapped for juvenile and adult populations. As a geographical reference, the maps illustrate the −100 m depth. Specifically, for representative effects on the map, the density was represented as interpolations with the point kriging method using software Surfer 10. In order to optimize the analysis, the habitat at each sampling site was classified into four categories of substrate type: sand, sand and macroalgae, sand and debris and mixed coral. Additionally, each of the 72 sampling points was classified according to its location in the Serrana Bank MPA within the following categories: recovery and sustainable use (artisanal fishing), preservation and open area to the fishing activity.

## MULTI-YEAR DENSITY VARIATION OF QUEEN CONCH (*ALIGER GIGAS*)

A total of 352 observations were made during five sampling years between 2003 and 2013 at depths ranging from 2 to 23 m. The average population density was 123.4 ind. ha^{-1} for juveniles, 96.0 ind. ha^{-1} for adults and 219.4 ind. ha^{-1} for the total population. During the sampling period, the analysis showed that the population density doubled, with a considerable increase of adults and juveniles in 2013 and a minimum average population density for 2010 (**Figure 1** and **Supplementary Figure 1**). At the southeastern and western sectors, the sites with the highest juvenile's density during the study period had averages of 1398 ind. ha^{-1} (site 50) and 1221 ind. ha^{-1} (site 8). For adults, the highest average densities were 583 ind. ha^{-1} (site 8) and 494 ind. ha^{-1} (site 31) (**Figure 2A**). The general description of the density in each period and type of habitat showed that juveniles were more abundant in sandy bottoms with macroalgae, whereas adults preferred sand debris bottoms.

Juvenile density was not associated with the depth of the sampling sites ($r^2 = 0.249$, $p < 0.0001$) (**Figure 2**). On the other hand, there was a significant relationship between adults' densities and sampling depth ($r^2 = 0.080$, $p < 0.001$). Results showed that more adults than juveniles were found at greater depths (**Figure 2**).

FIGURE 1 | Digital maps of *A. gigas* total density (ind. ha^{-1}) on Serrana Bank (2003–2013) using kriging prediction.

Adult and total snail densities were associated with habitat type, sampling year and zoning with respect to conservation ($p < 0.001$), whereas juveniles were only affected by the type of habitat. Regarding the sampling year, the highest densities were observed in 2007, 2011, and 2013 (**Figure 1** and **Supplementary Figure 1**). The highest densities of adults and juveniles were found in the sand and debris habitat (**Supplementary Table 1**). Finally, open areas presented the highest densities of the snail, indicating preliminarily that the

definition of conservation areas have not been efficient for the protection of the resource. The recovery of the resource in the years 2007, 2011, and 2013 is highlighted, which overlaps with the fishery closed seasons on Serrana bank area. Adults were most sparsely distributed in the west sector of Serrana Bank reaching high densities between 400 and 1,800 ind. ha^{-1} (standard error = 0.120–0.132, **Supplementary Figure 1**). Density of adults in the east section of the bank was close to middle part of the bank. Juveniles presented a more
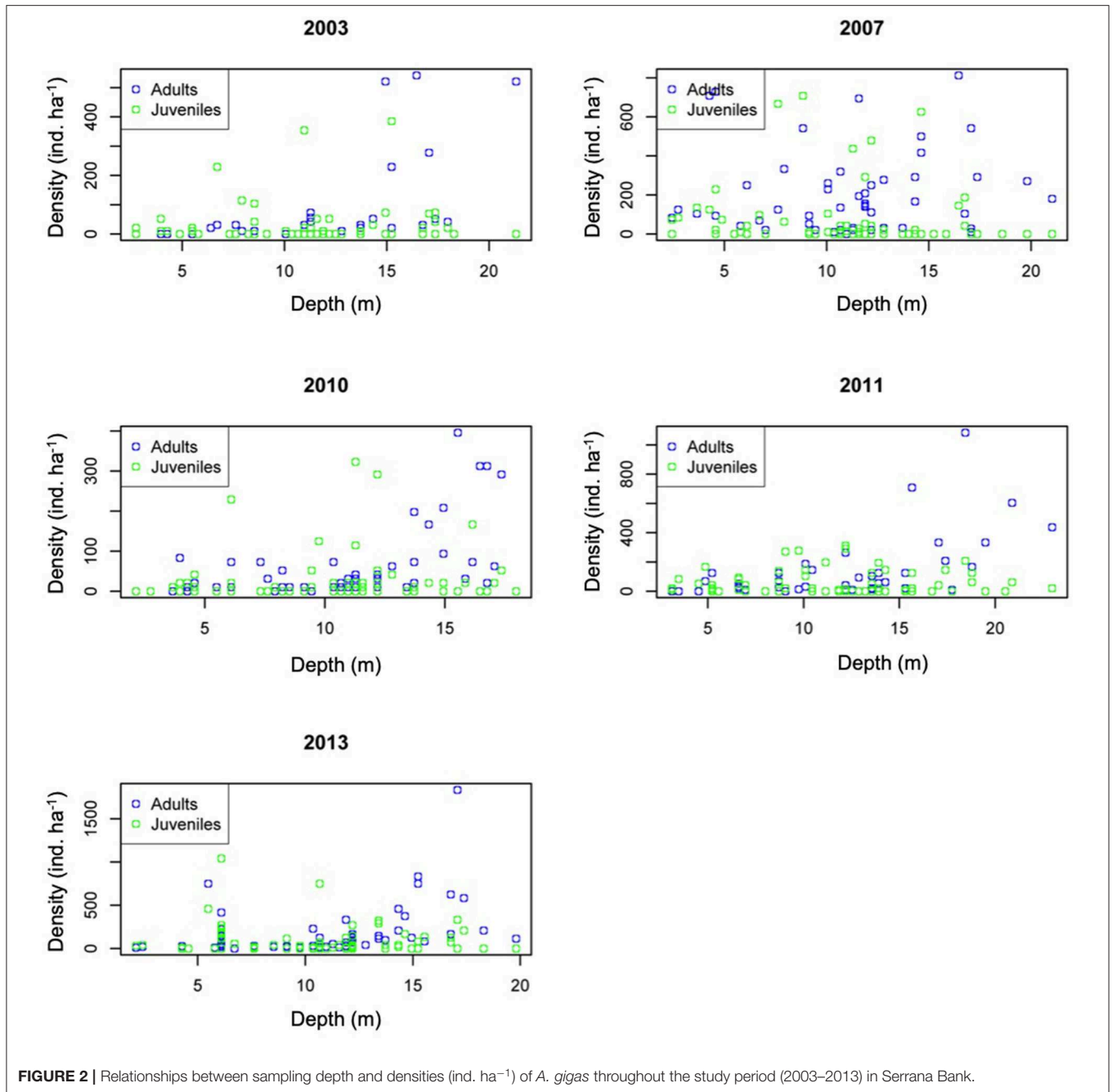
FIGURE 2 | Relationships between sampling depth and densities (ind. ha^{-1}) of *A. gigas* throughout the study period (2003–2013) in Serrana Bank.

dispersed distribution especially in the south of the bank in the last years (2007–2013; standard error = 0.128–0.132, **Supplementary Figure 2**).

IMPLICATIONS FOR FISHERIES MANAGEMENT

The highest densities of adults were observed in 2007 and 2013, with the sand-debris habitat displaying higher densities. On the contrary, the lowest densities were registered in 2003 and 2010. For juveniles, the densities were variable and presented highest values on sand-macroalgae, sand-debris and sand. The highest densities of juveniles were recorded in 2007, 2011, and 2013 and the lowest densities of juveniles were markedly recorded in 2010. Rapid increase in adult queen conch density is probably a direct function of fishing effort limitation due to the closure of the fishery. Several authors have suggested that these deep-water conchs, inhabiting beyond the depth range accessible to free divers, are the primary source of larvae for shallower populations and thus allow for the recovery of the resource (Stoner et al., 2018).

Densities recorded in Serrana bank are similar to those reported for Bahamas during 2011 (Stoner et al., 2012) and

can be up to 10–100 times higher than those reported for adults and juveniles in other studies in the Caribbean, such as in Guadalupe (Saha et al., 2013) and Archipelago Nuestra Señora del Rosario (Gómez-Campo et al., 2010). Likewise, the increase in adults density recorded between 2007 and 2013 can be associated with fishery closures between 2005–2007 and 2011–2013, which has been also noted in closures elsewhere in the Caribbean (Saha et al., 2013). These fishing regulations provided a better conservation strategy for the resource in this region, where the definition of conservation areas did not produce positive outcomes.

The significant relationship between the density of adults and sampling depth corroborated previous studies (García, 1991; Gómez-Campo et al., 2010) that concluded that the species distribution is depth-dependent. In different areas of San Andrés and Providencia Archipelago, it was observed that juveniles and pre-adults are located between 5 and 10 m depth and adults between 18 and 25 m depth (García, 1991). Nursery areas are often very shallow (<5 m), whereas larger organisms are distributed in deeper waters, including mesophotic environments down to approximately 60 m (Stoner and Schwarte, 1994; Garcia-Sais et al., 2012). The greatest association of adults with the "sand and debris" habitat, is due to the species reproductive activity associated with coarse sand and gravel bottoms (Glazer and Kidney, 2004).

REUSE POTENTIAL

The decrease of queen conch populations in different Caribbean areas is imminent and has led to the collapse of fisheries in many locations. The populations in Bermuda, Dominican Republic, Florida (USA), Haiti, Costa Rica, Puerto Rico, Trinidad & Tobago, Venezuela and those of the northern coast of Cuba and the Morrosquillo Gulf in Colombia are diminished and almost exhausted (CITES, 2003; Gómez-Campo et al., 2010). Serrana bank populations comprise an ideal reference dataset for comparisons, where some management measures delivered the expected positive results in recovering the queen conch stocks. In addition, Coralina (Corporación para el Desarrollo Sostenible del Departamento Archipiélago de San Andrés Providencia y Santa Catalina) is monitoring this population every year and this solid and extensive dataset will be needed to ensure continuity and to provide better predictions on this valuable resource.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

EC, NB, and JS conceived the study. EC, NB, and AR collected the data. NA, HH, AM-O, and ÓR analyzed the data. NA, HH, and JS wrote the manuscript. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.00646/full#supplementary-material

Supplementary Figure 1 | *A. gigas* average density (ind. ha^{-1}) by site (Juveniles and Adults) on Serrana Bank in the Seaflower Biosphere Reserve 2003–2013.

Supplementary Figure 2 | Adults density (ind. ha^{-1}) on Serrana Bank (2003–2013) using kriging prediction.

Supplementary Figure 3 | Juveniles density (ind. ha^{-1}) on Serrana Bank (2003–2013) using kriging prediction.

Supplementary Table 1 | Total, juveniles and adults densities by sites, coordinates, depth and bottoms types on Serrana Bank (2003–2013).

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