Is the Queen conch *Strombus gigas* (Mesogastropoda: Strombidae) a species with Allee effect?

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Abstract: The marine park of Xel-Há has a population of *Strombus gigas* which breeds in the area. We determined the relationship between reproductive activity, conch density and environmental parameters. Samples were collected from February to December 2012, using the transect method, at four sites of Marine Park Xel-Ha, Quintana Roo, Mexico. Sediment samples were analyzed and classified using Folk & Ward's method. Temperature, salinity and dissolved oxygen were also recorded. Density had a small correlation with sediment (Pearson r=0.29 with very coarse and r=0.26 with coarse sand), while mating and spawning had a correlation of r=0.54 and 0.62 with medium sand, respectively. Density was high in the four sites and was not associated with mating and spawning (r=0.08 and 0.03, respectively). For reproduction, *S. gigas* requires specific substrate conditions (*sandy effect*) and not just a density of 56 Conch Ha^{-1} (A*llee effect*). Rev. Biol. Trop. 62 (Suppl. 3): 207-213. Epub 2014 September 01.

Key words: *Strombus gigas*, Allee effect, reproductive behavior, Sandy effect.

The queen conch *Strombus gigas* is distributed from Brazil and Venezuela in the south up to Florida and the Bahamas in the north, including all the lesser and greater Antilles. *S. gigas* is now a luxury food. It represents one of the most valuable resources in the region, and was considered as second most valuable fishery with incomes of 6 US$ millions/year, exceeded only by the spiny lobster *Panulirus argus* (Brownell & Stevely, 1981; Pérez-Pérez & Aldana-Aranda, 2000). Now *S. gigas* is an overfished species protected by CITES who is regulated by the international commerce of this resource (de Jesús Navarrete, 2001; Brito-Manzano, Aldana-Aranda, de la Cruz-Lázaro & Estrada-Botello, 2006). However, illegal catch is practiced in all countries of the Caribbean region.

This organism has internal fertilization, it produces an egg mass and its development is indirect (Randall, 1964). Given the regional importance of queen conch in the Caribbean, and the critical status of most populations, the reproductive biology of this species has been studied in several Caribbean countries (Aldana Aranda et al., 2003a to 2003e; Delgado et al., 2004; Aldana-Aranda, 2006; Castro, Frenkiel, Baqueiro & Aldana-Aranda, 2007; Bissada-Gooding & Oxeford, 2010). Stoner, Sandt& Boidron-Metairon (1992) related *S. gigas* reproduction with temperature, photoperiod and density of adult conchs.

Stoner & Ray-Culp (2000) observed that mating and spawning in the Bahamas never occurred at a density <48 Conch·Ha^{-1}. These authors mention that the "*Allee effect*" (or "depensation") (Gascoigne & Lipcius, 2004) has an influence in the reproductive activity of *S. gigas, c*oncluding that the overfishing of this resource affects in the recovering and reproduction rates. de Jesús-Navarrete and Valencia-Beltrán (2003) reported a migration

for reproduction to sandy areas, associating the reproduction with density but not with sediment, based on these observations, the principal goal of this research was to evaluate the effect of the sediment, physicochemical and population parameters on the reproductive activity of *S. gigas* from February to December 2012.

MATERIALS AND METHODS

Study area: The study was carried in four sites of Xel-Há inlet (Bocana, Centro, Brazo Norte and Cueva) located in Quintana Roo, México, in the geographical coordinates 20°18'50"-20°19'17"N y 87°21'45.5"-87°21'02.5"W (Fig. 1). This site has a total water surface of 14Ha, where the average depth is 3.0m, showing a gradient in the physicochemical parameters (due to the underground river effluents).

Sample collection: In each site we placed three linear transects of 100 x 2m of length, giving an area of 200m^{-2} by transect. Weekly from February to December 2012, using scuba diving we registered the number of adult conch and the reproductive activity. Figures 2A-2C show mating, spawning and free egg masses of *S. gigas*. Monthly in each site siphonal length (mm) and thickness lip (mm) in adult conchs were measured. Temperature (°C), salinity (ppt), dissolved oxygen (mg·L^{-1}) were measured and sediment samples were taken. The sediment samples were dried and classified with the Folk & Ward methodology (1957). The Infostat software was used to calculated means, standard deviation, one-way Anova and Pearson's correlation among reproductive, physicochemical and granulometrics parameters.

RESULTS

Environmental parameters: Mean and standard deviation (S.D.) of temperature were 27.44±0.97°C**.** *Brazo Norte* showed the lowest records, while *Centro* recorded the highest (27.25±1.10 and 27.70±0.75°C, respectively). There was no significant variation between sites (p=0.2033). *Bocana* and *Cueva* showed mean salinities of 33.76±0.87 and 13.64±1.83ppt, respectively. Salinity showed significant

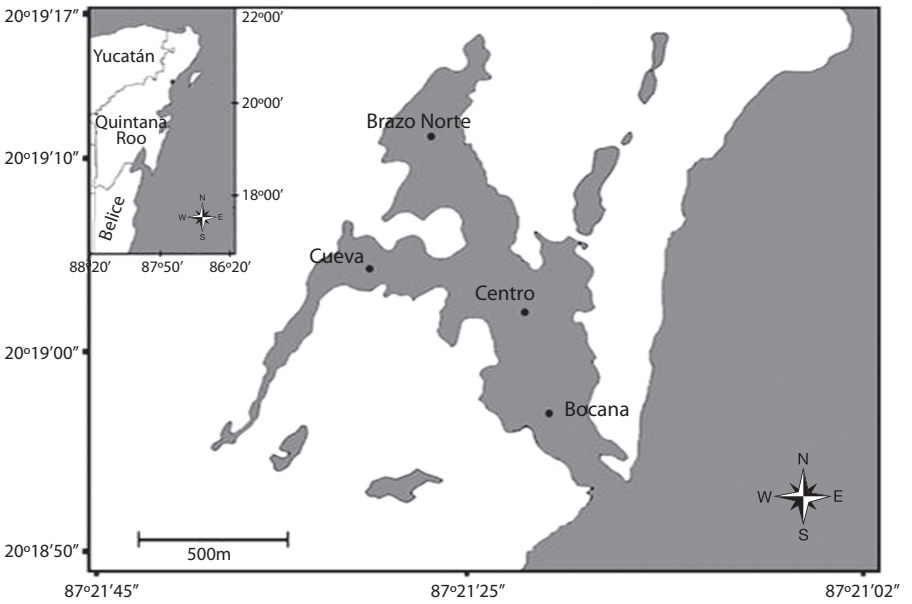

Fig. 1. Study area, Xel-Ha Park in the Mexican Caribbean, indicating four samples sites: Bocana, Centro, Brazo Norte and Cueva.

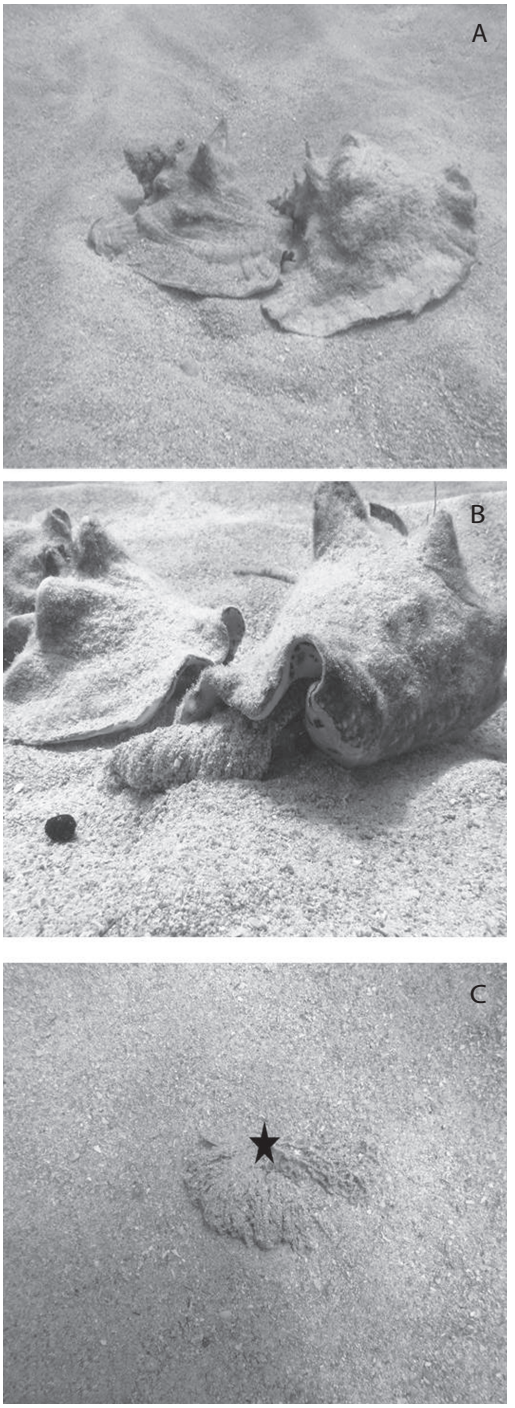

Fig. 2. Reproductive activity observed in Xel-Ha park during samplings: A) Mating conchs; B) Female spawning; C) Free egg mass (★). Photographies of Alejandro Aldana Moreno.

variation between sites ($p \leq 0.0001$). Mean of dissolved oxygen was $4.73 \pm 0.97 mg.l^{-1}$, with the highest concentration in *Bocana* and minor in *Cueva* (5.45 ± 1.28 and 4.01 ± 1.15 $mg.l^{-1}$, respectively), showing significant variation among sites ($p \leq 0.0001$). In relation to the sediments composition, *Bocana* showed 62% of coarse to medium to sands; *Centro* and *Cueva,* 60% to fine and very fine sands and *Brazo Norte*, 73.5% of fine to very fine sands (Fig. 3). The substrate composition among sites showed significant difference ($p \leq 0.0001$).

Sizes population: *Bocana* had a density of 665.58 ± 585.38 Conch.Ha^{-1}, followed by *Cueva*, *Brazo Norte* and *Centro* (647.17 ± 487.17, 596.92 ± 333.10 and 404.58 ± 454.21 Conch. Ha^{-1}) (Fig. 4A). Density was ≥10 times than density suggested by Stoner to have mating and spawning. There was significant variation among sites ($p \leq 0.0001$). The size structure in the four locations was very similar, with values of 203.68 ± 23.73mm of shell length in *Bocana*, to 187.61 ± 27.15mm in *Cueva* (Fig. 4B). Shell length did not change significantly among locations ($p=0.3080$). Using lip thickness (6mm) as an indicator of reproductive activity in conch (Aldana-Aranda & Frenkiel, 2007), we observed that conch of three sites have a lip thickness corresponding to adults: *Bocana, Centro* and *Cueva* with 15.25 ± 6.7, 11.66 ± 7.48 and 6.03 ± 5.47mm, respectively (Fig. 4C). However, lip thickness of conch showed significant variation among sites ($p=0.0198$).

Pearson correlation analysis showed a high association between mating and medium sands ($r=0.54$) and spawning with medium sand ($r=0.62$). Temperature was associated with spawning ($r=0.40$), while density conch exhibited a low association with mating and spawning ($r=0.08$ and $r=0.03$, respectively) (Table 1).

DISCUSSION

Stoner & Ray-Culp (2000) observed that mating never occurred when density was <56 Conch.Ha^{-1}, and spawning never occurred at

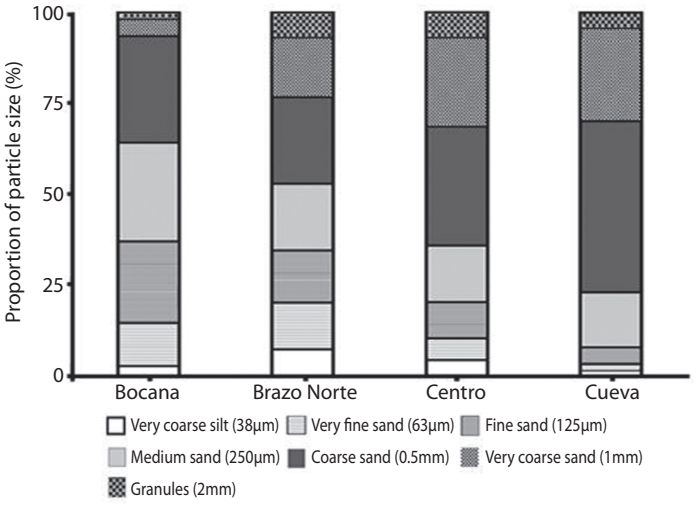

Fig. 3. Sediment category in percentage of four sampling areas in Xel-Há Park, Quintana Roo Mexico.

TABLE 1
Pearson correlation analysis between mating, spawning, density and environmental parameters (sediment category, temperature, dissolved oxygen and salinity)

Sediment category	Mating	Spawning
Granules (2mm)	-0.11	-0.16
Very coarse sand (1mm)	0.33	0.33
Coarse sand (0.5mm)	0.49	0.47
Medium sand (250µm)	0.54	0.62
Fine sand (125µm)	-0.20	-0.20
Very fine sand (63µm)	-0.62	-0.77
Very coarse silt (38µm)	-0.46	-0.57
Temperature (°C)	0.19	0.40
Dissolved Oxygen ($mg \cdot L^{-1}$)	0.34	0.23
Salinity (ppt)	-0.31	-0.10
Density ($Conch.Ha^{-1}$)	0.08	0.03

<48 $Conch.Ha^{-1}$, demonstrating the operation of depensatory mechanisms. In this study mean density was >400 $Conch.Ha^{-1}$ in four sites, however only the *Bocana* site showed mating and spawning behaviors. Peel and Aldana-Aranda (2012) reported a spatial segregation of juveniles and adults in Xel-Ha, pointing that the sites in the interior of the Inlet probably function as nurseries while *Bocana* could be associated with reproductive activity. It was observed in the present study that adults are placed in all the sites, which indicate that reproduction occurs in this inlet, but only at *Bocana* site. Stoner, Sandt and Boidron-Metairon (1992) and de Jesús Navarrete (1999) associated temperature with reproduction of *S. gigas*.

TABLE 2
Description of size classes of *Strombus gigas* of Xel-Ha park, Quintana Roo, Mexico, showing media and standard deviation (S.D.) of sifonal length and lip thickness, density and reproductive activity (mating, spawning and free egg masses). Sediment category is expressed in % (only coarse and medium sands are considered).

Indicator	Bocana	Brazo Norte	Centro	Cueva
Coarse + medium sands (%)	60.00	50.00	30.00	20.00
Density ($Conch.Ha^{-1}$)	665.58±585.38	596.92±333.10	404.58±454.21	647.17±487.17
Shell lenght (mm)	203.68±23.73	212.92±54.57	197.03±19.58	187.61±27.15
Lip thickness (mm)	15.25±6.77	4.05±5.49	11.66±7.48	6.03±5.47
Mating.week-1	4.35±3.96	0.00	0.00	0.00
Spawning. week-1	14.71±7.61	0.00	0.00	0.00
Egg masses.week-1	26.18±14.15	0.00	0.00	0.00

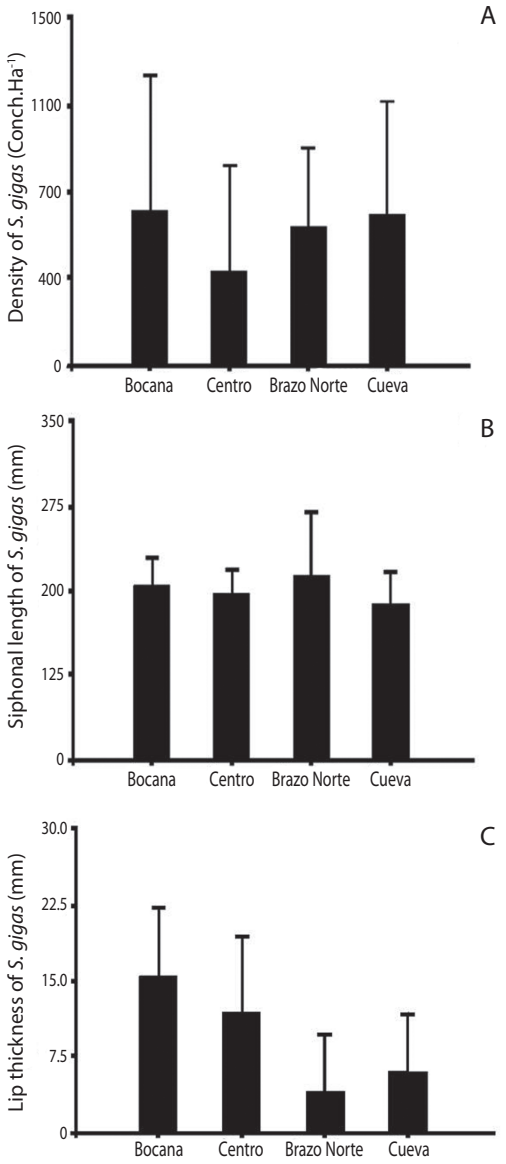

Fig. 4. Sizes population of *S. gigas* of four sites of Xel-Ha park, Quintana Roo, Mexico: A) Density (conch·m^{-2}), B) Siphonal length (mm), C) Lip thickness (mm).

In this study reproductive behavior was associated with temperature and dissolved oxygen, but conch presented mating and spawning only when sediments present ≥60 % of medium to coarse sands (Table 2).

Four sites exhibited a density suggested by Stoner & Ray-Culp (2000) to be related to reproduction, and had reproductive adults present at all times. Given that the physicochemical parameters were similar at all four sites, we suggest that *S. gigas* needs for mating and spawning a minimal density and a reproductive migration pattern related with sediment category (medium sand). Our theory is that *S. gigas*

for reproduction is a species with a specific sandy habitat, having two effects: "*Allee"* and "*Sandy*" effects.

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RESUMEN

Es el caracol marino *Strombus gigas* **(Mesogastropoda: Strombidae) una especie con efecto Allee?** El parque marino de Xel -Há tiene una población de *Strombus gigas* que se cría en la zona. Determinamos la relación entre la actividad reproductiva, la densidad de la concha de *S. gigas* y los parámetros ambientales. Las muestras fueron recolectadas de febrero a diciembre de 2012, utilizando el método de transecto, en cuatro sitios del Parque Marino de Xel -Ha, Quintana Roo, México. Fueron analizados y clasificados utilizando la metodología de Folk & Ward. También se registraron temperaturas, salinidad y oxígeno disuelto. La densidad de concha mostró una baja correlación en la categoría de sedimentos (r = 0.29 , con muy gruesos y r = 0.26 con arena gruesa), mientras que el apareamiento y desove con arena media mostraron una correlación de r = 0.54 y 0.62, respectivamente. Las densidades en cuatro sitios fueron altas y no se asociaron con el número de apareamientos y desove (r = 0.08 y 0.03, respectivamente). Para la reproducción, *S. gigas* requiere condiciones específicas de sustrato (efecto arenoso) y no sólo una densidad de 56 Conch Ha^{-1} (efecto Allee).

Palabras clave : *Strombus gigas*, efecto Allee, comportamiento reproductivo, efecto Sandy

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