Queen conch, *Eustrombus gigas*, in Fished and Unfished Locations of the Caribbean Sea: Combined Effects of a Marine Protected Area and Over-exploitation on Adults

Eustrombus gigas, en un Área de Pesca y una de no Pesca en el Caribe: Efectos Combinados del Área Protegida y la Sobrexplotación en Adultos

Eustrombus gigas, dans une Zone de Pêche et une Zone Interdite à la Pêche dans Mer Caraïbes: Effets Combinés de la Zone Protégée et la Surexploitation dans Adultes

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ABSTRACT

Marine Protected Areas (MPA) have been implemented in several places with the hope of reversing population decreases commonly observed in many marine resources. In this study, a comparison of the total density and adult density, population structure and frequency of reproductive evidence of the commercially important gastropod *Eustrombus gigas*, was made between a fished area in Mexico and an MPA in Cuba. At each area three climatic periods were included (rainy, dry and cold front periods) during 2009 to 2010 on 9 transects into the MPA and 15 transects into fished area. The total densities were 4 times higher on the MPA than fished area. Moreover, the adult densities were 20 times higher on the MPA than fished area. Apparently, the conch population at MPA is constituted by small conchs, with a gradual increase in weight and lip thickness, turning them into "dwarf" conchs. This fact was possibly density-dependent; on the other hand, the fished area showed that adult conchs are very scarce. In addition, is possible the presence of Allee effect in the area. Reproductive evidence was observed during the whole year in MPA, which suggests the existence of an important queen conch reserve in the southeastern region of Cuba and an apparently self-sufficient population for recruitment; in contrast, reproductive activity was very scarce in fished zone. Two effects were observed on this study, both important as fishery management of the conch population; consequently, both must be considered at the new revision of the management plans on each area.

KEY WORDS: *Eustrombus gigas*, Allee effect, dwarf conchs, reproductive evidence

INTRODUCTION

The queen conch *Eustrombus gigas* (Linnaeus 1758), formerly known as *Strombus gigas* (Petuch 2004, Petuch and Roberts 2007), is one of the most valuable coastal resources in the Caribbean region (de Jesus-Navarrete and Oliva-Rivera 1997, Theile 2001, Brito-Manzano et al. 2006). This large mollusk has a high aesthetic and ecological value throughout the Caribbean Sea and surrounding areas from Southern Florida in the United States to Brazil (Abbott 1974). The species is one of the most important coastal resources for the region and is second in importance after the spiny lobster (*Panulirus argus* Latreille 1804) (Appeldoorn 1994, de Jesus-Navarrete and Oliva-Rivera 1997).

At the regional level, it has been recognized that a decreasing population was caused fundamentally through overexploitation and the habitat destruction (Glazer and Kidney 2004). The rapid expansion of export markets and the increment of the markets internally, and subsequent over exploitation, has caused significant declines in queen conch populations in many areas of the Caribbean, particularly in shallow, near-shore waters where conch are easily collected by free-diving (Berg and Olsen 1989, Appeldoorn 1996, Béné and Tewfik 2005). Despite the use of various conventional fisheries management tools (minimum size, temporal and total closures of fisheries, dues of capture, etc.), stocks continue to decline in most parts of the Caribbean.

Marine protected Areas (MPAs) have been promoted as a viable complement to the other forms of fishery management (Robert and Polunin 1991). However, the management strategies of the protected areas depend on the objectives and the conceptions under which they were declared (Rowley 1994, Allison et al. 1998, Murray et al. 1999). Generally, the strategies have been focused on key species selected previously during the diagnosis process of the area, and since they do not reflect the ecosystems principle for management, the species groups of interest vary. This situation has resulted in several instances with effective management of a small group of key species but the deterioration of the ecosystem in general, as well as the loss of other species groups that are very important ecologically but have not been monitored.

The strict protection offered by the protected area is expected to induce some significant modifications to the population within the reserve itself (Béné and Tewfik 2005). Robert and Polunin (1991) presented three modifications for the protected areas, which have been cited in Béné and Tewfik (2005). First, if there is not negative density effect on recruitment, the reduced mortality rate within the MPAs should increase the abundance of the protected population. Second, the cessation of fishing mortality in the protected area is expected to modify the demographic structure of the population, leading in particular to an increase in average size/age reflecting greater longevity of the protected species. Finally, an increase in average size/age may boost egg production, depending on the species size/fecundity relationship.

The theoretical effects have already been empirically observed through several field studies (Munro 1983, Shepherd 1990, Polunin and Hunt 1999). However, these studies only have been focused on the fish of the primary fisheries, and they have concluded that fish abundance is higher and the average size is larger within the protected versus the surrounding areas (Rowley 1994), and only a few studies has been focused to the species of limited movement, specifically queen conch at Bahamas (Stoner and Ray 1996, Stoner et al. 2012a). The authors analyzed a conch population in fished and unfished locations in the Turk and Caicos isles (Béné and Tewfik 2005) and reported the "crowding effects" in a comparative study between two important places for the fishing and protection of the conch. Stoner et al. (2012b) analyzed the relationship between density of mature adults and mating frequency in queen conch in the Bahamas as well as the other possible negative effect of the conch fisheries.

The aim of the present study was to provide the first assessment of the biological performance of conch populations in protected areas subject to different objectives of management and where the conchs do not constitute the primary fishery. In addition, we propose a management consideration for the sustainable use of the resource at Desembarco del Granma National Park and new considerations for the effective management in the Banco Chinchorro Biosphere Reserve.

MATERIALS AND METHODS

Study Area

Cabo Cruz (Desembarco del Granma National Park, Cuba) — Cabo Cruz is located at the Southern Oriental region of Cuba (19°50'14.1"N and 77°44'15.7"W) (Fig.1) and at the Desembarco del Granma National Park has a 32 576 ha of protected areas. The sample area is within the reef lagoon, and the bottom has patches of seagrasses: (*Thalassia testudinum* and *Syringodium filiforme*) and some algae (*Penicillus* sp., *Dyctiota* sp.) (Alcolado 1976). Sometimes, noticeable turbidity can be observed in the lagoon, and it is associated at the terrestrial drainage, but in general transparent water predominates. According to Alcolado (1976), this can be due to the existence of a renovator oceanic current that feeds into the reef lagoon. The depth varies of 0 to 6.0 m.

Banco Chinchorro (Biosphere Reserve, México) — Banco Chinchorro is an atoll-like reef environment. It is located at the Mesoamerican Reef System within the Mexican Exclusive Economic, and also it is one of the largest of its type in the Caribbean basin that is part of the western Atlantic reef system, which is the second largest in the world (Chavez and Hidalgo 1984, de Jesús-Navarrete 2003, Vazquez-Yeomans et al. 2003). It has a surface of 144,360 ha, and include reef formations, reef lagoon, and three Keys: Lobos, Centro and Norte, and adjacent oceanic waters (Figure 1) (INE-SEMARNAP 2000).

The sample area is within the reef lagoon. The depth varies from 12 m in the south region to 2 m in the north, and 3 – 7 m in the central part. The bottom is covered with sea grasses, mainly *Thalassia testudinum*, *Syringodium filiforme*, and macroalgae (de Jesús-Navarrete 2003).

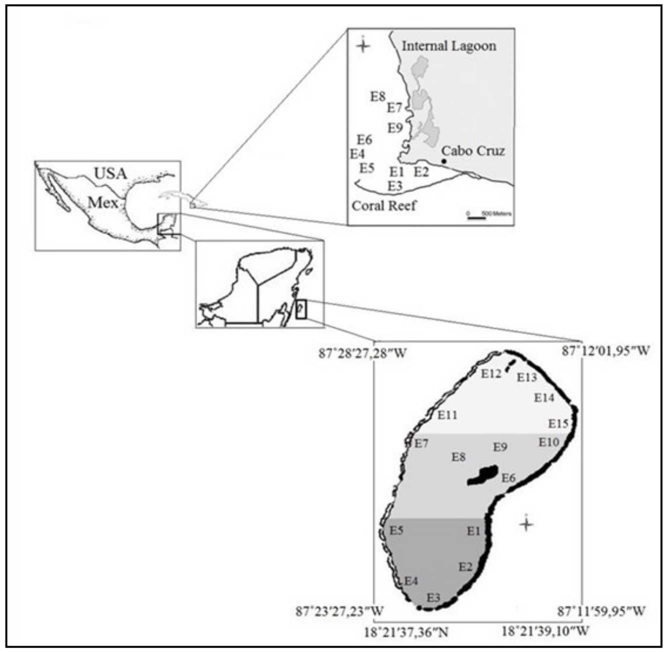

Figure 1. Location of study areas.

Sampling

Data was collected during 2009-2010 season. Samplings were carried out in three conch fishing zones at Banco Chinchorro: Norte, Centro and Sur, and three protected zones at Cabo Cruz: Guafe, Farito and Laguna and they included three climatic seasons: rainy, dry and cold front (de Jesús-Navarrete et al. 1999, Cala et al. In press).

At Banco Chinchorro due to his large extension, 15 stations were located within reef lagoon, five for each survey zone. At Cabo Cruz only nine stations were located within reef lagoon, three for each survey zone. In each station, triplicate transects of 100 m x 4 m (400 m^2) were set. To evaluate conch population density, we used the Distance Sampling software, considering the perpendicular distance and using the cosine function and the normal expansion series (Buckland et al. 1993).

The absolute frequency of the reproductive evidences were registered by transects and after we transformed to relative frequency depending on the number of adult into transects. The following reproductive evidences were recorded:

i) Copulation: the penis inside the genital channel,
ii) Spawning: females placing egg masses,
iii) Egg masses: eggs masses lay out by females, and
iv) Adult aggregations: groups of adults together and interacting.

With the purpose of not perturbing the individuals copulation and spawning, only the solitary conchs were collected and transported to the boat, where their shell length and lip thickness was registered to the nearest mm using Vernier calipers (Appeldoorn 1988).

The organisms were separated in two groups: mature adults (conch length ≥ 200 mm) and immature conch (conch length < 200 mm) taking into consideration that the minimal allowable capture size in Cuba and Mexico is 200 mm (SL) (Álvarez-Lemus and Formoso 2005, de Jesús-Navarrete et al. 2003). A parallel analysis was carried out using the Lip thickness (LT) as an indicator of sexual maturity. The conchs were classified into two groups according to Stoner et al. (2012c): Lip thickness < 15 mm as immature conch and lip thickness > 15 mm as mature conch.

An analysis of differences between abiotic variables in both areas was undertaken. The sampling was carried out at similar depths, and the temperature and salinity were measured according to that described by de Jesús-Navarrete (1999) using a portable refractometer RF20 model with a precision of 0.1 and the Practical Salinity scale. At each area, a data logger HOBO (temperature) was programmed to take readings of temperature every 30 minutes. The daily average of obtained data yielded the average monthly temperature.

The total density, adult density, reproductive evidence, and size structure distribution were evaluated relative to the water physical variables in each area.

Data analysis

For each area, two densities were calculated according to Béné and Tewfik (2005):

i) The total density for all conchs (ind/ha, Mean ± SE), and
ii) The adult density (ind/ha, Mean ± SE).

A series of statistical tests were used to determine the effect to the "area" factor (fished vs. protected) on population density. A bi-factorial Analysis of Variance (ANOVA), we have used to the assessment of the possible combined effect of the area and intrinsic factors. A non-normal distribution of the densities was anticipated at each study area (de Jesús-Navarrete et al. 1997, Cala et al. In press), and due to the typical patchiness within conch populations (Berg 1975, Stoner and Sandt 1992), density data at each site was log(x+1)-transformed to normalize the distributions. ANOVA results were followed by Scheffé test to achieve comparisons *a posteriori*.

The morphometric values of SL and LT were also analyzed. The correlation between SL and LT at each area was calculated using the coefficient of determination (r^2). Pearson correlation analysis was used to evaluate the possible relationship between reproductive activities.

RESULTS

Physical Parameters

The water temperature at Cabo Cruz varied from 26.00°C to 30.82°C at Cabo Cruz. At Banco Chinchorro, the water temperature varied from 24.4 to 29.8°C during sampling period. No statistically significant differences between studies area temperatures was found (ANOVA, $p > 0.5$). However, statistically significant differences among monthly temperatures were found within each area (ANOVA, $p < 0.05$). Salinity did not display substantial variations. At Cabo Cruz salinity varied from 32.4 to 35.4 UPS and fluctuated from 35.0 to 38.5 UPS at Banco Chinchorro. No significant differences in salinity were detected between studies area (ANOVA, $p > 0.5$). There were no correlations between conch densities (adult and total) and physical parameters in Cabo Cruz nor in Banco Chinchorro (Pearson correlation, $p > 0.50$).

Conch densities

Considering each sampling periods, a total of 210 transects were sampled (81 transects at Cabo Cruz and 129 transects at Banco Chinchorro). The conch distribution type in each study area was aggregated for all seasons.

At Cabo Cruz, the total density of conchs, varied between 647.4 ± 192 ind/ha in the rainy season to 1,395 ± 73.6 ind/ha in the dry season (Figure 2a). Adult analysis was carried out on two occasions: firstly, an analysis considering the minimum size into each area for fishing (SL ≥ 200 mm). This analysis showed that adult density varied between 66.7 ± 34.6 ind/ha during the cold front season to 102 ± 129.9 ind/ha during the rainy season (Figure 2a). However, a second analysis considering 15mm (LT) as a good indicator of conch maturity (Stoner et al. 2012c) showed an increase in the adult density with values of 330 ± 121 ind/ha in the dry season to 623 ± 189 ind/ha in the rainy season (Figure 2b). The analysis of variance showed that no significant differences among season in total density ($F = 1.8390$, $p = 0.1664$) or in adult density by area ($F = 2.61$, $p = 0.0745$).

At Banco Chinchorro, the total density of conchs varied between 172 ± 207.1 ind/ha in the rainy season to 384 ± 177.3 ind/ha in the dry season (Figure 2a). The adult density in the first analysis varied between 73 ± 132 ind/ha in the dry season to 258 ± 301 ind/ha in the rainy season. In contrast with Cabo Cruz, the analysis of adult density at Banco Chinchorro considering 15 mm (LT) as indicator of conch maturity showed a decreased considerably; as a result, adult density was almost null and only showed values of 6 ± 96 ind/ha in the dry season to 8 ± 125 ind/ha in the rainy season. An analysis of variance showed that no significant differences among season in the total density (F = 1.7231, p = 0.2034); however, showed that significant differences among season in the adult conchs (F = 2.516, p = 0.0001). The Scheffé test indicated that abundance of adult conchs in the rainy season was significantly higher than the dry and cold front seasons.

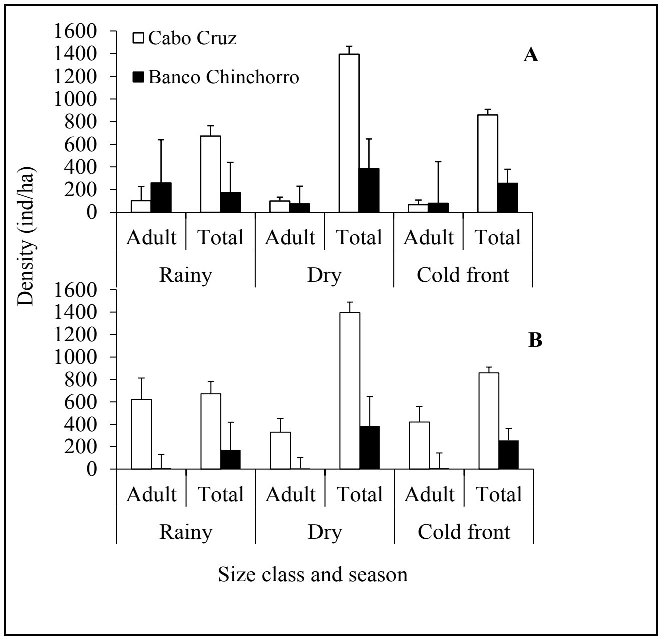

Figure 2. Mean total and adult conch densities (± standard error) at each zone during the three climatic seasons. (**A**) considering as adult the conchs with 200 mm or more of siphonal length, (**B**) considering as adult the conchs with 15 mm of lip thickness.

Size Structure

A total of 3,443 conchs were measured during the study period. At Cabo Cruz, the sizes varied from 87 to 276 mm siphonal length. Adults with SL higher than 200 mm constituted the 12.7% of the sample, sizes among 150 and 200 mm were predominant (67.9%) and a mean of 175.5 ± 26.4 mm (Figure 3). At Banco Chinchorro, conchs with SL > 200 mm constituted the 42.1% of the sample and a mean of 194.25 ± 28.19 mm (Figure 3).

The relationship between siphonal length (SL) versus Lip thickness (LT) for each study area was analyzed (Figure 4), and it shows that for Cabo Cruz, the higher quantity of conch have a complete lip formed but without having attained the length of 200 mm; in contrast, at Banco Chinchorro the conchs scarcely reach 15 mm of lip thickness when they have a 200 mm siphonal length.

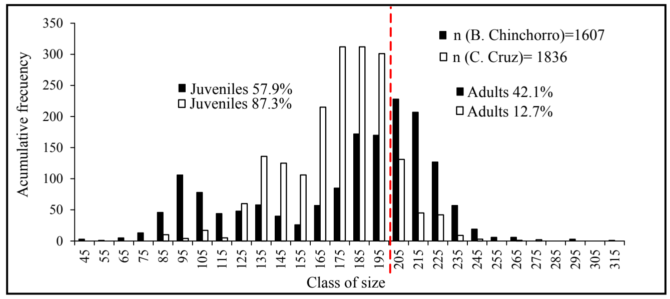

Figure 3. Total frequency of siphonal length in Cabo Cruz, Cuba and Banco Chinchorro, Mexico. Discontinuous red line indicates: TL = 200 mm (minimum size allowed for the fishery in both study sites)

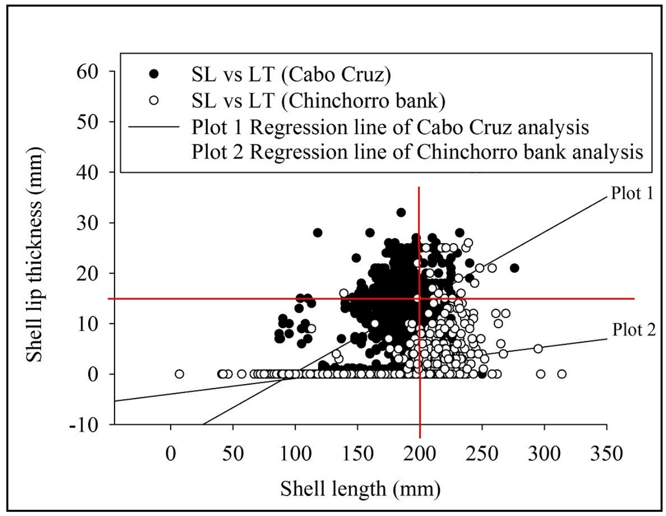

Figure 4. Relationship between siphonal length and lip thickness for conch populations of Cabo Cruz, Cuba and Banco Chinchorro, Mexico. Red lines indicate the intercept between TL = 200 mm and LT = 15 mm in both study sites.

Reproductive Encounters

At Cabo Cruz, 158 reproductive encounters were observed. The highest frequency according to adult density was observed during the rainy season (60%), followed by the dry (14%) and cold front seasons (11%) (Figure 5a). A significant correlation between the frequency of spawning and mating at the Cabo Cruz area was found (Pearson, p > 0.05) and between the copulation frequency and the absolute number of egg masses (Pearson, p > 0.05) (Table 1). The rest of the reproductive evidence did not show correlations (Pearson, p > 0.05). The temperature was positively correlated with the number of egg masses (r = 0.52, p < 0.05) and spawning frequency (r = 0.35, p < 0.05).

At Banco Chinchorro, reproduction activity was very rare. Only six reproductive encounters were observed during all surveys. The highest frequency of reproductive events according to adult density was observed during the rainy season (33%), followed by the cold front (28%) and dry seasons (26%) (Figure 5b). Egg masses and spawning

Table 1. Pearson correlation between reproductive evidence of *E. gigas* at Cabo Cruz.

	Copulation		Spawning		Egg masses		Aggregation	
	r	p	r	p	r	p	r	p
Copulation			0.8357	0.0012*	0.4357	0.0621	0.3350	0.0876
Spawning					0.7341	0.0161*	0.2496	0.2093
Egg masses							0.2004	0.3161

were absent; only two conch copulations were registered, in July 2009 in a shallow (3 m) sandy patchy coral and in April 2010, also in a shallow (2 m) sandy area. Only four aggregations of more than five conchs were registered in the surveys. Analysis of correlations between reproductive evidence was not possible, because the matrix of data was very small.

DISCUSSION

Conch Densities

Our results shows that although significant differences were not found between both areas in season or temperatures, the increase of densities during the dry season may be related with the ontogenetic migration that occurs from deep to shallow waters for reproduction (Laughlin and Weil 1985, Diaz-Avalos 1991, de Jesús-Navarrete et al. 1992, Domínguez-Viveros et al. 1999). These results suggest that protective management induces higher conch densities in the protected area, regardless of season.

At Banco Chinchorro, the conch densities were lower than at Cabo Cruz. In addition, densities were lower than in other studies in previous years at the same area (de Jesús-Navarrete et al. 2003, Basurto et al. 2007). The evidence revealed that not only the total densities are decreasing, but the density of adults as well.

Overfishing has been associated with conch decline elsewhere in the Caribbean (Appeldoorn 1994). Moreover, conch length and densities declined in Belize in 1979, causing a decrease in the commercial catch (Brownell and Stevely 1981), which also suggests overfishing as the cause of these changes. Overfishing of conch at Banco Chinchorro has been mentioned by de Jesús-Navarrete et al. (2003), showing a decreasing population density from 1990 to 1997. In addition, these authors mentioned that the conch population at Banco Chinchorro in 1997 was dominated by young individuals (over 89% in all study years) and suggest that either legal or illegal overfishing were responsible, despite management efforts by the national commission of natural protected areas (CONANP) to regulate the fishery.

Low densities were observed in this study in Banco Chinchorro, and the population was composed mainly of conchs with a SL greater than 200 mm. Adults represented less than 10% of the population when 15mm of LT was used. Evidently, illegal or legal overfishing is the main cause of the decreasing conch population at Banco Chinchorro, because fishers catch the maximum number possible of conchs to complete the quota assigned every year. This results in a decrease of both the adult population and encounter rate between females and males for reproduction, suggesting an Allee effect on that population.

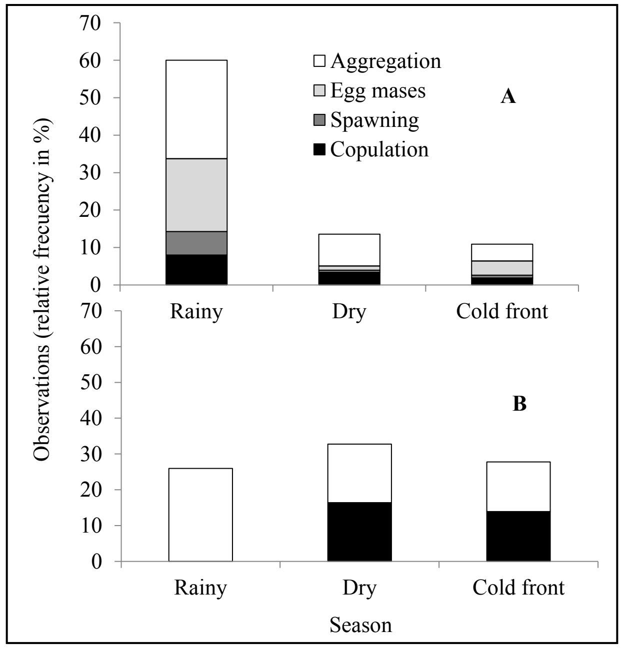

Figure 5. Relative frequency of the reproductive events for each climatic season, (**A**) Cabo Cruz, Cuba and (**B**) Banco Chinchorro, Mexico.

At Cabo Cruz, the strict protection offered by the protected area is expected to induce some significant modifications on the population within the reserve itself (Béné and Tewfik 2003). Robert and Polunin (1991) mentioned three modifications caused by the protected area and has been cited by Béné and Tewfik (2003). First, if there is not negative density effect on recruitment, the reduced mortality rate within the Marine Protected Areas (MPAs) should increase the abundance of the protected population. Second, the cessation of fishing mortality in the protected area is also expected to modify the demographic structure of the population, leading in particular to an increase in average size/age reflecting greater longevity of the protected species. Finally, an increase in average size/age may boost egg production, depending on the species size/fecundity relationship.

Thus, an increase in density may lead to greater competition for food by individuals, possibly resulting in the observed dwarfed adult condition. This effect has been referred to as "organism saturation" where conchs do not increase in length, but in weight and increase their lip thickness (Bené and Tewfik 2003). Thus density-dependence may be related to dwarfism. This hypothesis has been cited by Cala et al. (In press) for Cabo Cruz and they suggest a need of further research on that effect.

Size Structure

Our results suggest that conch have lower growth rates in the protected area. Similar results were found by Béné and Tewfik (2003) at Turks and Caicos Islands. Considering both adult and total densities in the reserve and the fishing area, it is possible that the differences in growth rates between fished and unfished areas are due to intra-specific competition in consumption of better quality algal food as a result of very high densities within protected area, in agreement with Alcolado (1976). Several studies have indicated that growth rate is highly density-dependent, and in particular, conchs grow more slowly at higher densities (Appeldoorn and Sanders 1984, Siddall 1984, Stoner 1989), possibly for the same reason suggested by Alcolado (1976).

At Cabo Cruz, the strict protection coupled with the movement limitations of adult conchs due to natural barriers cause the conch population at Cabo Cruz to be restricted to that area. As a result, food is limited, and the intra-specific competition can be considered as a factor that results in the decrease of size.

An analysis with the approach of Stoner et al. (2012c) was incorporated. Decreases in adult conch density with the change of criteria to evaluate sexual maturity is evidence of the conch fishery management mistakes at Banco Chinchorro for more than two decades and may be the cause for the population decrease and the fishery collapse at Banco Chinchorro and other areas of the Caribbean Sea (Stoner *et al*. 2012c). However, the analysis of Cabo Cruz revealed that adult densities increase when we take into consideration the new criteria and several individuals over 15 mm LT had not reached 200 mm SL.

The conch population of Cabo Cruz was dominated by adult conchs, but according to Béné and Tewfik (2003), a high density in "closed areas" also may result in a problem for the population by generating "organism saturation" and "dwarf conchs".

Reproductive Encounters

According to de Jesús-Navarrete and Valencia-Hernandez (In press), changes in population density at Banco Chinchorro have been evident from 1990 to 2009, and the population has dropped to almost 30%. The densities found during this study confirm diminishing population density of conchs.

Additionally, we found that a decreased adult density produces only a few individuals for reproduction. Despite the year-round reproduction of *E. gigas* at Banco Chinchorro (Cruz 1986, Corral and Ogawa 1987), only two copulations were observed in our study, which could be the consequence of a reduction in adult density. Apparent differences between seasons might explain local conch movements or could be a product of conch recruitment in the reef lagoon, but from our data we cannot demonstrate any of these statements.

At Cabo Cruz, it has been possible to observe reproductive activity throughout the year. High reproductive activity during the rainy season is probably associated with high values of temperature registered, because this factor was positively correlated with the number of egg masses (r = 0.52, $p < 0.05$) and spawning frequency (r = 0.35, $p < 0.05$). Stoner et al. (1992) found a positive linear relationship between mating frequency and temperature, and they suggested that this factor may influence the production of mature gametes or have a direct effect on the behavior of conch.

An increase of both spawning frequency and the amount of egg masses proportionally with temperature shows the importance of this variable in reproduction of *E. gigas* (Alcolado 1976, Stoner et al. 1992, Davis 1998). The significant statistical relationship between mating and spawning frequencies corroborates one of the mechanisms proposed by Appeldoorn (1988) that refers to a positive feedback between spawning and gametogenesis in females. According to of Appeldoorn´s (1988) hypothesis, copulation stimulates oocyte development and maturation, leading to more frequent spawning.

An intense reproductive activity of *E. gigas* year round occurs at Cabo Cruz. This suggests not only an important stock for this species om the southeastern shelf of Cuba, but also a possible self-sufficiency of this population to guarantee relatively stable recruitment (de Jesús-Navarrete 2006).

Final Considerations

Allee effect due to overfishing conditions, and the crowding effect that under "organism saturation" conditions can take place were the primary results of this work. An optimal density of the population should be achieved to prevent any of these two effects. The Conch Fishing Refuge can be a successful strategy because it can address the two aims into this area — the protection of the spawning stock and the sustainable fishery in down current areas. So, a network of Conch Fishing Refuges could provide the supply of recruits throughout the Caribbean region and ensure the functioning of the present conch meta-population in the Caribbean.

It will be necessary to conduct more research on the biology and ecological conch distribution at Cabo Cruz; biologically the work must include gonadal studies to evaluate the grade of sexual maturity of the conch in the Cabo Cruz population.

We consider it necessary to review the existing management plan in both Cabo Cruz and Banco Chinchorro. The revisions will be directed for the following strategies:

i) To guarantee the sustainable use of the resource, and
ii) To monitor the conch population and its habitat.

ACKNOWLEDGMENTS

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