# Densities and Age Structure of Fished versus Protected Populations of Queen Conch (*Strombus gigas L.*) in the Turks & Caicos Islands

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## ABSTRACT

In 1988 the Turks & Caicos Islands (TCI) government established a number of marine protected areas (MPAs) within the Caicos Bank. Such MPAs serve a large range of conservation and management objectives including the protection of both critical habitats and threatened organisms, and the enhancement of fisheries stocks. In the present study the density and the age-structure of the population of Queen conch *(Strombus gigas)* located within a specially designated marine protected area of the Caicos Bank (East Harbour Lobster & Conch Reserve, EHLCR) was compared to the population in the adjacent fished areas. A total of 36 sites were surveyed using scuba divers covering a total area of 21600 m2 and 1087 adult and juvenile conch were identified during the study. The survey demonstrates that the EHLCR displays a significantly greater density of conch than the fished areas, with a ratio close to 2:1. The analysis also shows that over the depth range, two to eight meters, density is primarily influenced by habitat type. For both areas, conch were found to be densest in algal plain habitats dominated by benthic algae, while sand plains, associated with sparse to moderate algal or seagrass cover, displayed significantly lower densities of conch. Within the EHLCR, mean densities were 2,162 conch/ha in the algal plain and 259 conch/ha in the sand plain, while in the fished area the mean densities were 687 conch/ha in algal plain and 134 conch/ha in the sand plain. Comparisons of age structure in each habitat show that the population observed in the EHLCR was significantly different from that in the fished area. In the fished areas juveniles were significantly more dense than adults, with the opposite being observed in the protected area. The limitation of the fishing pressure in the protected area resulted in a 355% and 717% increase in adult densities in the sand plain and algal plain habitat, respectively. The powerful effect of MPAs in altering population densities and size/age structure is thus well illustrated with the protection of adult spawning stock within the EHLCR. However the other benefits of MPAs in improving conch fishery productivity in the TCI, emigration of stock into surrounding fished areas (spill-over effect) and supply of new pelagic larvae (dispersal effect), remain untested.

KEY WORDS: Queen conch, Marine Protected Area, *Strombus gigas*

## INTRODUCTION

### Status of the Queen Conch in the Caribbean

The Queen conch, *Strombus gigas* (L. 1758), is a large, herbivorous, marine gastropod which ranges throughout the Caribbean, from Bermuda and southern Florida to the northern coast of South America. It is usually found in clear shallow water (0-20 m) areas associated with sandy, mixed algae substrates and seagrass beds where it derives both food and shelter (juvenile cohorts) (Randall 1964, Stoner and Waite 1990, Ray and Stoner 1995). Recently, extensive populations of conch have been observed living in significantly deeper water (> 20 m) (Berg 1985, Appeldoorn 1995, Tewfik 1996).

Conch has been a principal source of food for the inhabitants of the Caribbean region for several centuries and it still remains an important source of protein today. Economically, Queen conch is the second most important fishery in the region, after spiny lobster, *Panulirus argus* (Brownell and Stevely 1981). Overall harvest levels, used primarily for international export, have rapidly increased over the last 25 years and range annually from 4000 MT (Appeldoorn 1994) to 6000 MT (Tewfik 1997). The rapid expansion of export markets, and subsequent overfishing, has caused significant declines in conch populations in many areas of the Caribbean, particularly in shallow, inshore waters where these animals are easily collected by free-diving (Berg and Olsen 1989, Berg et al. 1992, Appeldoorn 1994, Rathier and Battaglya 1994). Thus far the declines have been limited to relatively shallow areas, while deep water provides a form of refugia from fishing due to the difficulty and/or uneconomic nature of exploiting such areas (Appeldoorn 1996). However the use of SCUBA and hookah equipment has allowed expansion of the harvest into previously unexploited deep water areas, thereby also placing these stocks at risk (Tewfik 1996). Measures applied to the management of conch stocks within the region include various size restrictions (shell length and lip thickness minimums), seasonal and area closures, gear and vessel restrictions, bulk harvest restrictions, and limited entry (Nichols and Jennings-Clark 1994, Appeldoorn 1996, Tewfik 1997). Continuing fears of the disappearence of commercial conch fisheries prompted *S. gigas* to be included under Appendix II of the Convention for International Trade of Endangered Species (CITES) in 1992. Appendix II listing requires that all international trade of queen conch involving a CITES signatory nation must be conducted under valid CITES export permits and be reported to the CITES secretariat (Mulliken 1996). Limits (quotas) of exports are based on the best available scientific information and sustainable management plans from exporting nations.

In many respects the situation of the queen conch in the Turks and Caicos Islands (TCI) is very similar to the rest of the Caribbean region. On the Caicos Bank (Figure 1) the queen conch has been exploited for commercial purposes since the middle of the 18th century (Doran 1958). It continues to be an important economic resource, second only to the superior-valued spiny lobster (Ninnes 1994). Conch are collected throughout the year by free-diving fishermen, operating out of small (5-6 m) fiberglass vessels, in waters rarely exceeding 15 meters in depth. The animals are then removed from their shell at sea with only the meat being landed at one of the 5 processing plants operating in the two main landing areas: Providenciales and South Caicos (Figure 1). Over the last 25 years fishers have had to travel farther from landing sites due to declining stocks (Medley and Ninnes 1997).

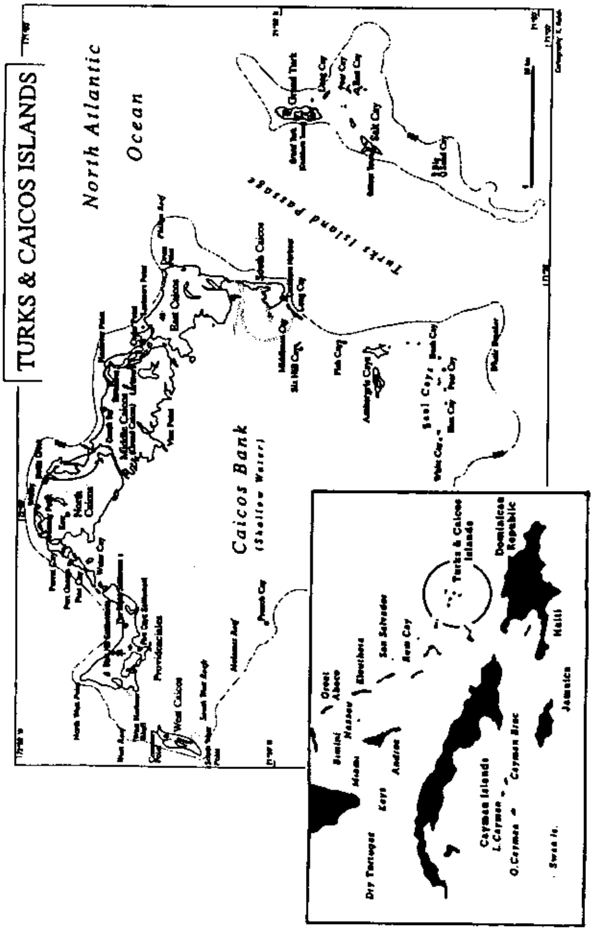

**Figure 1.** The general Caribbean Region and the detail of the Caicos Bank and Turks & Caicos Islands where the study was conducted.

The harvest activity for conch in the TCI is managed by the Department of Environment and Coastal Resources (DECR) through a minimum shell length regulation of 178 mm (7 inches), minimum landed meat weight regulation of 227g (8 oz), prohibition of SCUBA and Hookah equipment, and a licensing system that requires all fishermen to be "belongers", i.e. TCI citizens (Fisheries Protection Ordinance 1997). Furthermore a quota, regulated by the CITES, limits exportation of processed conch meat to approximately 259 MT (570 000 lbs) per year (Anon. 1995). Finally, a system of marine protected areas (MPAs) has been developed in the TCI through the National Park Order of March 4th, 1988 (Mitchell and Barborak 1991). Depending on their exact designation (National Park, Nature Reserve, Sanctuary), these areas prevent the taking of any animal or plant within their boundaries (National Parks Regulations 1992). In addition, a specific conch and lobster sanctuary (East Harbour Lobster and Conch Reserve) was established in South Caicos in 1993 through an act pasted by the Executive Council of the TCI Government. Its purpose was to add a specific area to the national system of MPAs where the commercial harvest of conch would be prohibited and easily monitored due to its proximity to DECR enforcement resources (Hall, DECR Director, pers. comm. 1998).

## POTENTIAL BENEFITS OF MARINE PROTECTED AREAS ON FISHERIES

An important objective of marine protected areas is to ensure that fishing activity continues by protecting a portion of the spawning stock from exploitation (Roberts and Polunin 1993). The establishment of protected areas (harvest refugia) closed to fishing has, therefore, been promoted by many as a viable complement to the other classical forms of fishery resource management (Bohnsack 1993, Sobel 1993, Polunin 1994). The justification for establishment of a harvest refugia relies on two major claims: First, these areas are thought to act as recruitment source to enhance or maintain fisheries outside protected areas through the release of larvae (dispersal effect); Second, the yields from areas surrounding reserves will be supplemented by emigration of fishes from the protected areas (spill-over effect). These two major benefits can be seen as the result of three underlying mechanisms (Roberts and Polunin 1991).

i) The effects of protection on the stock size/age structure. Fishing pressure leads to a decrease in average size of fishes as large and/or very mature individuals are removed. Consequently, suspension of fishing mortality in the protected areas will clearly alter the size/age-structure of the population and result in an increase in average size or maturity level of the fish present in the MPA.

ii) The effects of protection on the stock abundance. If there are no density-dependent effects of resource availability on recruitment, then reduced fishing mortality rates should result in an increase in abundance of the stock within the protected area boundaries.

iii) Growth effects on fishery production. Small fish allocate energy mainly to growth, whilst larger fish grow slowly but invest much of their energy into reproduction. Thus increases in average size and maturity level within a population can greatly increase the production of eggs, depending on the species specific size-fecundity relationship. Such an effect provides a basis for the claim that reserves can act as sources of recruits, through pelagic larval dispersal, for unprotected areas.

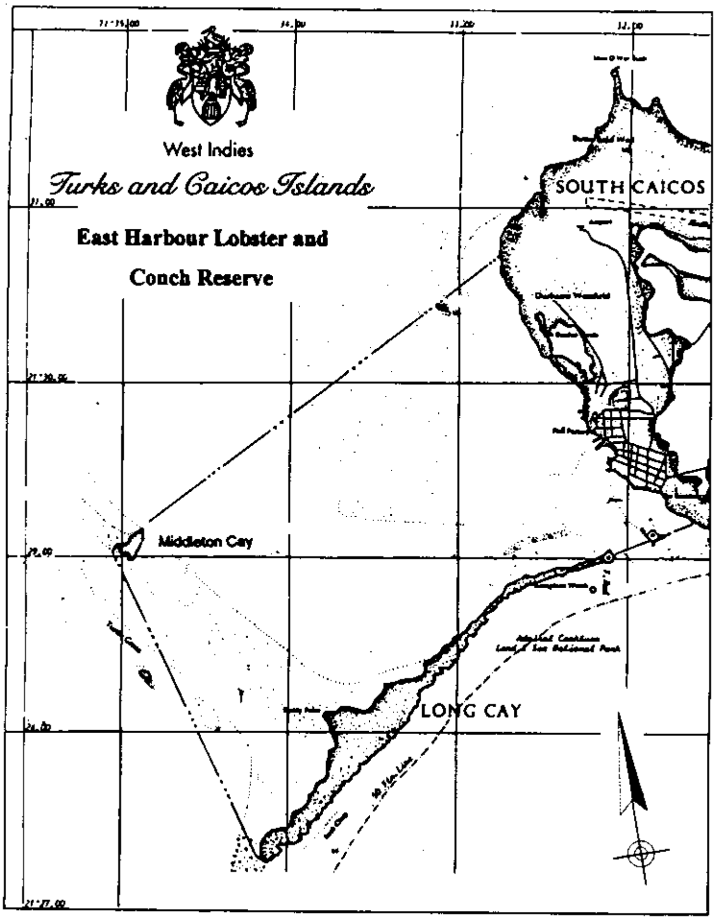

**Figure 2.** The geographical boundaries of the East Harbor Lobster and Conch Reserve (EHLCR), TCI

The purpose of the present study was to examine whether some of the potential benefits reviewed above apply in the case of the population of *S. gigas* within and surrounding the East Harbour Lobster and Conch Reserve. In particular our objectives were to compare the total density (conch per hectare) and the size/age structure (juvenile/adult ratio) of conch populations living within the protected area with those of the conch living in the surrounding fished areas. The population parameters used for this comparison (density and size structure) were obtained using a visual abundance survey technique (Belt transect method). The data collected have then been analyzed through classical descriptive statistical tests.

## MATERIAL AND METHODS

### Study Sites

The areas investigated are located on the eastern part of Caicos Bank at locations presently and formerly exploited by South Caicos-based fishers. These fished areas included the waters around Six Hills Cays, Fish Cays, Ambergris Cays, and Seal Cays (Figure 1). The total zone exploited by the South Caicos fishermen covers approximately one sixth (1300 $km^2$) of the entire Caicos Bank. The protected area used for comparison is the East Harbour Lobster and Conch Reserve (EHLCR) established adjacent to South Caicos. This reserve is approximately 28 $km^2$ in area, bounded by the east side of Long Cay and west coast of South Caicos and extends westward up to Middleton Cay (Figure 2). Both the protected and fished areas are characterized by shallow-water (2-12 m) over substrates consisting of mainly sandy plains with various densities of green and brown algae, scattered patch reefs and few seagrass meadows. Where the current conditions are strong, the sandy bottoms are replaced by hard bottoms with various densities of gorgonians and sponges.

### Sampling Method

A series of field surveys were conducted over a three month period (June-August 1998). Belt transects were run at sites chosen randomly within the fished and protected areas. A Global Positioning System (GPS) was used to determine the exact site locations. The sampling regime was designed such that the number of samples in each area was unequal and in favor of the fished area. This was done due to the large extent of the fished area as compared to the limited protected area. The data were collected on SCUBA. At each site, a 6n 60m transect was run by two divers, each sampling one side of the transect. Each transect had substrate/habitat category and depth recorded in meters. The substrate/habitat was classified according to seven categories: algal plain (AP), seagrass meadow (SG), sand plain (SP), patch reef (PR), coral heads (CH), coral rubble (CR), and gorgonian/sponge plain (GS) (Table 1). The number and size/age categories of all conch within the transect were also calculated. For this, all conch in the transect were brought to the support vessel, measured using vernier calipers and categorized, based on their total shell (siphonal) length, lip-thickness and overall shell morphology (Tewfik 1996). Six categories were distinguished: small juvenile (Sm), medium juvenile (Me), large juvenile (L), subadult (SA), young adult (YA) and old adult (OA) (Table 2).

**Table 1.** Substrate/Habitat Categories used in characterizing sites within fished and protected areas of Caicos Bank, TCIs.

| Category | Code | Description |
|---|---|---|
| Algal plain | AP | Fine mud, coarse sand, rubble bottom dominated by benthic algal cover (*Penicillus spp., Caulerpa spp., Halimeda spp., Udotea spp., Padina spp., Laurencia spp.*). |
| Seagrass meadow | SG | Coarse sand bottom dominated by Turtle *(Thalassia sp.*) and Manatee (*Syringodium sp.*) grass. |
| Sand plain | SP | Coarse sand botton with sparse benthic algae or seagrass cover. |
| Patch reef | PR | Large reefs composed of multiple colonies of various coral morphologies including branching (*Acropora spp.*), boulder (*Montastrea spp.*), and brain (*Diploria spp.*). |
| Coral heads | CH | Small patches of coral (dominated by a single colony) of various morphologies scattered within sand bottom. |
| Coral rubble | CR | Rubble bottom composed of dead and broken coral forming patches with sparse benthic algae or seagrass cover. |
| Gorgonian /Sponge | GS | Hard bottom areas with various levels of soft coral (*Plexaura spp., Pterogorgia spp., Peudoterogorgia spp., Gorgonia spp.*) and sponge cover. |

### Data Analyses

Data collected in the field were used to calculate densities extrapolated to one hectare (10,000 $m^2$). The density calculated at each site can be associated with a combination of habitat and area. The "area" factor holds for the distinction between protected and fished and the "habitat" factor applies to one of the seven substrate/habitat categories defined in Table 1. For each sample three densities were calculated: (1) the total density of all conch (i.e. with no distinction of size/age category), (2) the juvenile density (including Sm, Me, L, and SA categories), and (3) the adult density (YA and OA). Conch were considered adult when the shell lip was thicker or equal to 4 mm (Appeldoorn 1988).

A non-normal distribution of the densities was anticipated due to the patchiness usually observed with conch distribution (Weil and Laughlin 1984, Stoner and Sandt 1992, Friedlander et al. 1994). Therefore, prior to the analysis, the density at each site was log(n+1)-transformed in an attempt to normalize the distributions and the normality was tested through non-parametric Kolmogorov-Smirnov tests.

The first step of the analysis was to test simultaneously the potential effects of the two main factors (area and habitat) on the total density. For this purpose, a two-way analysis of variance (ANOVA) was performed on the total density data. Since the "area" factor was fixed but the "habitat" factor was random, a mixed model was applied. Furthermore, the number of sites sampled for each area being unequal (n = 12 for fished and n = 6 for protected), a classic two-way ANOVA would not be appropriate (Sokal and Rohlf 1981). A two-way ANOVA with unequal but proportional classes was therefore applied.

**Table 2.** Size/age categories of conch collected in fished and protected areas of Caicos Bank, TCIs.

| Category | Code | Description |
|---|---|---|
| Small juvenile | Sm | <150 mm siphonal length, no shell lip |
| Medium juvenile | Me | 150 to 200 mm siphonal length, no shell lip |
| Large juvenile | L | > 200 mm siphonal length, no shell lip |
| Sub-adult | SA | shell lip thickness < 4 mm |
| Young adult | YA | shell lip thickness ≥ 4 mm, broad flaring shell lip, prominent spines, limited effects of bioerosion |
| Old adult | OA | Shell lip thickness > 4 mm, worn , thick shell lip, worn spines, moderate to heavy effects of bioerosion |

The second step was to test the effect of the "area" factor on the total densities within each habitat using multiple comparison tests. Due to the failure of the normality condition and the small sample sizes (n<15), two non-parametric Wilcoxon-Mann-Whitney (WMW) tests were used. Finally, an additional series of 4 WMW tests were conducted to determine whether the juvenile/adult ratios in the two areas were significantly different.

## RESULTS

A total of 1087 conch were counted over the 36 sites with a total surveyed area of 21,600 $m^2$. Only the SP and AP habitat types were encountered. The total conch densities range from 0 to 3,778 conch per hectare with a mean value of 677 conch per hectare (Table 3). The total density seems to largely depend on both the substrate and the area (Figure3). These variations are mainly due to changes in the adult densities. The adult densities vary greatly between the fished and protected areas (Figures 4 and 5). For the SP and AP habitats respectively, these densities are 4.5 and 10.9 times higher in the protected area as compared to the fished area. On the contrary, juvenile densities seem to remain fairly stable with ratios between fished and protected areas of 1:1 for SP and 1: 1.4 for AP. The ratio of adults to juveniles shifts dramatically between fished areas, where it is largely skewed towards juveniles (1:2.9 for SP and 1:4.3 for AP), and protected areas, where it changes in favour of adults (1.5:1 for SP and 1.9:1 for AP). This translates into a tremendous increase in adult density of 355% between the fished and the protected SP habitats and 717% between the fished and the protected AP habitats.

**Table 3.** Mean density and details of the transects (area, habitat and number of sites sampled during the survey). F: Fished; P: Protected. Confidence intervals (CI) in parentheses.

| Habitat | Area | Site number | Surface sampled ($m^2$) | Mean Density (conch/ha) |
|---|---|---|---|---|
| AP | F | 12 | 12960 | 687.2 (541.3) |
| AP | P | 6 | 2160 | 2162.0 (1180.1) |
| SP | F | 12 | 4320 | 134.3 (108.2) |
| SP | P | 6 | 2160 | 259.3 (90.7) |
| Others | | n/a | n/a | n/a |
| Total | | 36 | 21600 | 677.4 (345.8 ) |

Notes: Others habitats = SG, PR, CH, CR, GS

### Test of Normality (Kolmogorov-Smirnov)

Tests of normality on the raw data and the log(n+1)-transformed data were conducted for the 36 samples (Table 4). They show that after transformation only AP-fished data failed to satisfy the normality distribution. The ANOVA test was therefore conducted on the log(n+1) transformed data.

**Table 4.** Normality test on the density distributions (Kolmogorov-Smirnov test). $H_0$ : the distribution tested matches a normal distribution. Test significance: Passed: can not reject $H_0$. n: number of data in each subgroups. $D_{obs}$ : Kolmogorov-Smirnov difference.

| Distribution tested | n | $D_{obs}$ | | Test |
|---|---|---|---|---|
| SP-Fished | 12 | 0.3262 | P = 0.0009 | Failed |
| SP-Protected | 6 | 0.2947 | P = 0.1068 | Passed |
| AP-Fished | 12 | 0.3724 | P < 0.0001 | Failed |
| AP-Protected | 6 | 0.2086 | P = 0.4937 | Passed |
| Log(SP-Fished) | 12 | 0.2253 | P = 0.0939 | Passed |
| Log(SP-Protected) | 6 | 0.2508 | P = 0.2671 | Passed |
| Log(AP-Fished) | 12 | 0.2957 | P = 0.0047 | Failed |
| Log(AP-Protected) | 6 | 0.2441 | P = 0.2999 | Passed |

### Effects of Area and Habitat on Total Densities of Conch

The two-way analysis of variance simultaneously tested the potential effects of the two main factors (area and habitat) on total densities (Figure 3). For this the ANOVA was performed on the log-transformed data of the 4 following subgroups: SP-Fished (n = 12), SP-Protected (n = 6), AP-Fished (n = 12), AP-Protected (n = 6). The null hypothesis was that there exists no significant difference between the different densities. The results (Table 5) indicate that the action of both the fixed factor (area) (F = 22.8, P < 0.001) and the random factor (habitat) (F = 10.4, P < 0.005) are significant while the interaction is not. It can therefore be concluded that the densities are significantly affected by both "area" (fished vs. protected) and "habitat" (sand plain vs. algal plain) factors.

Once the total densities have been shown to be significantly different, the second step of the analysis consists to test the effect of the "area" factor on the total densities within each habitat (SP and AP). This was done through two non-parametric WMW multiple comparison tests. One test compared the densities between the SP-Fished and SP-Protected sites and one compared the densities between the AP-Fished and AP-Protected sites. These two tests were conducted under a unilateral approach since, from Figure 3, the densities in the protected areas were assumed to be higher than in the fished areas. The results indicate that for both habitats, the total density in the protected area is higher than in the fished area (Table 6). This confirms the graphical results displayed in Figure 3.

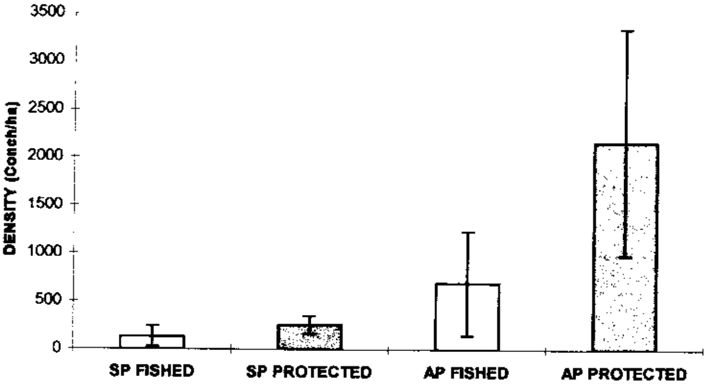

**Figure 3.** Mean density (+/- CI) of queen conch in sand plain (SP) and algal plain (AP) habitats in fished and protected areas of the Caicos Bank.

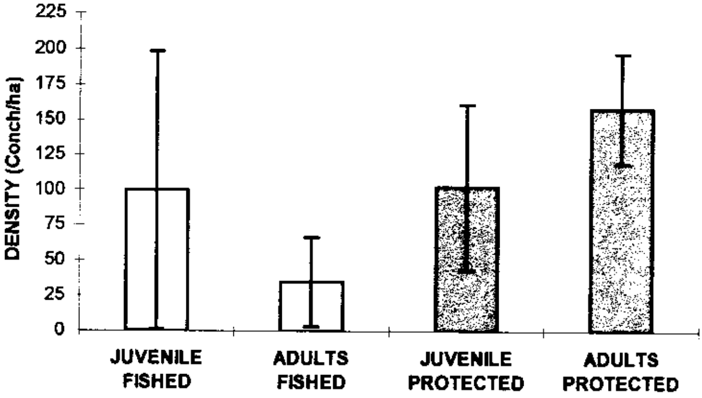

**Figure 4.** Mean density (+/- CI) of juvenile and adult queen conch in Sand Plain (SP) habitat in fished and protected areas of Caicos Bank.

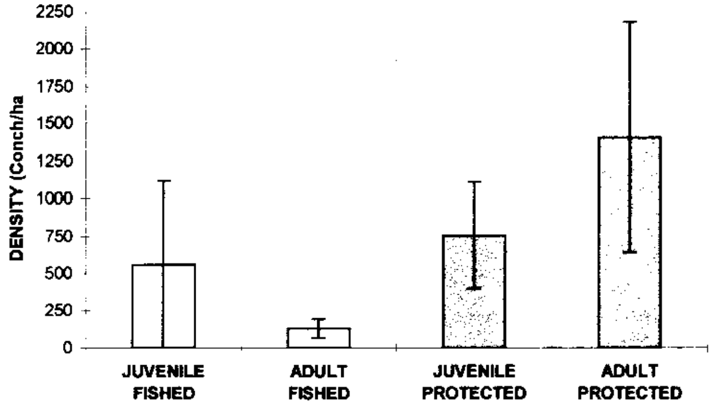

**Figure 5.** Mean density (+/- CI) of juvenile and adult queen conch in A;ga; Plain (AP) habitat in fished and protected areas of Caicos Bank.

**Table 5.** Effect of the two factors (area and habitat) on the total density of conch: two-way ANOVA with replications on unequal but proportional samples (n = 6 and 12). $F_{0.05(1,32)} = 4.15$ $F_{0.05(1,32)} = 9.0$.

| Source of variation | df | SS | MS | F | Test |
|---|---|---|---|---|---|
| Subgroup | 3 | 16.87 | 05.62 | | |
| Random factor (habitat) | 1 | 05.16 | 05.15 | 10.403 | P < 0.005*** |
| Fixed factor (area) | 1 | 11.31 | 11.31 | 22.804 | P < 0.001*** |
| Interaction¤ (area ¥ habitat) | 1 | 00.41 | 00.41 | 00.826 | ns |
| Within subgroup (error) | 32 | 15.86 | 00.49 | | |
| Total | 35 | 32.74 | | | |

¤ Notes: In the case of a mixed model, it is improper to test the effect of the main factors unless one can reliably assume that no added effect due to interaction (area ¥ habitat) is present (Sokal and Rohlf 1981, p.347). On the other hand, if the ANOVA leads to rejection of the null hypothesis for both the fixed factor and the random factor but there is no interaction, then one is allowed to take into account the random factor effect in the analysis.

A series of 4 WMW unilateral tests were then performed to test the graphical results of Figures 4 and 5. These tests were conducted between the raw values of juvenile and adult densities recorded in the SP and AP habitats for both protected and fished areas. The result of these tests indicated that in both cases the null hypothesis was rejected (Table 7). Juveniles densities are higher in the fished areas while adult densities are higher in the protected areas.

As a final investigation, the population structure of SP (Figure 6) and AP (Figure 7) for both areas are represented through the decomposition in the six size/age categories. The general trends of higher densities in protected areas remain true.

## DISCUSSION

The use of simple visual surveys and data collection techniques (belt transects with SCUBA) has allowed accurate assessments of habitats, direct examination and categorization of individual conch, and has lead to reliable estimates of density. The overall mean density reported in this study (677.4 conch/ha), for both protected and fished areas, is amongst the highest in the region (Fig.8).This may indicate that historically high productivity of conch from the Caicos Bank continues when compared to earlier studies (Hesse 1979). The increased food availability and potential protection from predation provided by the algal plain habitat makes it a preferred habitat for this species as observed by the present (Figure 5) and previous studies (Berg 1975, Alcolado 1976).

It is also clear that reduction of human impact within the EHLCR boundaries has allowed an accumulation of adult individuals, creating densities 335% (SP) and 717% (AP) higher than in surrounding fished areas (Fig.4 and 5). This is in perfect agreement with recent results presented in the literature concerning the effect of reserves on marine resources in general (Bohnsack 1993, Roberts and Polunin 1993, Polunin 1994) and on conch stocks in particular (Weil and Laughlin 1984, Appeldoorn and Rolke 1996, Stoner and Ray 1996). The reduction of the fishing mortality within the EHLCR over the last five years (although some limited harvest for personal consumption is permitted under fisheries officers authority) has allowed adult densities to rise significantly. Thus the results of the present study do confirm the protective effect of the EHLCR through the limitation of fishing activity.

However the reduction of fishing pressure is only the first condition for the protection of spawning adults. An appropriately sized MPA is the second condition. The marine protected area of Hol Chan, in Belize, shows an example where a protected area serves well to increase overall total densities of conch within its boundaries but is less successful in retaining the adult spawners of the stock (Appeldoorn and Rolke 1996). In this case, the high density of conch is mainly due to a significantly large density of juveniles while the adult density remains relatively similar between the protected and fished areas. It is speculated that due to the very small size of the reserve (2.6 $km^2$), the adult conch move out of the protected area around the time of maturation, and are either taken by the harvest sector or move to deep water refugia beyond the depth limits of free divers (Appeldoorn and Rolfe 1996).

**Table 6**. Effect of protected areas on the aggregated abundance of conch in SP and AP habitats: Wilcoxon-Mann-Whitney unilateral test. Test procedure: Null hypotheses $H_{0(SP)}$ and $H_{0(AP)}$ : the density distributions for protected and fished areas are similar. Alternate hypotheses $H_{1(SP)}$ and $H_{1(AP)}$ : the density in the protected area is shifted toward larger values. $U_{0.05(6,12)\ unilat} = 17$.

| Habitatt | $U_{Protec.}$ | $U_{Fished}$ | $U_{obs}$ | $H_1$ | Test procedure | Test |
|---|---|---|---|---|---|---|
| SP | 55<br>(n = 6) | 17<br>(n = 12) | 17 | Density in protec. area > density in fished areas | if $U_{obs} < U_{0.05\ unil}$<br>can not reject $H_0$ | reject $H_0$ |
| AP | 19<br>(n = 6) | 53<br>(n = 12) | 19 | Density in protec. area > density in fished areas | if $U_{obs} < U_{0.05\ unil}$<br>can not reject $H_0$ | reject $H_0$ |

Notes: in parenthesis: the number of transects included in the tests.

**Table 7**. Effect of the "area" factor on the structure of conch stock in SP-Fished and SP-Protected:Wilcoxon-Mann-Whitney unilateral test. Test procedures: Alternative hypotheses $H_{1(SP\text{-}Fished)}$ and $H_{1(AP\text{-}Fished)}$ for SP-Fished and AP-Fished tests: the densities of juveniles are higher than the densities of adults (i.e. juvenile densities are shifted toward greater values than the values of adults). Alternative hypotheses $H_{1(SP\text{-}Protec.)}$ and $H_{1(AP\text{-}Protec.)}$ for SP-Protected and AP-Protected tests: the distributions of densities of adults are higher than the densities of juveniles (i.e. adult densities shifted toward greater values than the values of juveniles). $U_{0.05(12,12)\ unilat} = 42$, $P(U_{0.05(6,6)\ unilat}) = 0.032$

| Test | $U_{Adults}$ | $U_{Juveniles}$ | $U_{obs}$ | $a_{unil}$ | $H_1$ | Test procedure | Test |
|---|---|---|---|---|---|---|---|
| SP-Fished | 89<br>(n = 12) | 55<br>(n = 12) | 55 | | Juveniles > Adults | if $U_{obs} < U_{0.05\ unil}$<br>can not reject $H_0$ | reject $H_0$ |
| SP-Protec | 6<br>(n = 6) | 30<br>(n = 6) | | 0.05 | Adults > juveniles | if $P_{(Uobs)} > a_{unil}$<br>can not reject $H_0$ | reject $H_0$ |
| AP-Fished | 49<br>(n = 12) | 95<br>(n = 12) | 55 | | Juveniles > Adults | if $U_{obs} < U_{0.05\ unil}$<br>can not reject $H_0$ | reject $H_0$ |
| AP-Protec | 10<br>(n = 6) | 26<br>(n = 6) | | 0.05 | Adults > Juveniles | if $P(U_{obs}) > a_{unil}$<br>can not reject $H_0$ | can not reject $H_0$ |

Notes: in parenthesis are indicated the number of transects included in the analyses.

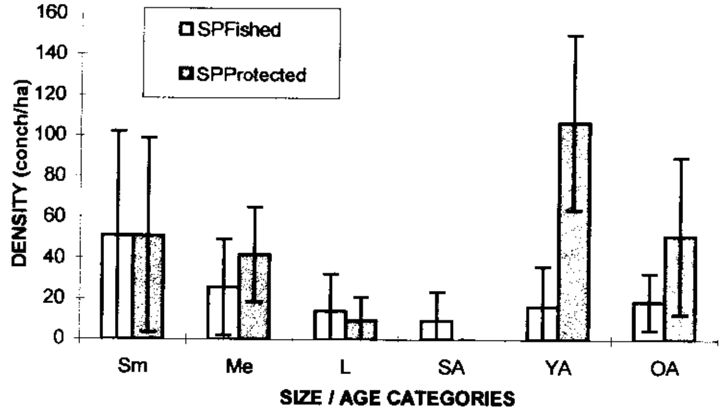

**Figure 6.** Mean densitties (+/-CI) of conch in a sand plain (SP) habitat for fished and protected areas of the Caicos Bank.

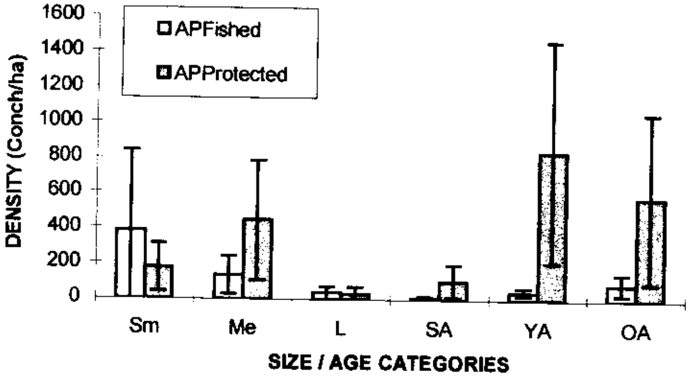

**Figure 7.** Mean densitties (+/-CI) of conch in an algal plain (AP) habitat for fished and protected areas of the Caicos Bank.

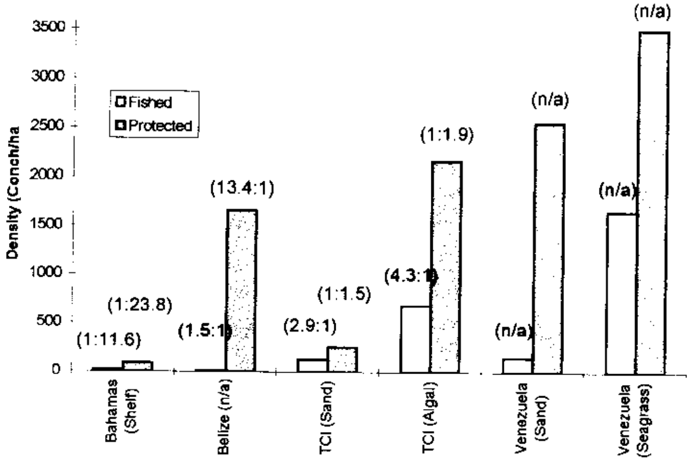

**Figure 8.** Total queen conch densities within (protected) and outside (fished) of various marine protected areas in the Caribbean (the ratios Juveniles/Adult for these different studies are indicated in parentheses when available). Sources: Bahamas: Stoner and Ray (1996); Belize: Appeldoorn (1998, pers. comm.); TCI: this study; Venezuela: Weil and Laughlin (1984).

In the case of the EHLCR, the success of the adult protection may be associated with several hypotheses. First, even if the total area of the reserve is relatively small (28 km$^2$) and conch are characterized by seasonal and/or reproductive movements (Hesse 1979, Stoner and Sandt 1992), the range of distance covered during these movements (radius of several km) is somewhat limited by the morphology of the organism. Therefore, the distance covered may appear small with respect to the size of the reserve. Second, in the case of EHLCR, emigration of adults from the reserve may also be hindered by the existence of several natural geographic barriers. These barriers can be seen on all four sides of the reserve. They take the form of extensive shallow sand bars to the south and east, the land masses of South Caicos and Long cay to the north and west and gorgonian/sponge plains in the cut between Long Cay and South Caicos (Fiure 2). The existence of these barriers, combined with the size of the reserve, may be sufficient condition to maintain the adult conch inside the reserve and thereby account for the very high density observed within the area.

Although this study presents strong evidence that MPAs can protect spawning portions of the stock in a very effective way, it does not directly address the two major benefits of spawning stock protection within MPAs. However some comments about the emigration (spill-over effect) of recruits and the dispersion of larval individuals (dispersal effect) can be made. First, due to the regular and heavy fishing effort that occurs in the areas surrounding the reserve, any emigration of juveniles or adults into these fished area, if they were to happen, would be quickly harvested and reduce greatly the spill-over effect. Therefore, the actual benefit of the EHLCR for the Caicos Bank conch stock might only stand in the production of pelagic larvae from the adults retained in the reserve. This question must be addressed in future researches. The scale and importance of long distance larval dispersal for conch is under debate and may simply be a matter of a stocks location in the region. Stoner (1997) suggests that the placement of reserves is important for supply of conch larvae to downstream populations under metapopulation theory. Appeldoorn (1997), in contrast, emphasizes that genetic studies (Berg et al. 1986, Mitton et al. 1989, Campton et al. 1992) show inconclusive results concerning larval dispersal and that local eddies and gyres generally keep larvae contained 10 to 100 km from their source of spawning adults. He further suggests that conch stocks are largely dependent on self recruitment, making the establishment of local reserves that much more important for sustainable management of fished stocks.

The questions of local emigration (spill-over) and larval dispersal, which have been investigated for other species (see Roberts and Polunin 1991 for a review) as well as for conch in other parts of the Caribbean (Stoner and Ray 1996), should represent a logical extension of the present work. Local tagging and monitoring of conch in surrounding areas may reveal to what extent (concentric ranges from the MPA) the spill-over effect influences the surrounding stock. The monitoring of larval dispersal, through planktonic tows in and around the reserve, may at the time help to quantify the extent to which spawning adults of the EHLCR contribute to larval recruitment locally and beyond.

Finally, due to the obvious adult retention in the reserve and the natural geographic barriers that may limit emigration, an investigation of a potential crowding effect will be accomplished using morphometric data on individual conch collected in the protected and fished areas. This potential crowding effect, and the associated food resource limitations, may be revealed as smaller mean shell lengths for adults within the protected area.

## ACKNOWLEGMENTS

The authors would like to thank Dr. M. Harrington for reviewing the manuscript and the numerous divers who participated to the field surveys. This study has been supported logistically by the School for Field Studies.

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