# Assessment of the Functional Effects of a Harvest Refuge on Spiny Lobster and Queen Conch Populations at Glover's Reef, Belize

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ABSTRACT

Marine harvest refuges have great potential for protecting, sustaining, and possibly, increasing fisheries resources. Since 1996, I have monitored populations of Caribbean spiny lobsters *Panulirus argus* and queen conch *Strombus gigas* in a new marine reserve at the Glover's Reef atoll, Belize. Habitat use accounted for the size-class distribution of lobsters and conch. Density initially fluctuated with fishing season in both the General Use zone (fishing by permit) and the Conservation zone (fishing prohibited), indicating that compliance in the no-fishing area was initially low. Trends show a recent increase in the density of adult conch in the no-fishing zone coinciding with increased enforcement, but the density of adult lobsters has not increased. The mean size of conch has also increased in the no-fishing zone, but there has been no significant change in the mean size of lobsters in the protected area. The spiny lobster population in the reserve has not responded as expected, most likely due to insufficient amounts of critical habitats under protection and fragmentation of habitats by zonal boundaries.

KEY WORDS: Spiny lobster, queen conch, marine reserves

## INTRODUCTION

Marine reserves that function as harvest refuges are increasingly being considered as a necessary management tool for sustaining, and even increasing, stocks of overexploited species (Bohnsack 1994, Davis and Dodrill 1980, Dugan and Davis 1993, Polacheck 1990). The potential consequences inside the areas permanently closed to fishing include increases in the density of animals and increases in the average size of individuals. Increased densities will subsequently result in net dispersal of animals from the reserve to adjacent fishing grounds ("spillover" effect). An increase in reproductive output of eggs from more and larger adults may lead to greater larval recruitment to the regional population (Carr and Reed 1993). Therefore, marine reserves that are fully functional are economically prudent investments, particularly in the Caribbean where most major fisheries are currently being overexploited (Chakallall and Cochrane 1997).

The two most economically valuable and heavily exploited species in the Caribbean are spiny lobsters, *Panulirus argus*, and queen conch, *Strombus gigas*.

Fishery trends for both species show consistent declines over the past two decades, indicating that most coastal stocks are being overexploited (e.g., Berg and Olsen 1989, Ehrhardt 1994). I have been monitoring spiny lobster and queen conch populations in the Glover's Reef Marine Reserve in Belize to assess population responses to protection from an artisinal fishery. I have also conducted experiments on dispersal dynamics and habitat requirements to evaluate the functional effects of the reserve on these populations. Here I describe changes in lobster and conch populations using the trends in density and average sizes in fished and unfished areas to assess the functional effects of this isolated reserve.

## STUDY SITE

Glover's Reef (16°50'N, 87°47'W) is an isolated coral atoll with an approximate area 12 x 28 km, located 45 km off the coast of Belize. The atoll is surrounded by deep water (400 m leeward and 1000 m windward) with the forereef sloping sharply to vertical walls that begin less than 2 km from the reef crest in most areas. The atoll is ringed by an emergent reef crest with only three major cuts and several small breaks. The lagoon of the atoll contains extensive shallow water habitats used by all life history stages of spiny lobsters and queen conch, including sand-algal flats, seagrass, and more than 700 coral patch reefs. These major habitats in the lagoon are shallow (2 - 3 m) and easily accessible to artisinal fishermen who are limited only by the logistics of fishing trips to the atoll (e.g., ice for storing the catch). Currently, no commercial fishermen are resident on the five islands at Glover's Reef.

The Glover's Reef Marine Reserve was designated in 1993. The Conservation Zone (with an internal Wilderness area) is permanently closed to fishing and encompasses 72.3 $km^2$ or about 20.5 % of the lagoon of the atoll (Gibson 1999). A seasonal closure area is also closed to fishing and mainly covers forereef habitat that is known to be a spawning site for groupers. The General Use Zone encompasses the rest of the atoll and is open to fishing by permit. Fishing by SCUBA, traps, or spearfishing is prohibited, although fishermen capture lobsters by gaffing the animals. Fishing is concentrated in the lagoon habitats that are easily accessible by snorkeling.

## METHODS

Quarterly surveys were conducted in representative habitats in the Conservation and General Use Zones from August 1996 to the present. Observations were recorded on the number of fishing boats near sampling sites and on the approximate amount of time rangers were present. Spiny lobsters were surveyed on patch reefs in the lagoon and on the forereef. Eight patch reefs in the Conservation Zone and eight in the General Use Zone (total patch reef area = 2.4 ha) were located using Global Positioning Satellite (GPS) and re-surveyed on a quarterly basis. Divers also surveyed 100 x 10 m transects at 10 sites on the forereef at depths of 5 and 20 m (total forereef area = 1.0 ha); due to logistical difficulties, only 5 forereef surveys were conducted. All lobsters were measured (carapace length, CL), sexed using external characters, and females were inspected for the presence of egg masses under the abdomen.

Queen conch were surveyed on the sand-algal flats of the back reef and around the patch reefs that had distinct sand-algal margins. Quarterly surveys were conducted at three Conservation and three General Use sites on sets of four 50 x 4 m transects (total sand-algal habitat = 0.48 ha). Conch were also surveyed around the margins of the 16 patch reefs in the lagoon (estimated reef margin = 1.2 ha). All conch were measured (total shell length SL and width/thickness of shell lip if present) and the presence of egg masses were noted.

To analyze population changes in space and time, a doubly multivariate repeated measures analysis of variance (RMANOVA) was conducted on density and mean size (dependent variables) and reserve zone and sample month (factors). Multivariate assumptions of normality, homoscedasticity, multicollinearity, and equality of variance-covariance matrices were tested, and all assumptions were met after the density data were log-transformed. Trend analysis was conducted on the abundance of adult lobsters and conch in and out of the no-fishing area over time. For analysis, adult status was considered to be the legal fishery-size animal (spiny lobster: 76 mm CL; queen conch: 180 mm SL).

## RESULTS AND DISCUSSION

The known habitat use patterns of spiny lobsters accounted for the observed distribution of different size classes. Most size classes ranging from two months old juveniles to adults occupied the shallow patch reefs of the lagoon. Juveniles were most abundant on patch reefs surrounded by seagrass (Acosta 1999, Acosta and Butler 1997). In contrast, only large subadults and adults occupied the forereef and deep reefs where they were twice as abundant (mean ± SE: 20.4 ± 2.1 lobsters/ha) as adults in the lagoon (mean ± SE: 9.4 ± 1.4 lobsters/ha). The average sizes of adult lobsters on the forereef were also larger (mean ± SE: 101 ± 6.8 mm CL) than the adults in the lagoon (mean ± SE: 78.1 ± 2.9 mm CL). Data from tracking and mark-recapture studies indicate that large adults regularly move between lagoon reefs and the deep reefs (Acosta, unpubl.). Most reproductive activity (90%) occurred January to November, substantially longer than the closed fishing season designated to protect breeding adults. On the lagoonal patch reefs, a small proportion of mature females (8%) carried egg masses on these shallow (< 3 m) reefs during the reproductive season.

Lobster population fluctuations were most pronounced in the Glover's Reef lagoon. Lobster density fluctuated significantly between sample months but not across the fishing zones (Table 1A). From 1996 to early 1998, the density of lobsters fluctuated with the fishing season, increasing significantly only during the closed season (about March through June) in Belize (Figure 1A). In the past year, density of lobsters increased in the no-fishing area, but this increase is not greater than during the closed fishing season. Over the three years, the trends in densities of adult lobsters in the fishing and no-fishing zones indicate that no statistically significant changes have occurred (Figure 1A). The abundance of small juvenile lobsters (< 40 mm CL) throughout the study area did not fluctuate over the three year period which suggests that larval recruitment remained relatively constant. Therefore, fluctuations in the density of adult, as well as large subadult, lobsters mostly accounted for these observed patterns. The spiny lobster population is reduced by 60% during the fishing season, and the data show that a substantial number of subadults (50-76 mm CL) are also taken in the fishery.

Changes in the mean sizes of spiny lobsters were similar to density patterns. Again, mean sizes increased only during the closed fishing season in both the fishing and no-fishing zones (Table 1A, Figure 2A). Although mean lobster size was generally larger in the no-fishing zone, this did not vary in a statistically significant way over time. In contrast to these results, MacDiarmid and Breen (1992) showed that a population of the lobster *Jasus edwardsii* in a New Zealand marine reserve had a five-fold increase in five years. Additionally, the number of legal-sized adults increased by 90% in the reserve. At the Glover's Reef Marine Reserve in Belize, inconsistent enforcement and violation of the no-fishing zone by fishermen may have initially kept spiny lobsters *P. argus* density and mean sizes low. However, with increased enforcement, the population has still not responded as expected.

Queen conch were distributed throughout the lagoon of the atoll but not on the forereef which lacked suitable habitat. Both juveniles and adults were abundant on the shallow sand-algal flats of the backreef with abundant macroalgae *Laurencia* spp. Mostly large adults foraged around the sand-algal margins of patch reefs in the lagoon. The distribution of juveniles on the sand-algal flats coincides with the nearby distribution of dense turtlegrass *T. testudinum* that is a primary settlement habitat for conch larvae. In preliminary surveys, few adults were found in the dense seagrass beds and deeper rubble fields in the lagoon. Most reproductive activity (90%) occurred on the sand-algal flats during April to October.

**Table 1.** Results of the doubly multivariate repeated measures analysis of variance with sample month and reserve zone as factors and density and size distribution as dependent variables for A. spiny lobsters and B. queen conch at the Glover's Reef Marine Reserve, Belize. The test statistic used for the factors is Pillai's trace and the mean square is used for the dependent variables.

A. Spiny lobsters

| Source | Value | Error (df) | Hypothesis (df) | F | P |
|---|---|---|---|---|---|
| Month | 0.473 | 252 | 18 | 4.34 | <0.001 |
| Density | 0.316 | 9 | - | 2.725 | 0.006 |
| Size | 1165 | 9 | - | 7.67 | <0.001 |
| Zone | 0.034 | 13 | 2 | 0.228 | 0.80 |
| Interaction | 0.154 | 252 | 18 | 1.168 | 0.29 |
| Error (density) | 0.116 | 126 | - | - | - |
| Error (size | 151 | 126 | - | - | - |

B. Queen conch

| Source | Value | Error (df) | Hypothesis (df) | F | P |
|---|---|---|---|---|---|
| Month | 0.614 | 140 | 10 | 6.197 | <0.001 |
| Density | 468 | 5 | - | 1.796 | 0.13 |
| Size | 16060 | 5 | - | 20.58 | <0.001 |
| Zone | 0.202 | 13 | 2 | 0.012 | 0.05 |
| Density | 0.011 | 1 | - | 0.98 | 0.10 |
| Size | 0220 | 1 | - | 5.87 | 0.05 |
| Interaction | 0.155 | 140 | 10 | 1.174 | 0.31 |
| Error (density) | 260 | 70 | - | - | - |
| Error (size | 780 | 70 | - | - | - |

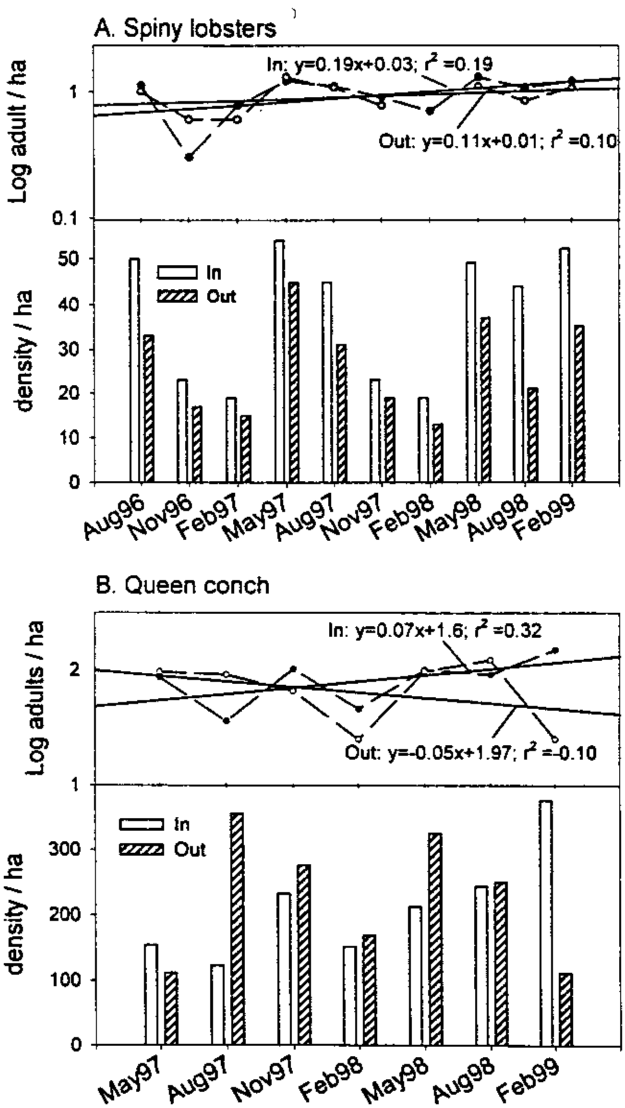


**Figure 1.** Abundance of A. spiny lobsters and B. queen conch in the no-fishing (In) and fishing (Out) zones of the Glover's Reef Marine Reserve, Belize. Bar graphs show total densities per hectare, and upper graph shows change in the densities of fishery-sized adults.

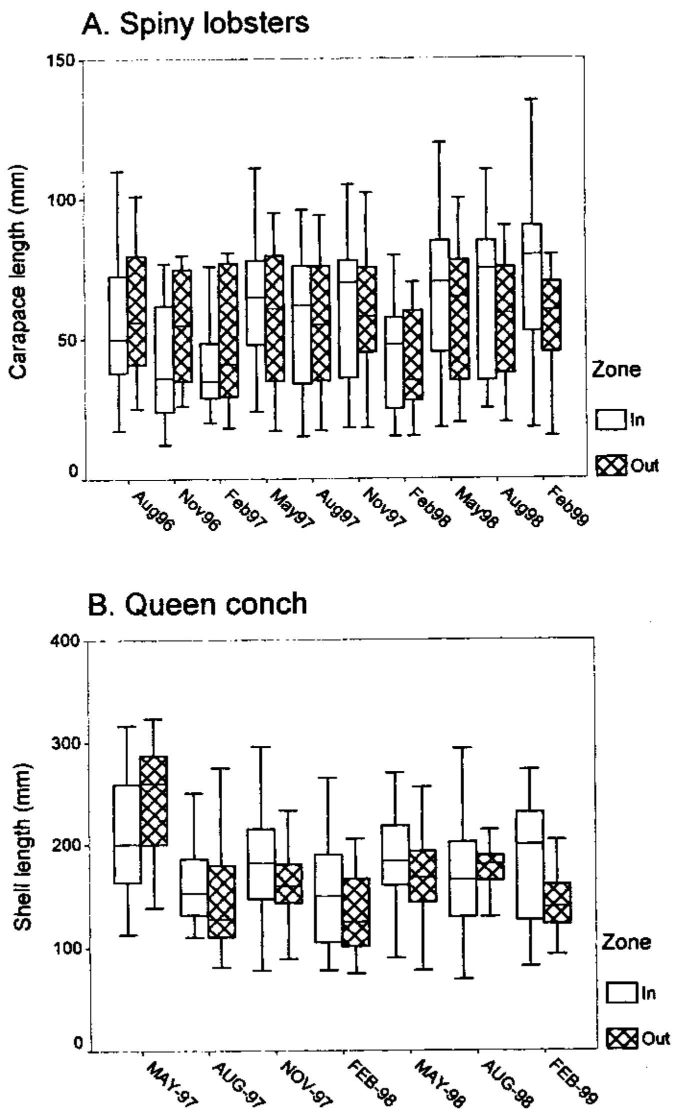


**Figure 2.** Mean sizes of A. Spiny lobsters and B. Queen conch in the no-fishing (In) and fishing (out) zones of the Glover's Reef Marine Reserve, Belize. Box plots show means, quartiles, and 95% confidence limits.

The highest concentration of juve niles consistently occurred on the southwest backreef that is open to fishing. This unusually high density of young conch (1,127 conch/ha) does not appear to be a result of benthic aggregative movement, but instead, may be linked to larval supply by water currents that flow northeast to southwest in the lagoon (Acosta, unpubl.). Due to juvenile densities at this single southwestern site, the relative density of conch in the fishing zone was generally higher than in the no-fishing zone, but density in the unfished area is slowly increasing (Figure 1B, Table 1B). Total conch density was generally higher in both zones during the closed fishing seasons. The trend for adult conch in the no-fishing zone accounted for most of the increase in this area, whereas adult abundance in the fishing zone has actually declined over time (Figure 1B).

Mean sizes of queen conch were larger on average in the no-fishing zone than in the fishing zone, but there were no significant changes over time in the no-fishing zone of the reserve (Figure 2B, Table 1B). In the Belize conch fishery, there is no provision for limiting fishing to sexually mature conch with shell lip formation. Gibson et al. (1983) reported that up to 70% of the legal catch in Belize may consist of immature conch, which is similar to the estimate (60%) at Glover's Reef.

Conch densities in both the no-fishing and fishing zones of the Glover's Reef Marine Reserve are considerably higher than recent estimates from other Caribbean areas (U.S. Virgin Islands: Friedlander et al. 1994, Bermuda and Florida Keys: Berg et al. 1992). Nevertheless, adult densities (89.3 adults/ha) in the no-fishing zone at Glover's Reef are considerably lower than reported for marine reserves at Las Roques, Venezuela (460/ha; Weil and Laughlin 1984) and the Bahamas (270/ha; Stoner and Ray 1996). Stoner and Ray (1996) reported that adult conch in the Bahamas reserve are at least five times as abundant as in the fished area.

The conceptual benefits of increased densities and mean sizes in marine reserves closed to fishing have been shown for populations of spiny lobsters (Davis and Dodrill 1980, MacDiarmid and Breen 1992) and queen conch (Stoner and Ray 1996, Weil and Laughlin 1984). At the Glover's Reef Marine Reserve, the queen conch population in the no-fishing area is slowly increasing, but the spiny lobster population has not responded as expected. This may be due to initially inconsistent enforcement or because three years is inadequate to detect significant changes. However, MacDiarmid and Breen (1992) observed dramatic changes in lobster density and sizes in the reserve in New Zealand in a five-year period. A number of factors may influence the magnitude of change in protected areas including the size, shape, and number of reserves necessary to protect a target species (e.g., Schonewald-Cox and Bayless 1986). For example, only those fish species whose home ranges are contained within the no-fishing area will be adequately protected in a marine reserve (Kramer and Chapman 1999). My data from studies in progress suggest that spiny lobsters and queen conch in the Glover's Reef Marine Reserve are differentially affected by the size of the no-fishing area and fragmentation of important habitats, like seagrass beds and reef cuts, by the zonal boundaries (Acosta, unpubl.). Current size regulations and closed seasons may be inadequate to protect regional lobster and conch populations. Marine reserves may be the best alternative tool for sustaining these fisheries, but protected areas must have certain characteristics, such as adequate area, to be effective.

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