Abundance and Size Frequency of Queen Conch in Relation to Benthic Community Structure in Parque Nacional del Este, Dominican Republic

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ABSTRACT

Queen conch (*Strombus gigas*) are important epibenthic herbivores in soft-sediment communities, but have been intensively exploited in Parque Nacional del Este (PNDE) for approximately 30 years. Consistent, applied fishing pressure alters the population dynamics, growth rate, ecological role, and spatial abundance patterns of the population. The main focus of this study is to correlate queen conch abundance and size frequency distribution with benthic community types and sediment characteristics in order to detect ontogenetic habitat preferences using a systematic sampling methodology. A benthic community map for PNDE was delineated and ground-truthed; from this map five soft-sediment community types were surveyed using 50 x 5m strip transects during March 1996 and 1997. Results indicate that queen conch are more abundant in benthic communities with sediments that consist mostly of sand-mud instead of sand. Abundance estimates also indicate that queen conch are significantly more numerous in communities with sparse to moderate seagrass cover (<30%). Yearly surveys showed a marked decline in queen conch abundance; however, there was a corresponding increase in milk conch (*Strombus costatus*). Size frequency data suggest that juvenile queen conch use seagrass beds on the eastern margin of the park as a nursery area. Despite the vast seagrass plains found in PNDE, conch only occupied a small fraction of the available habitat and plankton tows for veligers conducted during August 1995 and 1996 yielded low strombid densities; this may indicate recruitment limitation. These findings have important implications for resource managers and conservationists who want to evaluate the likelihood of stock recovery. A closed fishing season during breeding months (if recruits are produced locally) and total closure (no-take) of nursery grounds can have a positive impact on the stock in PNDE.

KEY WORDS: Benthic communities; Parque Nacional del Este, Dominican Republic; queen conch

INTRODUCTION

Importance of Queen Conch in Tropical Coastal Systems

Queen conch, *Strombus gigas* Linnaeus, 1758, is one of six species of molluscs in the Family Strombidae found in the wider Caribbean. It occurs in Bermuda, Bahamas, Florida Keys, Greater and Lesser Antilles, and the Caribbean coasts of Central and South America (Brownell and Stevely, 1981). Populations of this herbivorous gastropod have been exploited for approximately 400 years throughout its range in the Caribbean, originally as a subsistence fishery and now for commercial export. Despite the facts that populations have declined throughout its range (Adams, 1970; Appeldoorn *et al.*, 1987; Berg and Olsen, 1989) and that the species is listed as threatened by extinction (Commission on International Trade of Endangered Species), it is still one of the most important fisheries in the Caribbean. Yearly harvests are estimated to be worth as much as $40,000,000 US (Appeldoorn, 1994).

Juvenile and adult conch play an important ecological role in marine benthic communities. When in sufficient numbers, they are a major herbivore in soft-sediment communities. They graze on seagrass, epiphytes, and on certain species of algae (Hensen, 1984). They have also been implicated as a catalyst for change in benthic communities. Studies have shown that they influence the coverage of algae (Stoner, 1989), and the abundance and types of macrofauna in the community (Stoner *et al.*, 1995). However, the environment also affects the animal (the interactions between abiotic and biotic factors are complex). Variation in the morphology of marine gastropods can have a genetic cause; however, direct environmental induction can be the dominant process regulating morphologic patterns in populations (Alcolado, 1976; Martin-Mora *et al.*, 1995). Queen conch are also a source of bioturbation in soft settlement communities. Therefore, the removal of conch can cause changes in the structure of the benthic community; however, there are no long-term studies on this important question: can queen conch recover if their habitat has been altered by their absence?

Numerous studies have been conducted on the habitat requirements of juvenile queen conch, and the interactions or relationships that occur between seagrass beds and conch. Field experiments have shown that areas with similar depths, sediment, and macrophyte cover do not provide equivalent food and refuge for queen conch (Stoner, 1994). Long-term aggregations are usually limited to a few particular sites in these seemingly uniform seagrass beds; these historic nursery grounds seem to be related with tidal influences and the production of certain species of macroalgae that juveniles graze on (Stoner *et al.*, 1994). Most of these studies provide evidence that show that conch actively select among habitats (Sandt and Stoner, 1993).

Studies have shown that conch density and biomass increase directly with seagrass cover and shoot density, up to an optimal level, and that juveniles are much more selective in choice of habitat when compared with adults; however, adults seem to prefer denser seagrass beds (Stoner and Waite, 1990). Only a comprehensive understanding of habitat requirements, behavior, feeding ecology, and predator-prey interactions will lead to the long-term recovery of this species in an area. If successful outplanting of juveniles is to occur, one must know exactly when and where to release them. Juvenile conch transplanted to areas that have not been historic nursery grounds have suffered from high mortality and low growth rates; this implies that nursery grounds are ecologically unique areas and that these are the areas that must be identified for successful recovery (Stoner *et al.*, 1994).

Susceptibility and Impact of Overfishing on Stocks

The goal of conch stock evaluation in Parque Nacional del Este (PNDE) is to provide baseline information on the status of the queen conch population in terms of benthos and sediment characteristics. Because overfishing of conchs has been going on in PNDE for several decades, and stocks have been declining since the early 1970s (Towle *et al.*, 1973), this information will be critical in revising the management plan for the park. Marine fisheries reserves have been shown to work quite effectively for queen conch (the Exuma Cays Land and Sea Park, Bahamas and Los Roques, Venezuela are excellent examples), if the design considers the ontogenetic requirements, strategic locations for larval production, import, export, and population dynamics (Stoner and Ray, 1996).

Conch are a major herbivore in soft-sediment communities; it is hypothesized that the removal of a major herbivore will change the algal composition of the community; therefore, it is important to map potential and/or remaining conch habitats. This may be the key to successful releases of hatchery-reared conch, as areas that historically had conch may no longer be able to support a population (Ferrer and Alcolado, 1994).

Parque Nacional del Este, Dominican Republic

On the southeastern coast of the Dominican Republic lies Parque Nacional del Este (PNDE) (Figure 1). Topographically PNDE lies between San Rafael de Yuma to the north, the Bahía de Yuma to the east, and the Caribbean Sea to the south. It was declared a protected area in September of 1975 and consists of approximately 42,000 hectares of land (including small islands).

The currents in and around PNDE usually flow from east to west although there is evidence of many intricacies in the Mona Passage between Puerto Rico and the Dominican Republic (Metcalf *et al*, 1977; Figure 2). If the prevailing winds are from the south then surface currents have been observed to flow south to north (Delgado, pers obs). There also seems to be a complicated pattern of tidal and residual currents in PNDE.

A study was done by Dominican archaeologists on Catalinita and Isla Saona on the conch piles located in PNDE. In this study, the discovery of huge conch piles called "conchales" or "concheros" demonstrated the historic-economic importance of queen conch for both the Taino Indians who occupied the area in pre-Columbian times and for modern fishermen (Vega, 1987). The tremendous number of conch in these piles provides evidence that at one time conch stocks were quite plentiful. The largest modern conch piles in the Dominican Republic are found on Isla Catalinita which is within the boundaries of the park.

Benthic Community Classification and Mapping

Using 1:24,000 scale, aerial photos and satellite imagery, a benthic community map of the park was delineated and polygons were attributed. Ground truthing or field confirmation of the community polygons was accomplished via the belt quadrat method (Van den Hoek *et al*., 1975; Sullivan and Chiappone, 1993). This map is based on The Nature Conservancy's Marine Benthic Community Classification Hierarchy (Appendix 1). The classification consists of eleven soft-sediment or unconsolidated community types and nine hard-substrate or consolidated bottom community types. In total, 19 of the 20 community types were encountered and mapped in PNDE; the total area of all the mapped marine communities is 11,416.7 ha. However, only five benthic community types were surveyed for conch: Moderate to Dense Seagrass (MDSG), Sparse Seagrass in Sand (SSGS), Sparse Seagrass in Sand-Mud (SGSM), Mixed Algal Canopy (MAC), and Seagrass Patches on a Matrix of Soft Sediment (SGP). Table 1 shows the area coverage (in hectares) and frequency of each community type. The community type that had the greatest area coverage was Moderate to Dense Seagrass in Sand-Mud; while Patch Reefs were the most frequent community type.

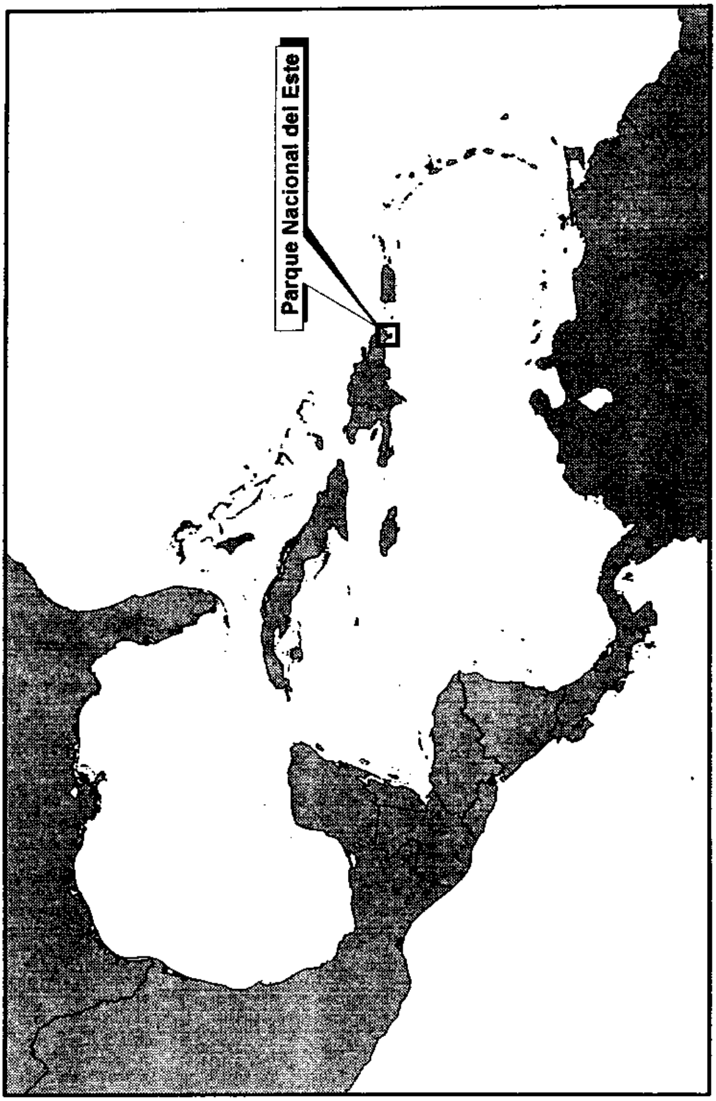


Figure 1. Map showing the location of Parque Nacional del Este, Dominican Republic within the wider Caribbean.

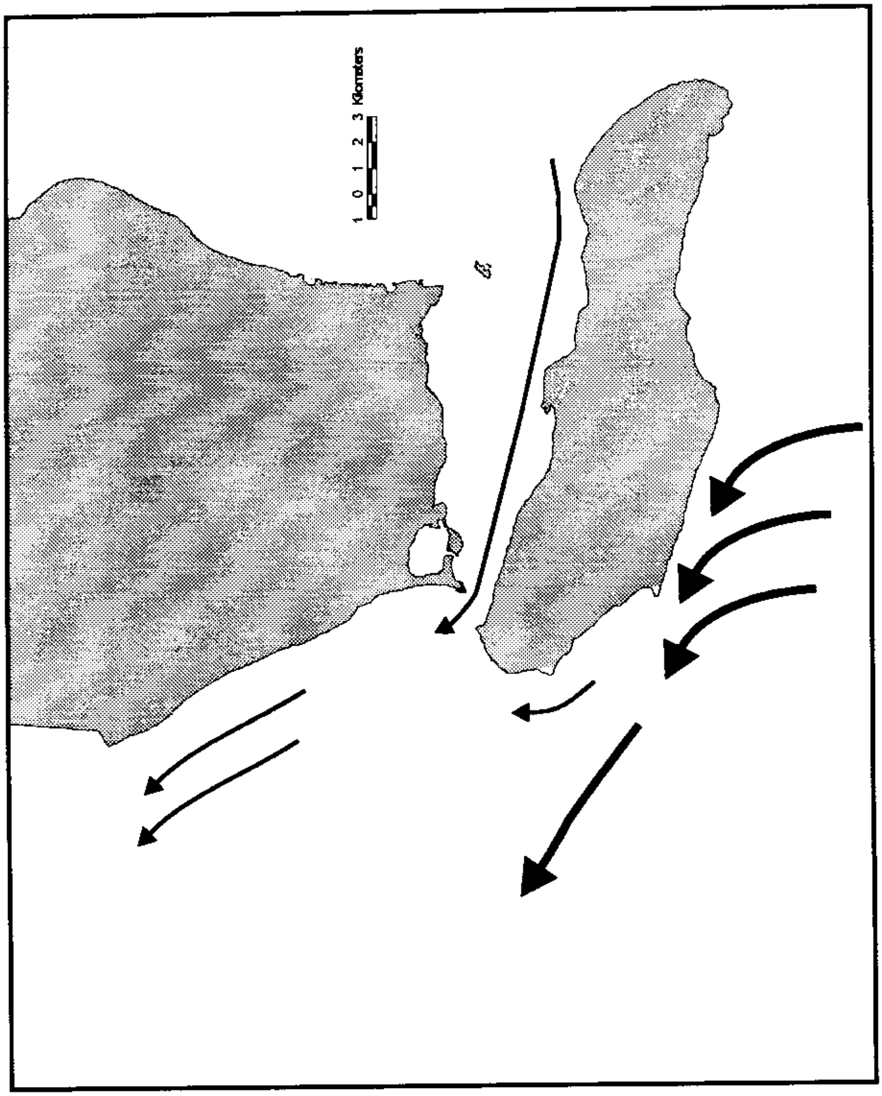


Figure 2. Diagram of the prevailing currents in and around Parque Nacional del Este, Dominican Republic

Table 1. Area, in hectares, and frequency occurrence of the benthic community types in Parque Nacional del Este

Benthic Community Type	Area (ha.)	Frequency
Land	42,502	22
Sand-Mud/Bare Bottom	297.5	8
Sparse Seagrass (Sand-mud)	1,370.6	1
Moderate-Dense Seagrass (Mud-sand)	2,631	14
Seagrass patches on Soft Sediment Matrix	1,164.3	2
Sand Beachs	37.7	9
Sandy Shoals and Sand Bars	455.9	11
Sparse Seagrass (Sand)	910.7	7
Sandy Algal Canopy	48.6	6
Mixed Algal Canopy	1,001.9	19
Reef Rubble Communities	125.2	3
Sparse Hard Bottom	1,202.5	11
Dense hard Bottom	384	12
Dense Seagrass Patches on Hard Bottom Matrix	234.6	6
hard Bottom Matrix with Dense Seagrass Patches	507.7	7
Patch Reefs	126	21
Platform Margin/Shelf Edge Reefs	713.3	10
Fringing Reefs	18	3
Windward Rocky Community	155	8
Leeward Rocky Community	22.2	3
Total Marine Communities	**11,467.7**	**N/A**

METHODS

Conch Size, Density, and Population Estimates

Objectives — A reliable estimate of the queen conch population size in Parque Nacional del Este is fundamentally important as the species is currently exploited, and a management plan may have to call for quotas, enforcement of minimum size limits, or a closing of the fishing grounds for part or all of the spawning season, which spans from June to September. The main focus of this study is to correlate queen conch abundances and size frequency distributions with community type and sediment characteristics in order to detect ontogenetic habitat preferences. Estimating conch abundances and densities is somewhat problematic as the species is wide ranging and has a patchy or clumped distribution. Therefore, dividing the survey area into different, easily recognizable habitats based on the community classification was essential.

Methodology — These different habitat types were mapped using Geographic Information Systems (GIS), and a grid system was overlaid on the map (Figure 3). The grid is random with respect to the conch because the conch are not oriented in any manner with the lines of latitude. A systematic sampling regime was used to determine conch abundances in PNDE. The sampling methodology is also stratified with respect to the community types because the larger a community is the more transects it will have. The advantages to this type of sampling is that a population estimate and a distribution map (in relation to community type) of the conch can be easily obtained from the data (Pennycuick *et al.*, 1977). This method of estimating population size does not include conch that are younger than one year in age because of their burrowing habits and resulting sampling problem. Those transects that fell completely within a community polygon were chosen for surveys. Transects are oriented perpendicular to the prevailing currents. For this study, sampling units were defined as the 50 x 5m ($250m^2$) transects used to survey the larger transects. In other words, Transect #1 (which is 1,000m long) would have twenty 50x5m transects or twenty sampling units (Figure 3). A population estimate of queen conch in PNDE was calculated using this formula: Y = Ny, where N is the number of sampling units (50 x 5 m transects) in the population and y is the mean number of conch per sampling unit (Pennycuick *et al.*, 1977).

Surveys were carried out in March/April 1996 and 1997. The method of data acquisition for quantifying queen conch populations consisted of measurements of density (# per unit area) and size (shell length and lip thickness for adults) correlated with habitat parameters. Size measurements were taken with calipers. Lip thickness was measured at the area of greatest thickness which is about 2/3 of the distance from the end of the siphonal groove.

Information collected from these transects was used to determine mean densities in that particular community type. Transect data was also used to estimate the total abundance of conch in the park and each community type. Size parameters were also averaged to determine if there was any ontogenetic habitat preference among community types, however, the fishing pressure on the queen conch stocks will introduce a bias into the analysis. Since the variances among the transects are not homogenous, a non-parametric test was used for the comparisons. The analogous non-parametric test of the ANOVA is the Kruskal-Wallis test. A Kruskal-Wallis ANOVA was run to determine significant differences in density among the community types in each year.

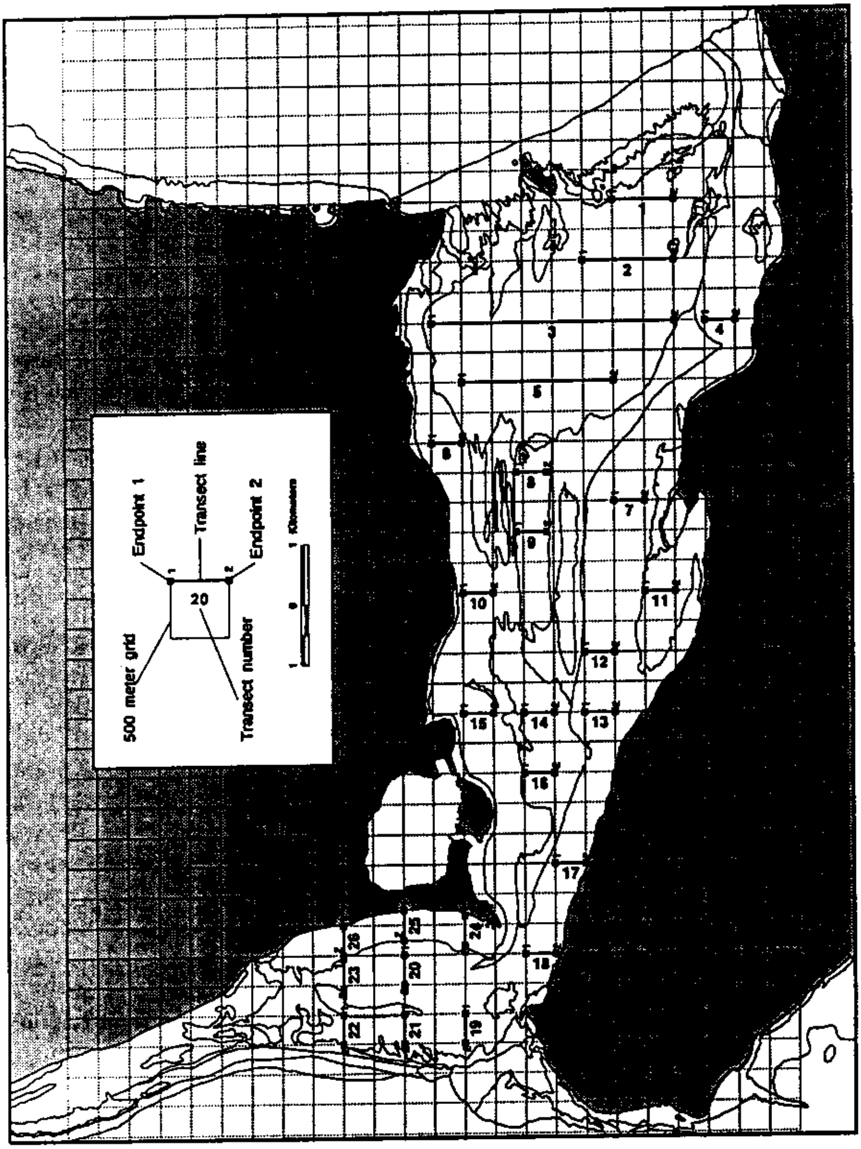


Figure 3. Map showing the queen conch stock assessment transects

Kolmogorov-Smirnov tests were run on the size frequency distributions of two of the community types. The Moderate to Dense Seagrass and the Sparse Seagrass in Sand-Mud communities were the only ones tested in this manner because of lack of data from the other types. The Kolmogorov-Smirnov test is able to determine if two data sets come from the same distribution. When sample size was too large, 25 randomly chosen data points were used in the statistical test.

Plankton Surveys for Strombid Veligers

Objectives — It is very important to sample the planktonic larvae of queen conch because sampling only adult or juvenile conch does not give the complete picture of the community structure. Selective processes weed out a large majority of the individuals before they reach maturity. Sampling larval communities also gives an indication of the importance of the area as a nursery and breeding ground for conch. A high density of early-stage veligers in the water column indicates a high level of spawning in the area and that the veligers may be transported upstream of PNDE (the circulation patterns around the study site influences transport processes). High abundances of late-stage larvae might be an indication that the area is used as a nursery for juveniles.

Methodology — Plankton comes in a variety of sizes, and plankton sampling techniques are size selective. The occurrence or spatial distribution of queen conch veligers can be extremely patchy, and sampling strategies need to take into consideration the variability between tows and between stations; therefore, four replicates at each of six stations were taken. Veliger densities from 1995 and 1996 were compared using a two-way ANOVA where year and location were the factors. These larval abundances can then be compared with the existing conch population to determine if there is a correlation between recruitment and veliger densities.

For this investigation, 20 minute tows (0.5 m below the surface) using a 333 micron-mesh plankton net (0.5 m diameter) were carried out at six sampling stations during daylight hours in August of 1995 and 1996 (Figure 4). Sampling was conducted in August because strombids congregate to breed during the summer months; therefore, the density of veligers in the water column should give some indication of the amount of conch breeding in PNDE. The stations provided a synoptic characterization of the spatial and temporal variability of veligers in the park. Stations were chosen based on the prevailing currents, in order to assess recruitment as the veligers are transported through PNDE.

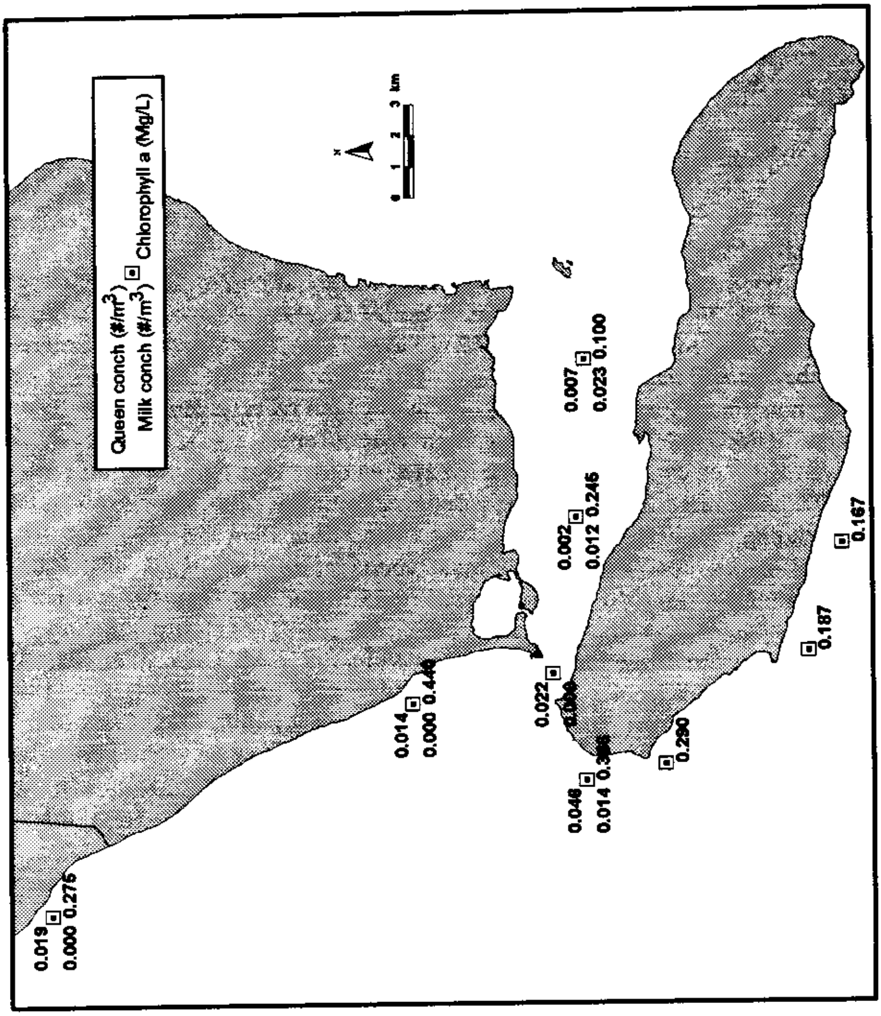


Figure 4. Map showing the spatial distribution of queen and milk conch veligers (no./m^3) and the concentration of chlorophyll a (µg/l) in Parque Nacional del Este during August 1996

The circulation patterns, hydrographic features, productivity, and turbidity of a water mass will all impact the type of plankton community found there as well as the distribution of larvae. Therefore, the concentration of chlorophyll a throughout the park was determined in August 1996 in order to link it with veliger density. Fifteen water samples (replicates) were taken at eight stations (Figure 4). Samples were filtered onto a 0.45 µm filter using a millepore apparatus. The chlorophyll was extracted using a 70% methanol-30% tetrahydrofuran solution and analyzed using a fluorometer.

RESULTS

Conch Population Estimates

Five of the community types in PNDE were surveyed for queen conch: Moderate to Dense Seagrass (MDSG), Sparse Seagrass in Sand (SSGS), Sparse Seagrass in Sand-Mud (SGSM), Mixed Algal Canopy (MAC), and Seagrass Patches on a Matrix of Soft Sediment (SGP). Over 90% of the juvenile queen conch in the park were found in SGSM during both years; juveniles were second most abundant in MDSG during both years (Tables 2 - 3). However, the juvenile queen conch population decreased an order of magnitude from 1996 to 1997. According to the equation mentioned in the methods, the juvenile queen conch populations were estimated to be 1,886,302 in 1996 and 149,839 in 1997. Adult queen conch were also most abundant in the SGSM and MDSG community types, and also decreased in 1997, but the decrease was not as precipitous as with the juveniles (Tables 2 - 3). The adult population was estimated to be 29,664 in 1996 and 10,649 in 1997. Milk conch, on the other hand, increased from a population of 155,924 in 1996 to 378,021 in 1997. Milk conch, like the queen conch, were most abundant in SGSM and MDSG (Tables 4 - 5). Despite the large amount of seagrass habitat in the park, conch only occupied a small fraction of the available habitat. Similar studies in other locations suggest that this result may indicate recruitment limitation (Stoner *et al.*, 1996).

Conch Size and Density Estimates

Yearly surveys (1996) — There was a significant difference in juvenile queen conch density among the five community types during March 1996 ($H=10.1$, $df=4$, $P<0.05$) (Table 2). Adult queen conch density also exhibited a significant difference among community types during March 1996 ($H = 10.1$, $df = 4$, $P < 0.05$) (Table 2). Milk conch density was significantly different among community types during March 1996 ($H = 13.2$, $df = 4$, $P < 0.05$) (Table 4).

Table 2. Estimates of juvenile and adult queen conch, *Strombus gigas*, densities (mean ± 1 SD/ha) and population estimates in benthic habitats of PNDE from surveys conducted in March 1996. Transects were 50 m x 5 m in area. SGP = Seagrass Patches on a Matrix of Soft-Sediment; SGSM = Sparse Seagrass in Sand-Mud; MDSG = Moderate to Dense Seagrass; SSGS = Sparse Seagrass in Sand; MAC = Mixed Algal Canopy; F = % of community surveyed.

Community	No. transects	F (%)	Juvenile conch/ha	Pop. est. (juv.enile)	Adult conch/ha	Pop.est. (adult)
SGP	30	0.06	0.0 (0.0)	0.0	0.0 (0.0)	0.0
SGSM	130	0.24	707.4(2,386.1)	969,612.1	5.9 (18.5)	8,013.3
MDSG	110	0.20	64.7 (94.1)	142,244.7	6.9 (6.7)	15,183.4
SSGS	20	0.06	2.0 (2.8)	1,821.4	0.0 (0.0)	0.0
MAC	60	0.15	1.3 (2.1)	1,349.3	0.7 (1.6)	674.7
Total	350	0.13	283.4 (1488.1)	1,886,302.2	4.5 (14.3)	29,663.6

Table 3. Estimates of juvenile and adult queen conch, *Strombus gigas*, densities (mean ± 1 SD/ha) and population estimates in benthic habitats of PNDE from surveys conducted in March 1997. Transects were 50 m x 5 m in area. SGP = Seagrass Patches on a Matrix of Soft-Sediment; SGSM = Sparse Seagrass in Sand-Mud; MDSG = Moderate to Dense Seagrass; SSGS = Sparse Seagrass in Sand; MAC = Mixed Algal Canopy; F = % of community surveyed.

Community	No. transects	F (%)	Juvenile conch/ha	Pop. est. (juvenile)	Adult conch/ha	Pop. est. (adult)
SGP	30	0.06	0.0 (0.0)	0.0	0.0 (0.0)	0.0
SGSM	130	0.24	46.8 (149.0)	64,106.6	2.8 (10.2)	3,795.8
MDSG	110	0.20	14.2 (37.4)	31,166.0	1.5 (7.5)	3,196.5
SSGS	20	0.06	0.0 (0.0)	0.0	0.0 (0.0)	0.0
MAC	60	0.15	4.0 (14.2)	4,048.0	0.7 (1.6)	674.7
Total	350	0.13	22.5 (95.1)	149,839.3	1.6 (7.9)	10,648.5

Table 4. Estimates of milk conch, *Strombus costatus*, densities (mean ± 1 SD/ha) and population estimates in benthic habitats of PNDE from surveys conducted in March 1996. Transects were 50 m x 5 m in area. SGP = Seagrass Patches on a Matrix of Soft-Sediment; SGSM = Sparse Seagrass in Sand-Mud; MDSG = Moderate to Dense Seagrass; SSGS = Sparse Seagrass in Sand; MAC = Mixed Algal Canopy; F = % of community surveyed.

Habitat	Number of transects	F (%)	Milk conch /ha	Population estimate
SGP	30	0.06	0.0 (0.0)	0.0
SGSM	130	0.24	32.8 (25.8)	27,835.8
MDSG	110	0.20	50.6 (67.7)	111,078.7
SSGS	20	0.06	0.0 (0.0)	0.0
MAC	60	0.15	0.0 (0.0)	0.0
Total	350	0.13	23.4 (72.3)	155,924.2

The size frequency distributions of juvenile queen conch were significantly different between the SGSM and MDSG community types (D = 0.44, df = 25, $P < 0.05$) (Table 5). However, the size frequency distributions of adults and lip thickness were not significantly different between the two mentioned community types (D = 0.16, df = 19, $P > 0.05$ and D = 0.26, df = 19, $P > 0.05$, respectively) (Table 5). The size frequency distribution of juvenile queen conch was significantly different between Transect #1 and Transect #2 and 3 in the SGSM community type (D = 0.96, df = 25, $P < 0.05$) (Figure 5).

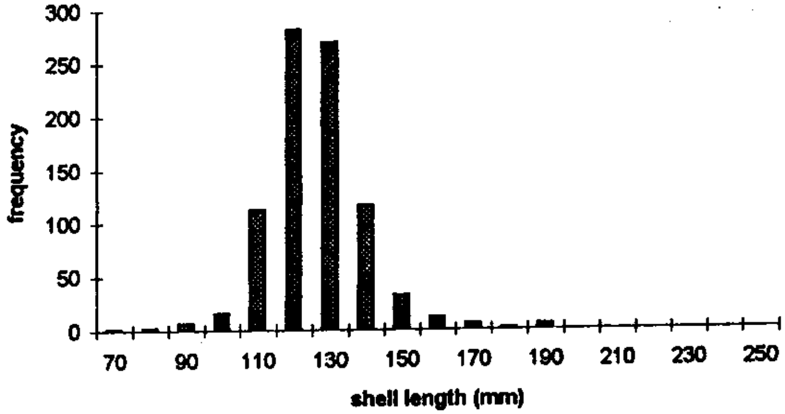
Yearly surveys (1997) — There was a significant difference in juvenile queen conch density among the five community types during March 1997 (H = 10.8, d = 4, $P < 0.05$) (Table 3). There was no significant difference in adult queen conch density among community types during March 1997 (H = 4.57, df = 4, $P > 0.05$) (Table 3). Milk conch density was significantly different among community types during March 1997 (H = 12.6, df = 4, $P < 0.05$) (Table 6).

The size frequency distributions of juvenile queen conch were significantly different between the SGSM and MDSG community types (D = 0.40, df = 25, $P < 0.05$) (Table 5). However, the size frequency distributions of adults was not significantly different between the two mentioned community types (D = 0.56, df = 4, $P > 0.05$); yet, the lip thickness frequency distribution was significantly different (D = 0.89, df = 4, $P < 0.05$) (Table 5). The size frequency distribution of juvenile queen conch was significantly different between Transect #1 and Transect #2 and 3 in the SGSM community type (D = 0.88, df = 25, $P < 0.05$) (Figure 6).

Table 5. Mean (SD) shell lengths of juvenile and adult queen conch and lip thickness of adults from five benthic community types in PNDE. SGP = Seagrass Patches on a Matrix of Soft-Sediment; SGSM = Sparse Seagrass in Sand-Mud; MDSG = Moderate to Dense Seagrass; SSGS = Sparse Seagrass in Sand; MAC = Mixed Algal Canopy.

Habitat	Juvenile 1996 (mm)	Adult 1996 (mm)	Lip 1996 (mm)	Juvenile 1997 (mm)	Adult 1997 (mm)	Lip 1997 (mm)
SGP	n/a	n/a	n/a	n/a	n/a	n/a
SGSM	126.0 (20.0)	214.8 (16.2)	2.7 (2.5)	136.5 (33.9)	231.8 (20.2)	10.2 (4.2)
MDSG	134.9 (31.1)	217.3 (15.3)	1.8 (1.2)	148.5 (24.8)	245.5 (3.4)	2.7 (2.5)
SSGS	125.0	n/a	n/a	n/a	n/a	n/a
MAC	175.0 (21.2)	204	1.0	198.0 (11.4)	235.0	3.0
Total Mean	126.0 (20.0)	215.7 (15.5)	2.2 (1.9)	140.7 (33.7)	235.9 (17.1)	7.6 (5.0)

Transect #1



Transects #2&3

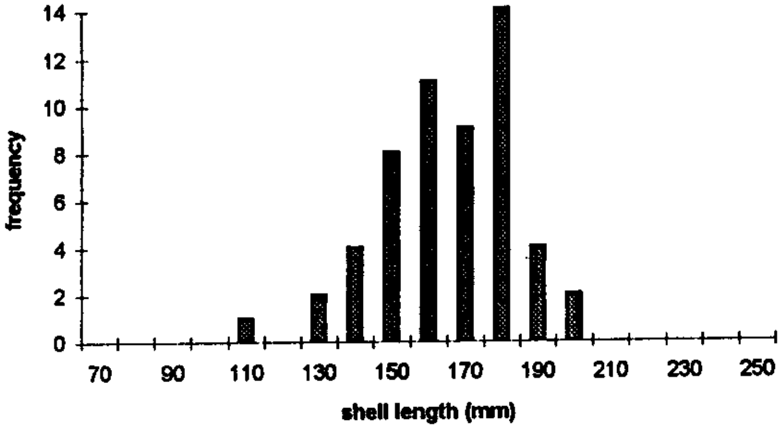
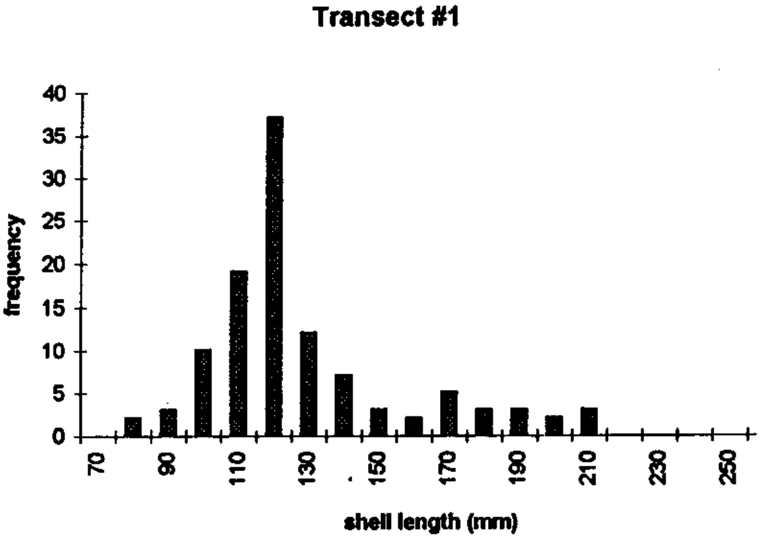


Figure 5. Size frequency distributions (SL mm) of juvenile queen conch found in Transect #1 and Transects #2 and #3 (Sparse Seagrass in Sand-Mud) during March 1996



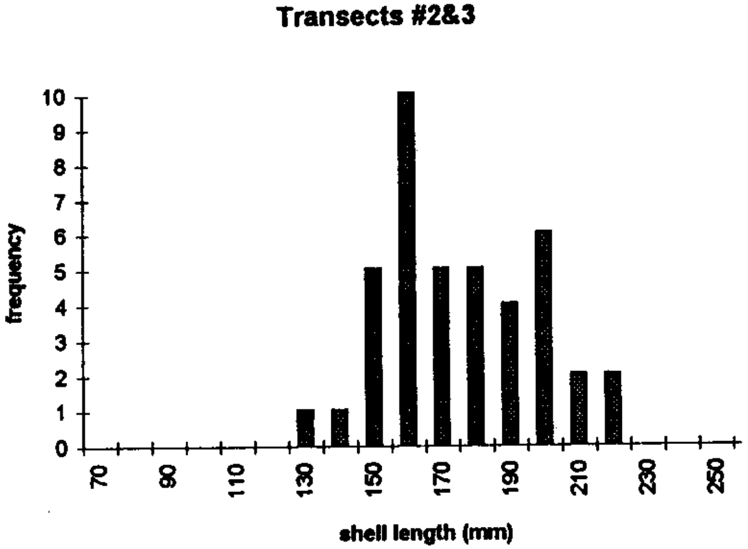


Figure 6. Size frequency distributions (SL mm) of juvenile queen conch found in Transect #1 and Transects #2 and #3 (Sparse Seagrass in Sand-Mud) during March/April 1997

Yearly comparisons — Juvenile queen conch, adult queen conch, and milk conch all had significant differences in density from year to year and among community types, as well as having a significant interaction between the factors (Table 7).

A summary of mean shell lengths (juvenile and adult queen conch) and lip thicknesses by community type and year is given in Table 5. Juveniles and adults were slightly larger in 1997 across all community types. The smallest juveniles were found in SGSM and the largest adults were found in MDSG during both years.

Table 6. Estimates of milk conch, *Strombus costatus*, densities (mean ± 1 SD ha^{-1}) and population estimates in benthic habitats of PNDE from surveys conducted in March 1997. Transects were 50 m x 5 m in area. SGP = Seagrass Patches on a Matrix of Soft-Sediment; SGSM = Sparse Seagrass in Sand-Mud; MDSG = Moderate to Dense Seagrass; SSGS = Sparse Seagrass in Sand; MAC = Mixed Algal Canopy; F = % of community surveyed.

Habitat	Number of transects	F (%)	Milk conch /ha	Population estimate
SGP	30	0.06	0.0 (0.0)	0.0
SGSM	130	0.24	118.2 (401.5)	161,953.5
MDSG	110	0.20	40.7 (110.3)	89,502.3
SSGS	20	0.06	0.0 (0.0)	0.0
MAC	60	0.15	0.7 (1.6)	674.7
Total	350	0.13	56.8 (256.2)	378,021.0

Plankton Surveys for Strombid Veligers

Plankton tows conducted during the summer of 1995 yielded a density of 0.007 ± 0.010 queen conch veligers/m^3 and 0.036 ± 0.035 milk conch veligers/m^3. Plankton tows conducted during the summer of 1996 yielded a density of 0.018 ± 0.027 queen conch veligers/m^3 and 0.008 ± 0.016 milk conch veligers/m^3. There was a significant difference in queen conch larval densities from year to year and among sites, but there was no significant interactions as determined by a two-way ANOVA (Table 8). Milk conch larval densities were significantly different from 1995 to 1996, but the density was not significantly different among the sites; there was no significant interaction between the factors (Table 8). Representative samples of queen and milk conch veligers are housed at the Bailey-Matthews Shell Museum at Sanibel Island (Accession #370) and at the University of Miami's Marine Invertebrate Museum at RSMAS.

Larval strombid densities showed no strong correlation with chlorophyll a concentration ($r^2 = 0.24$ for queen conch veligers and $r^2 = 0.50$ for milk conch veligers); however, larval density reached a peak at 0.35 µg/l and then dropped rather precipitously (Figure 7).

Table 7. Significant differences in strombid densities among benthic community types and years at PNDE as determined by two-way analysis of variance. ns = not significant; ** = P < 0.05.

Parameter	Factor	df	F-value	Significance
Juvenile queen conch	Year	1	5.60	**
	Community Type	4	6.41	**
	Interaction	4	5.18	**
Adult queen conch	Year	1	18.7	**
	Community Type	4	19.7	**
	Interaction	4	7.14	**
Milk conch	Year	1	4.04	**
	Community Type	4	7.00	**
	Interaction	4	4.47	**

Table 8. Significant differences in larval strombid densities among survey sites and years at PNDE as determined by two-way analysis of variance. ns = not significant; ** = P < 0.05.

Parameter	Factor	df	F-value	Significance
Queen conch	Year	1	4.55	**
	Site	4	3.88	**
	Interaction	4	0.65	ns
Milk conch	Year	1	8.97	**
	Site	4	1.08	ns
	Interaction	4	0.33	ns

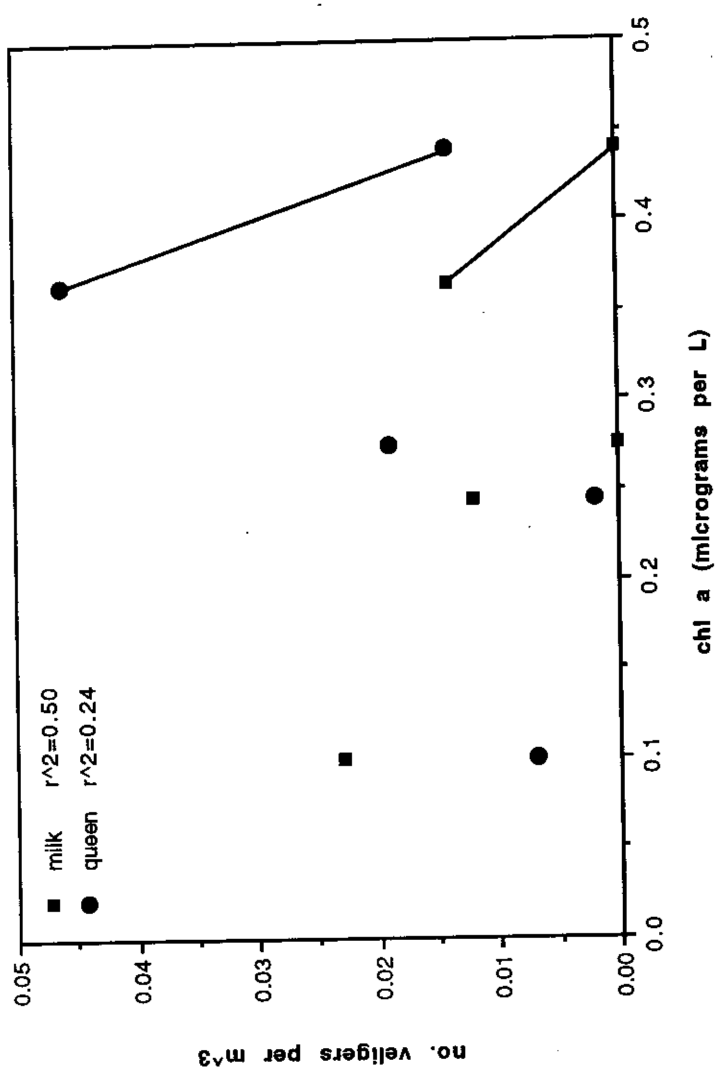


Figure 7. Graph showing the relationship between chlorophyll a concentration and the density of strombid veligers in Parque Nacional del Este during August 1996

DISCUSSION

Conch Size and Density Estimates

Juvenile Queen Conch — The importance of seagrass communities to a variety of macrofauna is well established (Orth *et al.*, 1984). The association of conch distributions with benthic communities has been the focus of habitat studies throughout the Caribbean (Weil and Laughlin, 1984; Iversen *et al.*, 1987; Stoner and Waite, 1990). Juvenile queen conch density showed a significant difference among the five community types surveyed in the present study. Juveniles were most abundant in Sparse Seagrass in Sand-Mud in both 1996 and 1997. In fact, Transect #1 (the eastern-most transect) had two orders of magnitude more conch than any of the other transects in 1996 and one order more in 1997. This indicates that the Sparse Seagrass in Sand-Mud community in PNDE acts as the juvenile nursery area for queen conch. This result is similar to studies in the Bahamas, where 1 - 2 year old conch were most abundant in seagrass of moderate cover (Sandt and Stoner, 1993). The apparent preference of juveniles for these sparse seagrass communities is probably a function of food availability and predator avoidance (Stoner and Waite, 1990; Ray *et al.*, 1994). This community type probably provides the necessary detritus, high algal production, and structural complexity needed for refuge from predators (Stoner *et al.*, 1994; Ray *et al.*, 1994).

Juvenile queen conch suffered a significant decrease in density from 1996 to 1997. The decrease occurred at Transect #1 where juvenile density was an order of magnitude higher in 1996 (this also explains the significant interaction between factors [year and community type] in the 2-way ANOVA). There are two possible explanations for this phenomenon. The first is that there was recruitment failure during the summer of 1997, but since queen conch larvae were actually more plentiful that summer than the previous year, another possibility must be taken into account. Since size restrictions are difficult to enforce in the park, the most likely scenario is that the juvenile nursery was heavily fished before the field surveys.

Because of lack of data from the other community types, only the size frequency distributions of juveniles from the Sparse Seagrass in Sand-Mud and Moderate to Dense Seagrass communities were compared. The juveniles from the former were significantly smaller during both years. If size is used as an indicator of age, then the juveniles in the Sparse Seagrass in Sand-Mud community type were younger. In fact, when Transect #1 is compared to the other transects within that community, the former had significantly smaller juveniles than the rest of the community type during both years. This would indicate that Transect #1 (the eastern-most transect in PNDE) is an area of active recruitment and should be considered a juvenile nursery area.

Adult Queen Conch — Very few adults were found during the surveys. Adult queen conch exhibited a significant difference in density from year to year and among community types. Adults preferred Sparse Seagrass in Sand-Mud and Moderate to Dense Seagrass about equally. There was about a three-fold decline in adult density from 1996 to 1997. This would indicate that the adults are being fished out; the few adults that were found had very thin lips which means they had just reached sexual maturity. Size frequency distributions were not significantly different among community types; however, when community types were compared across years, larger adults were found in 1997.

The density of adult queen conch in PNDE was lower than most study areas in the Caribbean. This may be the result of lower production due to a smaller coastal shelf area or intense fishing. In the Bahamas, very few adult queen conch are found shallower than 10 m due to inadequate food supply (Stoner and Schwarte, 1994); this may be the case in PNDE.

Milk Conch — Milk conch exhibited a significant difference in density from year to year and among community types. Like the queen conch, milk conch preferred the Sparse Seagrass in Sand-Mud and Moderate to Dense Seagrass community types. However, unlike queen conch, milk conch density more than doubled in 1997. This was due to the increase of milk conch in the Sparse Seagrass in Sand-Mud community type (which also explains the significant interaction between factors [year and community type] in the 2-way ANOVA). In fact, the increase in this community type was due to an order of magnitude increase on Transect #1, where queen conch decreased an order of magnitude. However, milk conch veligers decreased from 1996 to 1997; therefore, increased recruitment is not a viable explanation. The most probable explanation for this event is a higher survivorship due to a lack of competition from queen conch. Queen conch bring a higher market price than milk conch and are subjected to more fishing pressure.

Plankton Surveys for Strombid Veligers

Veliger Abundance — The objective of conducting plankton tows for strombid veligers was to assess any recruitment that may have been occurring in PNDE. Analysis of the plankton tows conducted for strombid veligers suggest that the larvae were hatched nearby as most of the individuals found were less than 10 days old (mostly Stage III veligers) (Davis *et al.*, 1993). No competent veligers were found. Larval abundances are also very low which suggests that the spawning stock is heavily fished or very small as the population estimates have shown. In fact; other studies have shown that larval densities within a marine fishery reserve can be 4 to 17 times higher than in fished areas (Stoner and Ray, 1996). However, the larval densities may be artificially low because the mesh size used was not designed to catch early stage veligers.

Since, the juvenile nursery area is located along the eastern margin of PNDE (Transect #1) it is hypothesized that these conch originate from a deep population just to the east of the park (fishermen are seen in this deeper area using hookah to harvest conch) or that these juveniles originated from populations in Puerto Rico. The Sparse Seagrass in Sand-Mud community would be the first suitable habitat that the veligers heading west from the Mona Passage would encounter and in a typical Caribbean current of 0.2-0.5m/s, these veligers could have traveled the distance in time to settle out. Gene flow between queen conch populations in the Caribbean is reported to be quite high (Mitton *et al.*, 1989); a study of the gene flow between Puerto Rican and Dominican populations would allow resource managers to decide if international conservation initiatives need to be implemented for stock recovery. Larval dispersal patterns are one of the keys in optimizing benefits from marine fishery reserves.

Queen conch showed a significant increase in veliger abundance from year to year while milk conch decreased significantly. These results are seemingly contradictory to the population estimates which show that the queen conch population decreased while the milk conch population increased. However, since local dispersal patterns have not been established, it is possible that these larvae did not originate within PNDE and reflect what may be occurring just outside of the park's eastern boundaries in deeper, unsurveyed habitats.

Chlorophyll Concentration — There was not a strong correlation between chlorophyll a concentration and veliger abundance. This would suggest that food is not a resource limiting larval densities. As stated previously, the most likely explanation for low larval abundances is the fact that the spawning population is quite small.

The most likely explanation for the sudden decrease in veliger abundance with increasing chlorophyll concentration is that the efficiency of feeding in veligers is low and as the concentration of food particles increases so does the interference among them, making them more difficult to capture. Veligers filter feed via a ciliated structure called the velum, which also enables them to swim (it produces feeding and locomotory currents). The feeding currents concentrate food particles between two opposing bands of cilia; in between these two bands is the food groove which takes food to the mouth (Strathmann and Leise, 1979). Veligers capture their food by direct interception of a food particle and/or by having the preoral cilia overtaking and adhering to the particles on the effective stroke. There is a significant decrease in clearance rate [clearance rate is defined as the volume of water cleared of food particles (unicellular algae) per unit time per larva (ml/hr/veliger)] with increasing food concentration which has been documented by several authors (Baldwin and Newell, 1995; Beiras *et a*l., 1994; Perez-Camacho *et al.*, 1994; Riisgard, 1988). Riisgard (1988) states that this decrease in clearance rate with increasing algal concentration is due to the functional response that larvae have when they are full or saturated. This is not the case for veligers, as food concentrations at the clearance rate drop are lower than those at saturation capacity (Sprung, 1984; Perez-Camacho *et al.*, 1994). The most likely explanation for the inverse relationship between these two factors are that the efficiency of feeding in veligers is low; the water flow through the capture zone of a veliger makes up only 15 - 30% of the total water flow through the velum, and to compound matters, only a small number of the particles moved by the velar cilia are actually captured and ingested (Gallager, 1988). Also, as the concentration of food particles increases so does the interference among them, making them more difficult to capture; limited gut volume and/or food processing capability can also have an affect on this phenomenon (Baldwin and Newell, 1995; Perez-Camacho *et al.*, 1994). Smaller larvae usually encounter the problem of limited gut volume, which would produce lower clearance rates as an artifact.

Management and Research Recommendations

Queen conch have been studied extensively throughout the Caribbean, but scientists have had little success in explaining ecological requirements (Stoner *et al.*, 1994; Stoner *et al.*, 1996). An effort has been undertaken by the Dominican Republic to establish the waters around Parque Nacional del Este as a marine reserve. The potential control of conch exploitation within the reserve provides a system in which to study the population dynamics and spatial distribution of queen conch among different habitats as the stock attempts to recover. Future studies in this area can provide additional information on queen conch population and size frequency estimates. Therefore, continued monitoring using the methods outlined by the present study is recommended. By correlating these parameters to mapped benthic community types, one can gain a better understanding of the ontogenetic migrations that this species undergoes, as well as mapping remaining or potential habitats. However, future studies must be more comprehensive as well and address the questions of benthic resource analysis and the environmental impact of large scale removal of the species.

Continued monitoring of strombid larval abundances can also give indications of the health of the population in the park. During their planktonic phase, larvae may drift great distances, which can allow for successful dispersal to suitable recruitment habitats; however, there are high levels of mortality and some larvae will be transported away from suitable habitats. For this reason, it is important to understand the current regimes that affect the water flow in

Parque Nacional del Este.

Statistics are needed on the status of conch harvesting in the park. Specifically, information is needed on the areas fished, depth, number of fishermen removing conch, effort, and gear used. Fishery independent data are needed on the density and size of conch in deeper water (10-30m) habitats throughout the park, particularly to the east of PNDE as these areas may be the primary habitats of the adult spawning population.

Specific recommendations for the recovery of queen conch in PNDE is as follows:

i) enforce size restrictions that are already in place; the minimum shell length is 24cm, but rangers are not equipped to enforce this legislation

ii) establish a closed fishing season on conch during the months from June to September; this is when the population is most vulnerable to overfishing as adults congregate to breed

iii) protect juvenile nursery areas from harvest; fishermen in the area have the "if I don't take it, the next person will" philosophy, as such juvenile nursery areas can be devastated by uncontrolled harvest

iv) continue to try to establish PNDE as a no-take zone (marine fishery reserve); if this plan was implemented, there would have to be some compensation or other forms of employment must be found for the fishermen that depend on the marine resources of Parque Nacional del Este.

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Appendix 1. Descriptions of the benthic community types encountered in Parque Nacional del Este.

Soft-Sediment / Unconsolidated Bottom Communities

1A. Sand-Mud / Bare Bottom

1.1. These communities include calcareous mud banks and flats, island moats, anchialine ponds, and mangrove channels or lagoons.

1B. Sand-Mud / Seagrasses

1.2. Sparse Seagrass -Physically similar to mixed algal turf areas with smaller-sized sediment grains (.12 to .5mm), but *Thalassia testudimum* predominate (<30% coverage). Usually deeper than mixed algal turf, and can be adjacent to patch reefs or octocoral/sponge reefs.

1.3. Moderate to Dense Seagrass Communities - Described as a dense blanket (>30% coverage) of seagrass, typically *Thalassia testudinum* or *Syringodium filiforme* in deeper water. The bed area is extensive and forms a large mound of trapped sediment.

1.4. Seagrass Patches on Matrix of Soft Sediment - Described as small patches of moderate to dense seagrass, but each patch is separated by an area of bare sediment; usually found in shallow water. The spatial extent of this community can be quite large.

2A. Sand / Bare Bottom

2.1. Sand Beaches -Described as intertidal, calcareous, sand beaches.

2.2. Sandy Shoals and Sand Bars - Calcareous sands or sandy shoals composed of coarse-grain (.5 to 2mm) sand that is very uniform in size. These banks are actively precipitating sediments or oolites because of their round shape. These banks may be exposed at low tides, and have no conspicuous benthos.

2B. Sand / Seagrasses / Algal Canopy

2.3. Sparse Seagrass - Similar to sparse seagrass in sand-mud; however, the seagrass is rooted in sediment the size of sand grains. This community is usually found in shallow, nearshore waters.

2.4. Sandy Algal Canopy - Green, calcareous algas such as *Halimeda, Penicillus, Udotea*, and *Caluerpa* dominate.

2.5. Mixed Algal Canopy - These communities are composed of sparse seagrasses, red algae (such as *Laurencia intricata*), and green algae (such as *Halimeda* spp.). Sediment size typically ranges from .5 to 2mm in diameter.

3. Rubble / Loosely Consolidated Hard Bottom

3.1. Calcareous Rubble Beaches - These beaches are intertidal, with cobble-sized grains.

3.2. Reef Rubble Communities - These communities are usually located nearshore or adjacent to reefs, and consist of a predominately bare bottom with rubble-sized sediment (> 5mm), which can include large rocks that have weathered from the neighboring coast or reef.

Hard Substratum / Consolidated Bottom Communities

4A. Hard-Bottom / Algal Turf-Octocoral-Sponge Communities - Hard bottom communities are described as having a combination of sponges, octocorals, and/or algae as the dominant benthos.

4.1. Sparse Hard-Bottom Communities - Lifeforms cover < 30% of the consolidated substrate.

4.2. Dense Hard-Bottom Communities - Lifeforms cover > 30% of the consolidated substrate.

4B. Hard-Bottom / Seagrasses

4.3. Dense Seagrass Patches on a Matrix of Hard-Bottom - Seagrasses comprise > 50% of the total area.

4.4. Hard-Bottom Matrix with Dense Seagrass Patches - Seagrasses comprise < 50% of the total area.

4C. Hard-Bottom / Coral Reef Communities

4.5. Patch Reefs - Every patch reef can be recognized in imagery, but groups of patch reefs make up unique communities. These groups will be lumped into one polygon, including the outside of the halo identifying each patch reef. There are two kinds of patch reefs: linear or bank patch reefs and domed or lagoonal patch reefs.

4.6. Platform Margin / Shelf Edge Reefs - These communities can be transitional reefs, reef crests, or spur-and-groove reefs.

4.7. Fringing Reefs - These reefs are similar to platform margin / shelf edge reefs; however, they occur offshore.

5. Hard-Bottom Nearshore Platform / Rocky Intertidal - These communities occur along windward or leeward shore areas, and are characterized by sharp zones of algal and animal species with differing tolerances to heat and desiccation.

5.1. Windward Rocky Community

5.2. Leeward Rocky Community