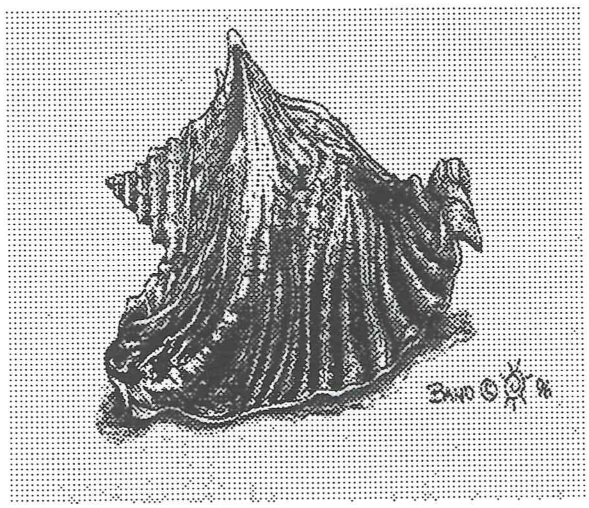
STOCK ABUNDANCE AND POTENTIAL YIELD OF THE QUEEN CONCH RESOURCE IN BELIZE



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INTRODUCTION

The queen conch (*Strombus gigas*) fishery is the second most valuable in Belize, with landings in recent years averaging about 180,000 kg (400,000 Lbs). The resource is fished by skin divers along the back reef and seagrass beds of the main reef system and the three adjacent atolls. Fishing occurs in relatively shallow waters ($<$ 15 m) and reports of juvenile conch in the landings are common. However, minimum legal size for landing conch is 18 cm (7 in) shell length, or 85 g (3 oz) of cleaned meat, and according to data in Strasdine (1988), adults average 22 cm in length, with 95% found above 20 cm in length. Thus, juveniles in the catch are to be expected.

A conch abundance survey was conducted in Belize from January to August 1996 by the Belize Fisheries Department and the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP). The purpose of the survey was to estimate conch abundance, particularly in the commercially important fishing grounds, and to identify juvenile conch grounds along the Belizean coast.

The principal method utilized to assess conch abundance has been visual census (Wood and Olsen 1983, Torres Rosado 1987, Berg and Glazer 1992, Friedlander et al. 1994, Appeldoorn 1995, Stoner and Ray 1995), and this was the approach used in the present survey. Visual census has the advantages that (1) it is non-destructive to the environment or the resource, (2) it can be conducted in all types of habitats, (3) the distribution and abundance of habitat in relation to the resource can be determined, and (4) size estimates can be obtained. The principal disadvantage is that only a limited area can reasonably be covered. The number of stations and their distribution are generally constrained by the limits of diving safety and effort, while the area covered within each station is further constrained by the distance over which conch are visible. In fixed-width transect surveys, where it must be assumed that all conch within the transect are counted, a minimum transect width is used based on worse possible conditions (small conch, heterogeneous habitat, poor water clarity). Although this reduces the potential area of coverage, it is logistically preferred to line transect methods in areas where habitat is variable because the latter method would require for each habitat the calculation of separate probability functions for observing conch with distance from the transect line.

The purpose of this report is to analyze the data obtained from the survey pursuant to the above goals. In addition, the abundance data were used to estimate potential yield for the fishery.

METHODS

The area to be surveyed was determined through interviews with conch fishermen and limited to a depth of 15.2 m (50 ft). These areas were plotted on a chart, digitized, and areas calculated. The survey area was divided into six zones (Figure 1). Zones 1-3 correspond to the offshore atolls: Turneffe, Lighthouse and Glovers Reefs, respectively. Zones 4-6 correspond, respectively, to the northern, central and southern areas of the barrier reef. The Northern Zone extends north of Belize City, while the Southern Zone extends south of Gladden Spit. Total areas of the conch grounds within each zone are given in Table 1.

At each station (Figure 1), parallel, adjacent transects were swum by divers. Transects were swum to a total distance of 2000 m when possible. Transects extended from the backreef west towards shore. Stations were spaced evenly (north to south) throughout the zones. By design, one transect was run through each existing marine reserve area, thus potentially violating the assumption of random sampling for these transects. However, for only one of these (Station 2, Hol Chan) was the reserve area functioning for a sufficient duration that stock enhancement could have resulted from the protection from fishing. Thus, only this station warranted exclusion from the data for further analyses based on average density.

For each diver, the transect width was 4 m. Each diver recorded the following data: Habitat Type, the Start and End Distances for each habitat type, and the number of conch observed within each habitat block by size/age class. The definitions of the size age classes are given in Table 2. The habitat types were defined according to the classification system of the Division of Coastal Zone Management and are given in Table 3.

The primary goal of the sampling program was the estimation of total abundance useful for calculating potential yield. The calculation of potential yield (see below) requires an estimate of the exploitable biomass. Thus, a new size classification category was developed: Legal conch - defined as any individual greater than 15 cm in total length. This limit is the largest juvenile size defined by the size/age categories used in data collection. Thus, the abundance of legal conch was the sum of the J4 juveniles, and the subadults, adults and samba conch. The vast majority of conch harvested are large juveniles. The true minimum legal size of conch in Belize is 17.8 cm

(7 in.) shell length, or a meat weight of 85 g (3 oz.). However, according to the relationships given by Strasdine (1988), a meat weight of 85 g corresponds to a conch significantly less than 17.8 cm in length. Meat weight is assessed at the landing sites, and it is assumed that fishermen know what size conch correspond to 85 g such that the real minimum size of harvest is below 17.8 cm. Therefore, it is felt that the use of the 15 cm definition for legal conch is appropriate.

Statistical analyses were based on the estimation of density. To obtain total population abundance, estimates of density were multiplied by total area. Estimates of density by station were not normally distributed, nor was it possible to transform the data to achieve normality. Therefore, all estimations of variance (standard deviations) were calculated using bootstrap methods (Efron 1982, Efron and Tibshirani 1993). Because the paired diver observations are not independent, estimates of density (and hence abundance) were calculated on a per station basis.

The idea of bootstrap is simple: a large number of data sets are generated by sampling with replacement from the original data (for overall density, one sample = paired transects at one station). The mean is then computed from each set of bootstrap samples. To account for variation, bias-corrected and accelerated (BCA) confidence intervals were calculated. This is essentially a corrected form of percentile-based confidence intervals. In the latter, if for example one wanted the 95% confidence interval on a bootstrap data set of 10,000 means, the percentile confidence interval would use the 250th and 9750th observations of the 10,000 means sorted in increasing order. The BCA confidence interval is calculated by computing the percentage of the bootstrap mean-estimates that is smaller that the mean estimated from the original data together with a jackknife estimate.

To compare differences between zones, multiway dotplots of the square root of the abundance by zone and age/size class were constructed. The square root transformation was used to diminish the effect of the skewness in the data. The Wilcoxon Signed-Rank test was applied to each of the pairs of zone abundance estimates.

To examine differences in habitats, multiway dotplots of the square root of the abundance were again constructed by age/size class and the eight habitats containing the most conch (pooling the two patch-reef habitats).

RESULTS AND DISCUSSION

Abundance

Table 1 summarizes the survey results for the 50 stations (i.e., excluding Station 2). Table 4 presents the estimates of density of legal conch for the six zones and the estimate of density over all 50 stations. The multiway dotplots shown in Figure 2 shown no differences between zones for either legal or sublegal-sized conch. The comparison showing the largest difference was that of legal-sized conch at Turneffe Reef (Zone 3) compared to Lighthouse Reef (Zone 1).

Table 5 and Figure 3 present the results of the bootstrapping estimates of average density of legal and sublegal conch and total abundance based on all stations (excluding Station 2). Mean estimates of density from the original and bootstrapped samples were similar, at 14.3 conch/ha for sublegal conch and 14.9 conch/ha for legal conch. Over all stations, the abundance of legal conch was approximately 2,260,000. The 95% confidence limits ranged from 1.57 to 3.76 million conch.

Size\Age Structure

Figure 4 shows the relative abundance of conch found in each of the seven size/age classes pooled over all 50 stations (i.e., excluding Station 2). The population is dominated by juveniles (approximately 70%) greater than 10 cm in length. Smaller juveniles would be underrepresented because they would not have fully recruited (fully emerged from the sediment where they primarily reside for the first year), and perhaps also being under counted due to small size making they less visible. Adults make up about 20% of the population. As a snap-shot of size/age structure, the above pattern could have several interpretations, these included the following: (1) the population is seriously overexploited and in danger of stock collapse due to spawning failure; (2) the population is seriously overexploited but recruitment is unaffected by the local spawning stock; (3) the population abundance has been low, but strong recruitment occurred after the 1993-1994 spawnings; (4) conch leave the survey area at about the time of maturation and were unavailable for sampling.

These options can be reduced by comparing these data to others. First, Figure 4 also shows the relative abundance of conch found in each of the seven size/age classes for the single transect run through the Hol Chan marine reserve (Station 2). Although this is only a single transect whose habitats may not be representative, a few points are relevant. About one-half of all conch encountered during the survey were found within Hol Chan. Hence, with protection, density was two orders of magnitude greater than average (one order of magnitude greater than the next highest station transect). This would argue that exploitation is intense. Nevertheless, the relative abundance of adult conch within Hol Chan is only about 10% - less than observed elsewhere on average. Thus, protection has not resulted in a relative increase in adults. Furthermore, studies made in the early 1980's by Strasdine (1984) also showed very low relative abundance of adults, yet fishery production has not varied significantly since that time. These observations suggest that recruitment in recent years has not been affected by apparent low adult spawning stock, and most conch move out of the survey area (or at least out of Hol Chan) at about the time of maturation. If so, this further suggests that recruitment results from a spawning stock not located within the survey area.

Habitat Use

Table 6 gives the observed counts and densities of conch within each type of habitat in order of increasing amount of habitat. This pools observations from both divers. A total of 14 habitat types were encountered during the survey. The last three habitat types covered about 70% of the area sampled, while another five habitat types account for most of the rest. Further comparisons will be limited to these eight habitats. Conch density is one indicator of habitat preference. Figure 5 presents dotplots comparing density by habitat type and size/age class. These clearly show the high degree of variability in density among habitat types or size/age classes, which would preclude finding statistically meaningful differences with such low sample sizes. Another simple index of preference was calculated, defined as Percent Conch - Percent Area. For this index, positive values indicate occurrence of conch at a rate greater than that proportional to available habitat, while negative numbers indicate occurrence of conch at a rate less than that proportional to available habitat.

A pattern emerges from these data and is summarized below. Here the results for the

Diffuse and Distinct Patch Reef have been pooled into a single habitat of "Patch Reef" . Assigning the codes of P = Preference, A = Avoidance and R = Random, and rearranging the order of habitats yield the following:

HABITAT	JUVENILE	LEGAL	ADULT
1-Sand w/ sparse seagrass	P	A	A
2-Sparse Seagrass & algae	P	P	A
3-Moderate Seagrass & algae	A	P	P
4-Gorgonian Plain	A	P	P
5-Patch Reef	A	A	R
6-Dense Seagrass & algae	A	A	A
7-Sand w/ sparse mixed algae	A	A	A

The general trend is that as conch get older/larger they switch from very sparse to sparse seagrass (Juveniles: habitats 1 & 2) to sparse to moderate seagrass and gorgonian plain (Legal: habitats 2, 3 & 4) to moderate seagrass and gorgonian plain (Adult: habitats 3 & 4). In all other habitats (except Patch Reef) conch are found in abundance disproportionally low relative to available habitat. The above table identifies areas of sparse seagrass (30% of the area surveyed) as particularly important nursery areas, a result generally consistent with previous studies (e.g. Stoner and Waite, 1990). Figure 5b supports these observations and shows that differences in mean trends arise from differences in maximum densities observed (i.e. increase range of observations). For example, for Sparse Sea Grass and for Sand with Sparse Sea Grass the maximum densities observed decrease progressively from sublegal conch to legal conch to adult conch.

A comparison was made of the distribution of Sparse Seagrass and Algae habitat (accounting for 61% of sparse seagrass habitat) among the different zones. Zone 4 (Norther Barrier Reef) and Zone 2 (Lighthouse Reef) were found to have a disproportionally low abundance of sparse seagrass habitat relative to that found in the other zones. For the northern barrier reef this is in agreement with the distribution of habitats shown in Figure 1 as mapped by the Belize Coastal Zone Management. However, for the three atolls the survey and map are in disagreement.

Depth Preference

Table 7 gives the preference of conch by 1.52 m (5-ft) depth classes. Data from both divers were pooled. The table indicates that sublegal conch preferentially occurred at depths between 0.3-1.52 m (1-5 ft) and 3.33-4.55 m (11-15 ft), with relative avoidance of depths between 1.52-3.33 m (5-10 ft). No explanation of this split was readily apparent in the data. For example, within the most preferred habitats (Sparse and Moderate Seagrass) the same pattern was evident. Conch of 10-15 cm length dominated the samples and are responsible for the resulting depth distribution.

Adults preferentially occurred at depths of 4.85-6.06 m (16-20 ft) and 6.36-7.58 m (21-25 ft). However, this result is driven by isolated observations of high numbers. For example, within the depth range of 4.85-6.06 m (16-20 ft), 67% of the adult conch were found in one location of a single transect (Number 19; both divers). Similarly, in the next deepest depth zone half the adults were found at a single location.

Estimation of Potential Yield

Estimation of potential yield was approached using the formulas of Garcia et al. (1989). This approach requires an estimate of average biomass (B) of the exploited stock, plus the yield (Y) resulting from that stock. The formulas are as follows:

$$MSY_S = \frac{BM^2}{2M-F} = \frac{BM^2}{2M-(Y/B)}$$

$$MSY_F = MB\exp\langle (Y/MB)-1 \rangle$$

where MSY is Maximum Sustainable Yield, and M and F are coefficients of natural and fishing mortality, respectively. The subscripts S and F refer to the underlying stock-production model, Schaefer or Fox, respectively. The models are subject to the assumption that at MSY, F = M, such that total mortality is equal to 2M. However, a different relationship between F and M at MSY can be explicitly modeled, where F = X M.

The estimate of abundance for legal size conch was used to estimate exploited biomass. To convert number to weight requires an estimate of the average meat weight per individual conch. The figure chosen for this (170 g; 6 oz) was obtained from a manager of a fishing cooperative where conch are processed. Multiplying abundance of legal conch (approximately 2,260,000 by this weight results in an estimate of exploited biomass of 384,200 Kg (845,240 Lbs). For the estimate of Y, the total estimated landings for 1995 was used: 185,545 Kg (408,200 lbs).

The estimation of M is problematic because M declines significantly with increasing age in conch (Appeldoorn 1988). Thus, adult conch would be expected to have significantly lower natural mortality than legally harvestable juveniles. For example, for older adults M would be low (<0.1), average adults might have a valued of about 0.6, while for juveniles the value would be > 1. In assessing potential yield using the Garcia formula, a range of values of M were used. A value of M = 0.6 was considered as an approximate midpoint estimate.

Tables 8 and 9 give the response surfaces of Garcia's formulas for a range of values of M and Biomass. Using a value of M of 0.6, potential yield was estimated at 193 and 189 thousand kilograms (425 and 417 thousand pounds) by the Schaefer and Fox models, respectively. In both cases, the models are nonlinear with respect to M or Biomass for a given value of catch. Minimum estimates of potential yield are always equal to the catch estimate (this follows from the assumption of equilibrium). Potential yield increases from this point as M (rows) or Biomass (columns) increases or decreases. For this reason, substitution of the upper and lower 95% confidence limits on stock biomass (approximately 226,000 and 639,000 kg [587,000 and 1,406,000 Lbs], respectively) generally result in higher estimates of potential yield.

Two assumptions of the models should be explicitly addressed. First, the estimate of catch

(Y) is supposed to be the catch that results from the estimated catch. In this case, the catch was for 1995, the year before the survey was conducted. However, as shown in Figure 6, catch rates in Belize have been stable for the recent past, which gives confidence that the 1996 catch will be similar to that for 1995.

Second, the effectiveness of the model predictions depends on the assumed underlying stock-production model, i.e., the relationship between stock-biomass and the rate of biomass production. In particular, Garcia et al. (1989) showed that both models will be nonlinear in their ability to predict MSY when true production follows a Beverton and Holt yield-per-recruit model, i.e., recruitment is largely independent of stock size. In this case, either model would substantially (if not unrealistically) overestimate MSY if fishing levels significantly departed from the region where F approximated M. In Garcia et al.'s (1989) study, the Fox-based equation performed slightly better because it tended to have a flatter base and therefore predicted MSY did not change as markedly with changes in F. Nevertheless, both equations were able to generate estimates that approximated the "true" MSY under the Beverton and Holt model ($\pm$ 10-20%) for the regions where F approximated M. Since current fishing mortality (F) in Belize is unknown, but is suspected of being high (see below), the fishery may not be in the range where F approximates M and the results of the Garcia et al. model may therefore be suspect.

In the current fishery, there are few adults present in the fished area. This indicates that either adults are well overfished or that adults are occupying areas not covered by the survey, and presumably not fished. Most likely areas would be on the outer shelf in front of the barrier reef or behind the barrier reef in waters deeper than 15.2 m (50 ft). If a deep, unexploited stock of adults exists, and if current fishing is low enough to allow recruitment of juveniles into that adult stock, then production may indeed be independent of stock size. Rather production may be directly dependent upon recruitment success caused by environmental fluctuations in larval survival and dispersal. Stoner (pers. comm.) has shown in both the Bahamas and Florida that recruitment success in nursery areas is directly related to the abundance of larvae in of those areas, and less so by the abundance of reproductively active adults.

The increase in conch abundance within the Hol Chan reserve indicates that conch are being heavily exploited. However, there are no greater percentage of adults within the reserve than outside it (Figure 4). Therefore, adult conch, on average must be moving out of the reserve at about the time of maturation. Either these conch are quickly exploited or they escape to presumably deeper habitat. Two points argue that at least a significant percentage do indeed obtain refuge through migration. One is that the fishery is closed for a quarter of the year, thereby allowing conch to reach refuge during this time. The known potential rates of motion of adult conch would be sufficient for this to occur. Secondly, the catch rate in Belize has been fairly steady since excess biomass was harvested back in the 1970's, yet reproduction in conch is rarely (if ever) reported by fishermen. Continued recruitment in the absence of observed spawning would argue that a supporting spawning stock exists elsewhere. The apparent equilibrium nature of the fishery, and the possibility that yield is independent of spawning stock size (but dependent upon recruitment) is consistent with the predictions of yield obtained from the Garcia equations, that is, that maximum yield is approximately equal to catch. If yield is independent of spawning stock size, use of the Beverton and Holt model for estimating potential yield might be more appropriate.

A resource and fishery in apparent equilibrium and catch independent of spawning stock size would be beneficial for management purposes. As long as fishing effort were maintained such that sufficient conch gain refuge into the adult conch, the fishery can be maintained indefinitely, and recruitment, stock status and future catch could be monitored from length-frequency sampling. However, this scenario is entirely dependent upon the existence of a refuge area for spawning adults, and that larvae from these reseed the area on average. It is simple and of the utmost priority to test the first assumption: is there an abundant adult spawning stock in deep water. Testing the second assumption (larval reseeding) is more difficult and costly, and would not be worth addressing unless the first assumption were sustained.

CONCLUSIONS & RECOMMENDATIONS

The estimated population of legal-sized conch in Belize was 2,259,000 (95% C.I. = 1,570,000 - 3,760,000) individuals. At a mean value of 170 g (6 oz) per individual, the estimated value of maximum sustainable yield was approximately 190,000 kg (420,000 lb). The degree of caution in applying this estimate cannot be overemphasized. Not only are the confidence limits on population size large (-30%, +67%), they also cannot be incorporated into the estimate of yield. The analysis also assumes that the average weight/individual is accurate, that the value of natural mortality (M) is known with precision, that the catch rate used (1995) would be similar to that for the current year (1996) and that production is related to biomass according to the models used. There is a fair, but unknown, degree of uncertainty in all of these assumptions. Given this uncertainty, a conservative management approach is clearly warranted. Further studies examining some of the above assumptions (e.g. the distribution of individual meat weights) could easily be conducted.

That almost half the conch found during the survey occurred in the protected area of the Hol Chan Reserve indicates that (1) fishing rate is high, and (2) that reserves, even when small, can have a significant beneficial impact. This strongly suggests that marine reserves can be used as a management tool to buffer the health of the stock from management uncertainty and the high rate of fishing.

The similarity in the size or age structure of the population between Hol Chan and other stations, with both showing relatively few adults, and the relatively stable annual yields over the past 18 years suggest that the adult spawning stock supporting Belizean conch production exists outside the areas included in the survey. However, this is a dangerous assumption under which to manage the fishery. There are three aspects to be considered. The first is whether this separate spawning stock is in Belizean waters and hence under local control (and particularly that it is unexploited). The second aspect is whether this adult population is being actively maintained by recruitment, or whether it is a residual population. Since conch may live upwards of 30 years, an unexploited spawning stock without recruitment potentially could still support the fishery for several decades before collapsing. Lastly, management based on this assumption (i.e., not protecting adults within the fished areas), when the assumption is wrong, would eventually lead to recruitment failure and stock collapse. Thus, it is highly recommended that additional surveys be taken in deeper waters to verify the existence of a sufficient number (and density) of adults. In particular, the sonic tagging of large juveniles or recently matured adults over the course of a year may give a clearer indication of whether these individuals migrate from backreef areas into deeper water.

If there exists a protected spawning stock, and hence yield is strictly a function of recruitment to the fished areas, then the fishery may be managed through analysis of yield-per-recruit. However, some necessary parameters (e.g., M) are still difficult to account for under this approach.

The above uncertainties illustrate the difficulty in attempting management while accounting for all possible factors. This difficulty suggests two points. One, the risk of management failure should always be considered. This leads to conservative management, including the use of marine reserves, as emphasized above. Second, periodic stock monitoring offers a check on management success and stock health. Such monitoring is recommended for two aspects: abundance and size-frequency. Although confidence limits for abundance from any given survey are large, they are still reasonable enough to detect large scale differences over time. The monitoring of size-frequency (length of juveniles, lip-thickness of adults) can be done relatively simply and inexpensively, and thus could be done on an annual basis. In particular, monitoring of size-frequency allows recruitment success and adult survival to be tracked, therefore giving some picture of stock dynamics and variability.

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LIST OF FIGURES

Figure 1. Location of sampling strata and stations for queen conch survey in Belize.

Figure 2. Dotplots of the square root of the abundance (rate) by zone and size class. (A) Zone by size class; (B) Size class by zone.

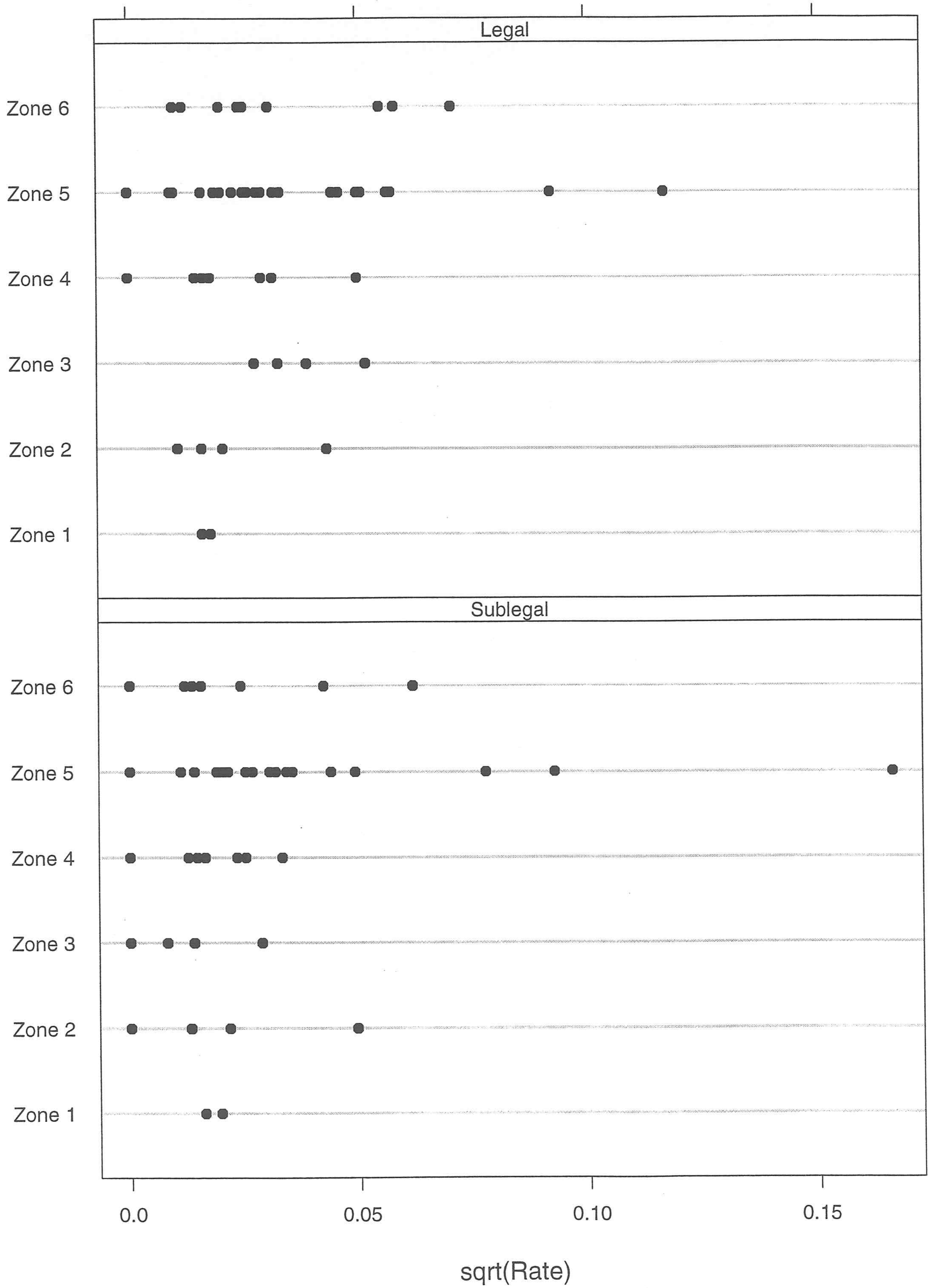
Figure 3. Distribution of bootstrap mean estimates (figure) and 95% confidence limits for total abundance of sublegal and legal size conch in Belize.

Figure 4. Percent frequency distribution of queen conch among the different size/age classes for Hol Chan and for all other stations combined.

Figure 5. Dotplots of the square root of the abundance (rate) by habitat type and size/age class. (A) Habitat by size/age class; (B) Size/age class by habitat.

Figure 6. Total queen conch production for Belize.

Figure 2A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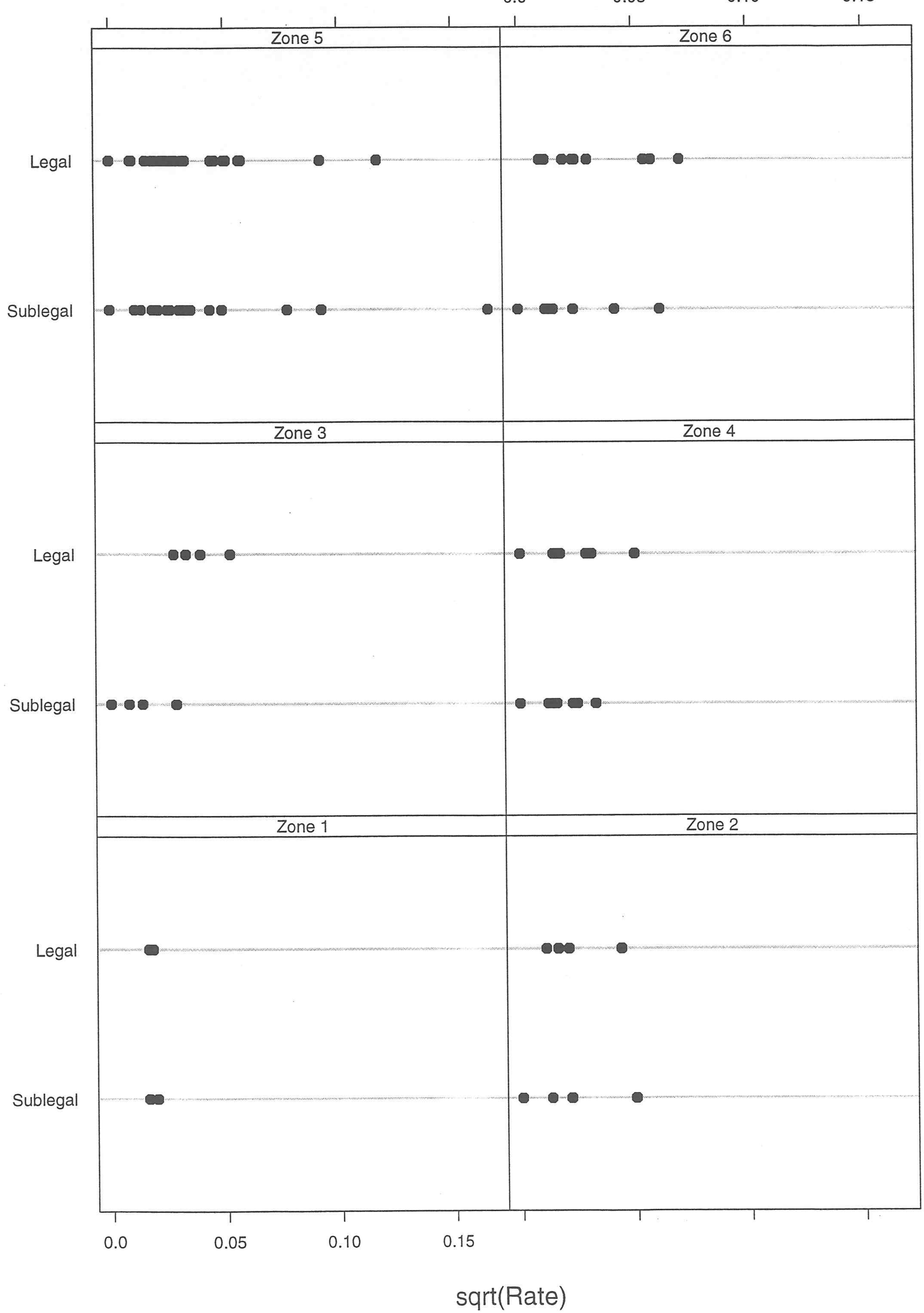
Zone 6
Zone 5
Zone 4
Zone 3
Zone 2
Zone 1
Sublegal
Zone 6
Zone 5
Zone 4
Zone 3
Zone 2
Zone 1
0.0
0.05
0.10
0.15
sqrt(Rate)

Figure 2B

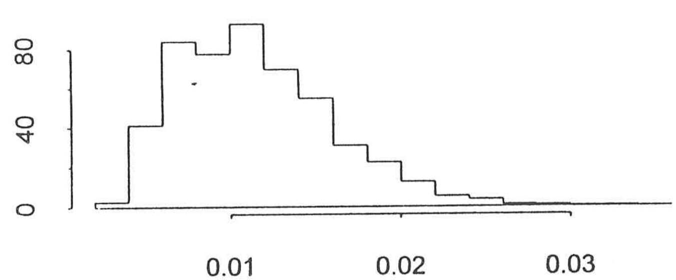


Zone 5
Zone 6
Zone 3
Zone 4
Zone 1
Zone 2
Legal
Sublegal
0.0
0.05
0.10
0.15
sqrt(Rate)

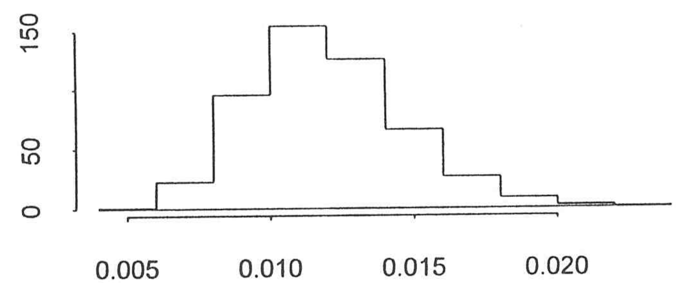
Figure 3

Bootstrap Estimates for Combined Data

Sublegals



Legals

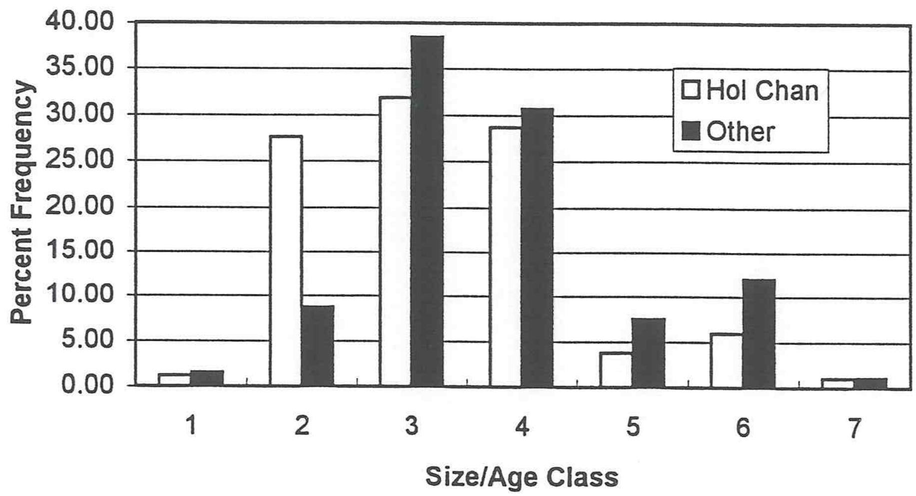


Sublegals	
Normal:	(486000,3860000)
Percentile:	(918000,4130000)
BCA:	(1140000,5630000)

Legals	
Normal:	(1290000,3230000)
Percentile:	(1430000,3360000)
BCA:	(1570000,3760000)

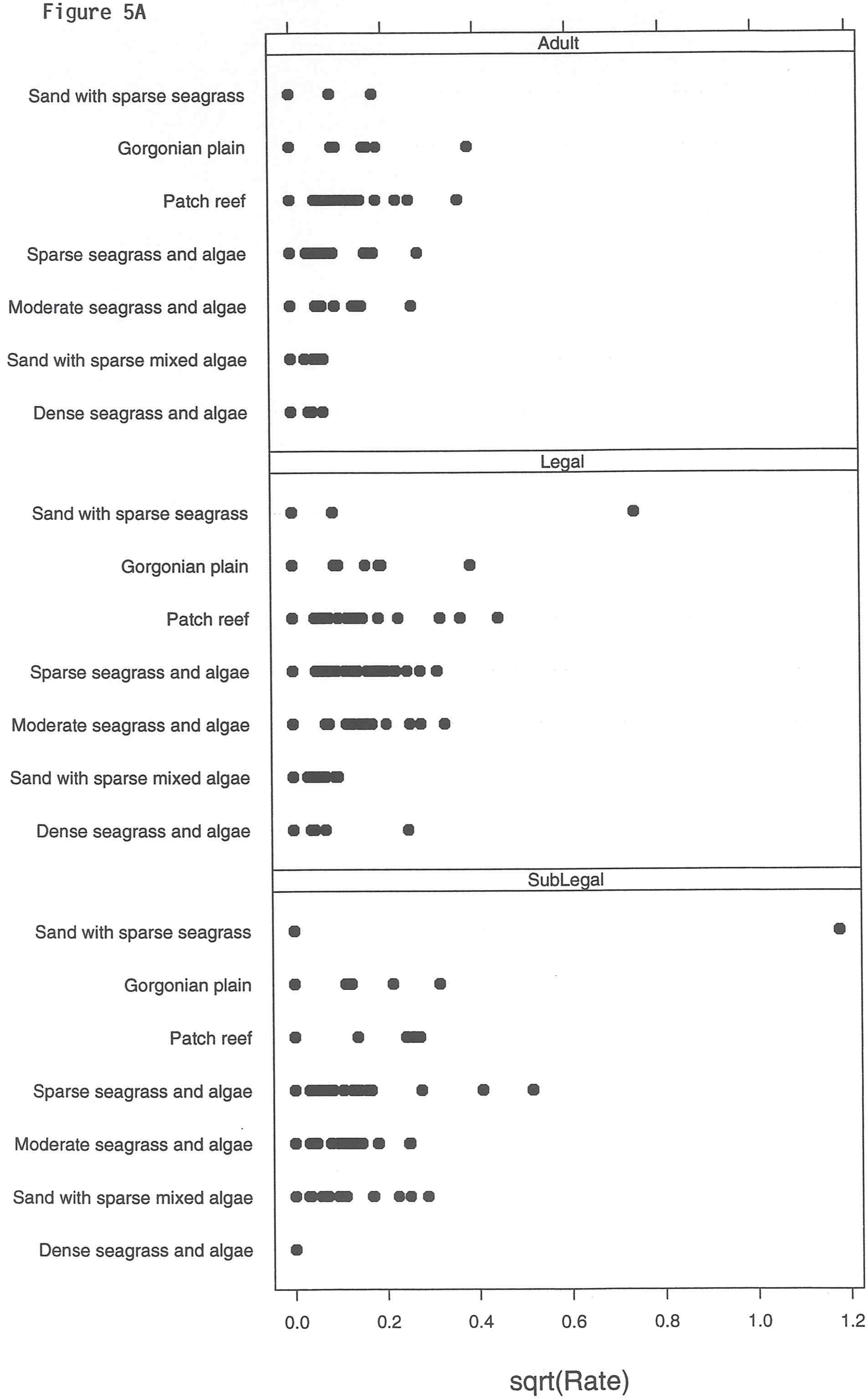
Based on 5000 Bootstrap Samples

Figure 4

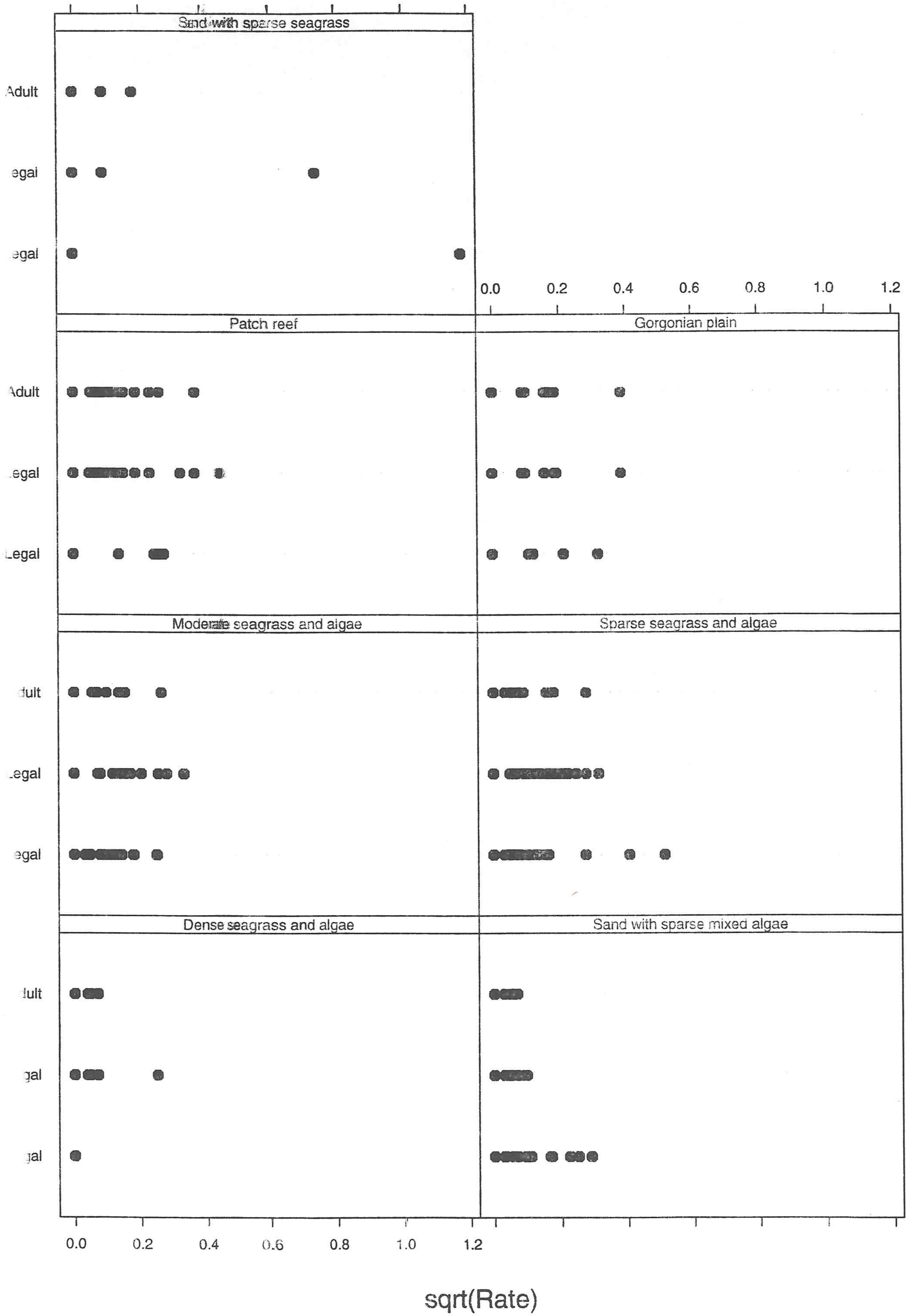


40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Percent Frequency
Hol Chan
Other
1
2
3
4
5
6
7
Size/Age Class

Figure 5A

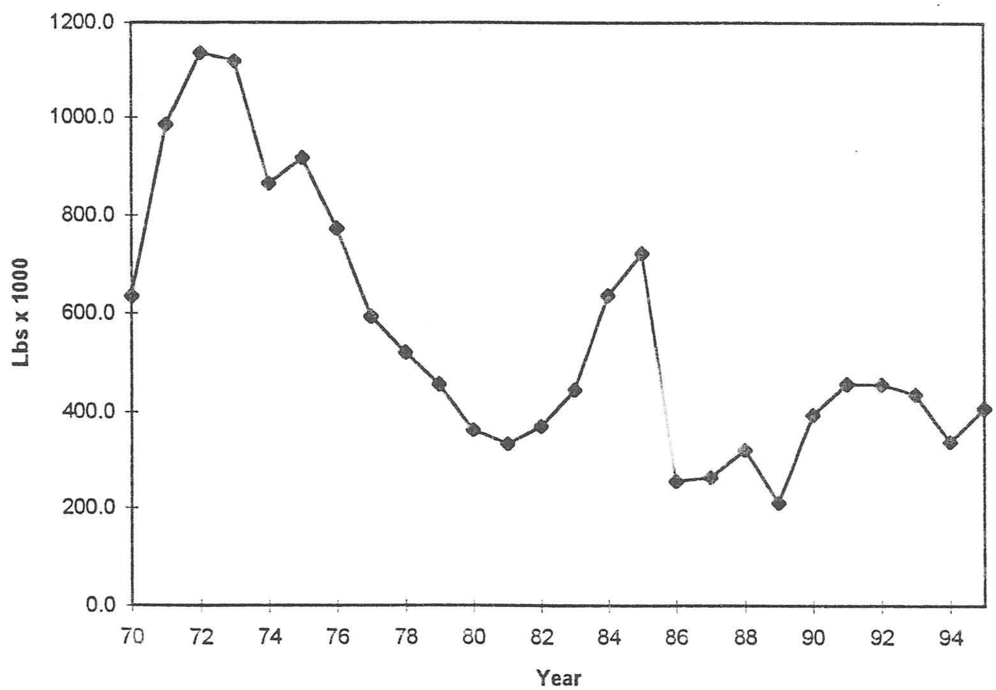

Adult
Legal
SubLegal
Sand with sparse seagrass
Gorgonian plain
Patch reef
Sparse seagrass and algae
Moderate seagrass and algae
Sand with sparse mixed algae
Dense seagrass and algae
0.0
0.2
0.4
0.6
0.8
1.0
1.2
sqrt(Rate)

Figure



Sand with sparse seagrass
Adult
egal
egal
0.0
0.2
0.4
0.6
0.8
1.0
1.2
Patch reef
Gorgonian plain
Adult
Legal
Legal
Moderate seagrass and algae
Sparse seagrass and algae
dult
Legal
egal
Dense seagrass and algae
Sand with sparse mixed algae
dult
gal
gal
sqrt(Rate)

Figure 6



1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Lbs x 1000
70
72
74
76
78
80
82
84
86
88
90
92
94
Year

Table 1. Areas contained within each Queen Conch sampling zone, plus estimates of density and abundance for legal-sized conch.

Zone	Location	Area (Ha)	Density (N/Ha)	Abundance
1	Turneffe Reef	18,997.7	15.03	285,590
2	Lighthouse Reef	21,522.6	2.97	63,954
3	Glovers Reef	20,161.4	6.64	133,836
4	Northern Barrier Reef	13,339.7	6.76	90,197
5	Central Barrier Reef	66,178.9	20.67	1,367,925
6	Southern Barrier Reef	11,140.7	15.78	175,748
	TOTAL	151,341.1		2,117,253
		Overall Average Density = 14.93		2,259,256

Table 2. Definitions of size/age classes of queen conch.

Juveniles

- J1 - Juveniles < 5 cm in shell length
- J2 - Juveniles between 5-10 cm in shell length
- J3 - Juveniles between 10-15 cm in shell length
- J4 - Juveniles > 15 cm in shell length

badults

Individuals with a flared shell lip beginning but not fully formed

dults

Individuals with a fully formed shell lip with minimal to moderate erosion

mba

Adults with heavy to serious shell erosion, thick worn lip, heavy epizootic fouling

Table 3. Habitat classification system for Belize marine environments. Habitats in bold were observed during the survey.

- Land
    - Mangrove
- Seagrass and Algae
    - **Sparse seagrass and algae (10-30% live cover)**
        - **Sparse seagrass with distinct coral heads**
    - **Moderate seagrass and algae (30-50% live cover)**
    - **Dense seagrass and algae (>50% live cover)**
        - Shallow (,).5) seagrass turf
- Reef
    - **Patch Reef**
        - **Distinct patch reef**
        - **Diffuse patch reef**
        - **Gorgonian plain**
    - **Sand and coral matrix**
- Mixed Community
    - Sparse mixed community (10-30% live cover)
    - Moderate mixed community (30-50% live cover)
    - Dense mixed community (>50% live cover)
- Bare Bottom
    - Mud
    - Sand
        - **Sandy shoals and sand bars**
        - Sand with patches of bedrock
        - **Sand with sparse mixed algae**
        - **Sand with seagrass**
        - **Sand with algae and gorgonians**
    - **Rubble**
    - Hard Bottom
        - Hard bottom with sand and sparse coral heads
        - **Hard bottom with mixed corals, sponges and algae**

Table 4. For each station, distance surveyed, abundance of queen conch by size/age class, total number of all and legal-size conch, area surveyed at each station, and density of legal-size conch. Legal conch include all individuals >15 cm in length. Data for Station 2 were not used to calculate mean density of Zone 4.

Station	Distance	J1	J2	J3	J4	Subadult	Adult	Samba	Total Conch	Total Legal	Area (Ha)	Density (N/Ha)
1	600	0	1	2	2	1	1	0	7	4	0.48	8.33
2	600	9	219	253	228	30	47	8	794	313	0.48	652.08
3	800	0	0	1	1	1	0	0	3	2	0.64	3.13
4	1200	1	1	0	0	0	2	0	4	2	0.96	2.08
5	1400	1	4	1	1	2	8	0	17	11	1.12	9.82
6	2400	0	2	3	0	0	5	0	10	5	1.92	2.60
7	1600	0	1	13	7	10	15	0	46	32	1.28	25.00
8	1600	0	0	0	0	0	0	0	0	0	1.28	0.00
9	2000	0	0	0	0	0	5	0	5	5	1.60	3.13
											Zone 4 Average =	6.76
10	1700	0	0	5	6	0	1	0	12	7	1.36	5.15
11	1100	20	1	32	24	2	3	0	82	29	0.88	32.95
12	1000	0	1	4	5	0	3	0	13	8	0.80	10.00
13	1000	0	0	0	0	0	0	0	0	0	0.80	0.00
14	378	0	0	0	1	4	1	0	6	6	0.30	19.84
15	200	0	2	0	2	1	1	0	6	4	0.16	25.00
16	500	0	1	3	1	0	0	0	5	1	0.40	2.50
17	800	0	2	2	0	1	5	1	11	7	0.64	10.94
18	1300	0	0	2	1	0	0	0	3	1	1.04	0.96
19	1200	0	1	3	8	10	49	15	86	82	0.96	85.42
20	2000	0	5	15	7	2	1	0	30	10	1.60	6.25
21	1246	0	1	6	4	0	0	0	11	4	1.00	4.01
22	1300	0	0	12	16	2	4	0	34	22	1.04	21.15
23	1400	0	2	3	6	1	2	0	14	9	1.12	8.04
24	1600	0	15	95	38	2	1	0	151	41	1.28	32.03
25	1400	0	5	22	21	4	4	0	56	29	1.12	25.89
26	1300	0	7	5	5	1	1	0	19	7	1.04	6.73
27	1000	0	24	197	109	1	0	0	331	110	0.80	137.50
28	1500	0	9	2	0	1	0	0	12	1	1.20	0.83
29	1500	0	2	21	7	1	2	0	33	10	1.20	8.33
30	2100	0	0	2	1	4	8	0	15	13	1.68	7.74
31	1800	0	2	3	2	0	3	0	10	5	1.44	3.47
											Zone 5 Average =	20.67
32	700	0	0	1	17	0	2	0	20	19	0.56	33.93
33	1300	0	0	0	1	0	0	0	1	1	1.04	0.96
34	700	0	2	8	8	6	3	0	27	17	0.56	30.36
35	2000	0	1	60	55	15	10	0	141	80	1.60	50.00
36	1200	0	0	0	2	1	3	0	6	6	0.96	6.25
37	1900	0	0	0	1	1	4	0	6	6	1.52	3.95
38	1300	0	3	3	5	0	1	0	12	6	1.04	5.77
39	1600	0	1	2	10	2	0	0	15	12	1.28	9.38
40	900	0	1	0	1	0	0	0	2	1	0.72	1.39
											Zone 6 Average =	15.78

Table 4 Continued.

Station	Distance	J1	J2	J3	J4	Subadult	Adult	Samba	Total Conch	Total Legal	Area (Ha)	Density (N/Ha)
41	2000	0	16	23	18	11	1	0	69	30	1.60	18.75
42	1500	0	1	1	0	1	2	0	5	3	1.20	2.50
43	1500	0	0	0	2	2	1	0	5	5	1.20	4.17
44	1100	0	2	2	1	0	0	0	5	1	0.88	1.14
											Zone 3 Average =	6.64
45	2000	0	0	1	5	2	10	0	18	17	1.60	10.63
46	2000	0	0	3	2	6	4	0	15	12	1.60	7.50
47	1900	0	0	0	22	1	0	0	23	23	1.52	15.13
48	2000	0	6	7	23	11	9	0	56	43	1.60	26.88
											Zone 1 Average =	15.03
49	1900	0	2	2	4	1	0	0	9	5	1.52	3.29
50	2000	0	4	2	2	0	2	0	10	4	1.60	2.50
51	2000	0	2	4	3	0	2	0	11	5	1.60	3.13
											Zone 2 Average =	2.97
											Total Average Density =	14.93

Table 5. Estimates of density and abundance of sublegal and legal-sized queen conch averaged over all stations. The 95% confidence limits were calculated from the bias-corrected and accelerated (BCA) estimates of 5,000 bootstrapped samples.

	Density (N/Ha)	95% Confidence Limit	Total Abundance	95% Confidence Limit	
Sublegal	14.37	7.53 - 37.20	2,175,000	1,140,000	5,630,000
Legal	14.93	10.37 - 24.84	2,259,000	1,570,000	3,760,000

Table 6. Area surveyed, number of queen conch observed and their percent values by habitat, and relative habitat preference. Legal conch include all individuals > 15 cm in length. Index of habitat preference is %Conch - %Area; positive values indicate greater than random occurrence, negative values indicate less than random occurrence.

HABITAT	Area (Ha)	Number of Conch			Percent				Index of Habitat Preference		
		Sublegal	Legal	Adults	Area	Sublegal	Legal	Adults	Sublegal	Legal	Adult
Sand & coral matrix	.04	0	0	0	0.08	0.00	0.00	0.00	-0.08	-0.08	-0.08
Hard bottom with mixed corals, sponges & algae	.12	0	0	0	0.22	0.00	0.00	0.00	-0.22	-0.22	-0.22
Sparse seagrass with distinct coral heads	.19	2	0	0	0.33	0.28	0.00	0.00	-0.06	-0.33	-0.33
Sand with algae & gorgonians	.25	4	3	0	0.44	0.55	0.39	0.00	0.11	-0.04	-0.44
Rubble	.67	5	8	1	1.19	0.69	1.05	0.56	-0.50	-0.14	-0.63
Sandy shoals & sand bars	.86	7	0	0	1.53	0.97	0.00	0.00	-0.56	-1.53	-1.53
Gorgonian plain	1.88	15	48	22	3.33	2.07	6.29	12.29	-1.26	2.97	8.97
Sand with sparse seagrass	2.06	44	22	4	3.64	6.07	2.88	2.23	2.43	-0.76	-1.41
Diffuse patch reef	3.08	4	19	13	5.45	0.55	2.49	7.26	-4.90	-2.96	1.81
Distinct patch reef	3.41	9	34	11	6.05	1.24	4.46	6.15	-4.80	-1.59	0.10
Dense seagrass & algae	3.69	11	18	3	6.53	1.52	2.36	1.68	-5.01	-4.17	-4.86
Sand with sparse mixed algae	10.96	76	59	11	19.41	10.48	7.73	6.15	-8.92	-11.67	-13.26
Moderate seagrass & algae	12.54	124	244	73	22.21	17.10	31.98	40.78	-5.11	9.77	18.57
Sparse seagrass & algae	16.76	424	308	41	29.69	58.48	40.37	22.91	28.80	10.68	-6.78
TOTAL	56.46	725	763	179							

Table 7. Area surveyed, number of queen conch observed and their percent values by habitat, and relative depth preference. Legal conch include all individuals > 15 cm in length. Index of depth preference is %Conch - %Area; positive values indicate greater than random occurrence, negative values indicate less than random occurrence.

DEPTH CLASS (Ft)	Area (Ha)	Number of Conch			Percent				Index of Depth Preference		
		Sublegal	Legal	Adults	Area	Sublegal	Legal	Adults	Sublegal	Legal	Adult
0 - 5	6.13	178	144	11	11.3	25.2	19.1	5.7	13.9	7.9	-5.6
6 - 10	17.84	153	153	30	32.8	21.6	20.3	15.5	-11.2	-12.5	-17.4
11 - 15	13.07	314	264	41	24.0	44.4	35.1	21.1	20.4	11.1	-2.9
16 - 20	11.09	42	140	88	20.4	5.9	18.6	45.4	-14.5	-1.8	25.0
21 - 25	2.52	10	35	17	4.6	1.4	4.7	8.8	-3.2	0.0	4.1
> 25	3.72	10	16	7	6.8	1.4	2.1	3.6	-5.4	-4.7	-3.2
TOTAL	54.37	707	752	194							