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ANTIGUA AND BARBUDA QUEEN CONCH ABUNDANCE SURVEY (1999)

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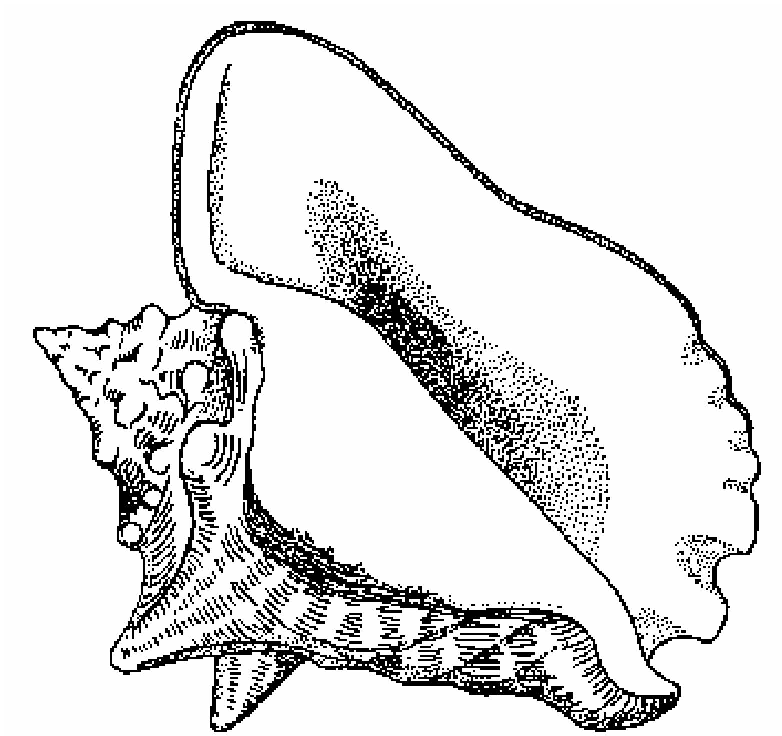

Kathy Orr

CARICOM FISHERIES UNIT, BELIZE CITY, BELIZE

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ANTIGUA AND BARBUDA QUEEN CONCH ABUNDANCE SURVEY (1999)

by:

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TABLE OF CONTENT

ABSTRACT

Queen conch (*Strombus gigas*) is the second most valuable (price per unit weight) species harvested by fishers in Antigua and Barbuda. A visual abundance survey was undertaken to assess the status of the exploited stocks. Belt transect methodology was employed with the assistance of underwater scooters. All conch found within a transect were placed into one of four size/age categories (juvenile, sub-adult, adults (young) and stoned (old adults)) using shell morphologies. Divers also recorded habitat/substrate types and depth at each site. Certain elements of the analysis required the use of data collected separately from the actual visual survey (mean annual fisheries yield, individual mean tissue weights, total exploitable biomass and natural mortality estimates). Descriptions of population structure used the distribution of the four size/age categories. Mean densities were calculated for all 34 sites sampled during the survey as well as for these same sites grouped by habitat/substrate types and depth strata. The bootstrap technique was used to calculate standard deviations and 95% confidence intervals for mean densities and abundance estimates. Total abundance and potential yield were estimated for the study area (23 543 ha) only. The study area was identified by the Fisheries Division as one of the main areas of commercial exploitation. Several methods, including empirical and area-based techniques, were used to calculate potential yield within the study area to provide some idea of the degree of uncertainty attached to any one yield estimate.

The overall density of conch in the study area was 17.2 conch/ha, 78.4% consisting of juveniles. Overall adult densities of 3.7 conch/ha indicate consistent fishing pressure. This level of density may result in decreased encounters between adult breeding partners, known as the “Allee effect”, which may subsequently decrease future recruitment. Abundance estimates over the study area were 404 238 with a 95% CI ranging from 131 629 (-67%) to 771 645 (+48%). Estimates of exploitable biomass (B), calculated as adult meat weight, were 32 metric tones within the study area. Reasonable estimates of potential yield for the study area ranged from –
9.3 MT to 17.9 MT.

A precautionary approach to management is proposed given the limited information on the stock. The present level of harvest (42-46 MT) and associated fishing effort is thought to be unsustainable within the study area (23 543 ha). It is recommended that a wide ranging visual survey be implemented immediately and every three years subsequently to assess and monitor the conch populations over the entire shelf area to a maximum depth of 35 metres. This must be done

in an effort to potentially reallocate fishing effort from heavily exploited areas described in this report. Further recommendations include potential modifications to size restrictions, implementation of possible closures, partial gear restrictions, total effort restrictions, mandatory reporting, details for future visual surveys, and the improvements to the collection of fisheries and biological data.

INTRODUCTION

Background

Queen conch (*Strombus gigas*) is considered the second most valuable species (price per unit weight), after spiny lobster, harvested by fishers in Antigua and Barbuda (O'marde 1996). During the early 1970's conch were gathered by free divers in the shallow waters surrounding both islands and the majority of this catch was flown to Puerto Rico (Brownell and Stevely 1981). Brownell and Stevely also report that by 1978 most harvesting of conch was being done by local divers using SCUBA, as shallow areas had been depleted, to satisfy local demand (meat price: US$1.10/kg, US$0.50/lbs) and small air shipments to Guadeloupe. Potential yield estimates for the stock, based on the entire area of the shelf (3568 km^2 to the 200 m contour), has been reported as 214 MT/year (FAO 1990). The most recent published value of the conch fishery landings is 69 metric tonnes (MT) accounting for approximately 9.8% (1994) of the total value of fisheries products in Antigua and Barbuda (OECS 1995). There are no reports of conch presently being exported from Antigua and Barbuda with the conch stock being harvested by a limited number of artisanal fishers based in southern villages of Antigua from Jennings to Old Road (O'marde 1996, pers. comm., Antigua & Barbuda Fisheries Division). These fishers dive from small boats using SCUBA down to depths between 24 and 33 m, supplying the needs of both the local and tourist sectors (Luckhurst and Auil-Marshalleck 1997, pers. comm., Antigua & Barbuda Fisheries Division). Fisheries regulations consist of a minimum shell (siphonal) length of 180 mm (7 inches) with a flared lip and a minimum tissue (including viscera) weight of 225 grams (8 oz). In recent years the concentration of fishing effort on the demersal resources of the coastal zones has resulted in overfishing and habitat destruction with increasing numbers of fishers in southern areas moving north (Royer 1997). CFRAMP and Antigua and Barbuda Fisheries initiated discussions of a conch visual abundance survey and associated methodology in May 1997. Antigua and Barbuda Fisheries Division, implemented the final survey with support from units of the National Coast Guard, in August 1999.

Purpose and Objectives

A visual abundance survey, in combination with other fisheries and biological data collection activities and subsequent data analysis, was been implemented to assess the status of the conch stocks and to ensure the sustainable management of these same stocks. The specific objectives of this report include:

1. Determination of conch densities, abundance and population structure in identified commercial conch fishing grounds and associated habitat types and depths zones.
2. Prediction of potential yield from identified commercial conch fishing grounds.
3. Formulation of management recommendations for identified commercial conch fishing grounds.
4. Formulation of management recommendations for the entire conch fishery where possible given the limitations of the survey.
5. Transfer of assessment techniques to the Antigua and Barbuda Fisheries Division, facilitated through a training workshop (completed May 2000), using the methods detailed in this report.

METHODOLOGY

Visual Survey: Field collections

The survey sites were confined within identified commercial conch fishing grounds off the South-western side of Antigua (Fig. 1). This area was divided into four sub-zones (A,B,C,D) for logistical purposes. A total of 34 sites were chosen randomly from within the four zones. Ten sites were designated to each of zones A, B and C with the final four sites being placed in area D. The start positions of survey sites were located using a global positioning system from the support vessel (Antigua and Barbuda Coast Guard). Once the support vessel was on site a team of two SCUBA divers with underwater scooters entered the water and moved down to the bottom. The support vessel followed surface buoys towed by the divers. A belt transect method was used by navigating the two underwater scooters parallel to each other and surveying a total width of four meters (two metres estimated by each diver). Total transect length was determined by multiplying time to complete a transect in minutes (varying due to air consumption as a result of depth) and the mean scooter speed. The mean scooter speed (50.313 m/min, SD = 16.96, n = 7) was determined during trials in 1998. The resulting transect length (X minutes * 50.313 m/min) was multiplied by the 4 metre width to give a total area surveyed per site.

All conch found within a transect were categorised into one of four groups using shell morphologies. These categories were juvenile (J, no shell lip), sub-adult (SA, flared lip forming but < 4 mm thick), young adult (A, fully formed lip, prominent spines, relatively smooth outer surface due to limited bioerosion) and old (stoned) adult (S, very thick lip, worn spines, rough outer surface due to moderate to heavy bioerosion). Divers also recorded habitat/substrate type and depth at each site. Habitat/substrate types included: sand plain (S, dominated by bare sand); sand/algal plain (S/A, fine mud to coarse sand dominated by green algae; Halimeda spp., Penicillus spp., Caulerpa spp., etc.); reef (R, variety of reef morphologies dominated by living colonies of stony corals; Acropora spp., Montastraea spp., Diploria spp.) and coral rubble (CR, dead, eroded and broken coral forming patches).

Fisheries and Biological Data

Certain elements of the analysis of survey data and subsequent yield estimates required the use of conch fishery and biological data collected separately from the actual visual survey. The importance of these elements will be made clear in subsequent sections of the methods but include: (1) mean annual landings (yield, Y); (2) mean individual tissue weights for adult and juvenile conch; (3) total exploitable biomass (B) and (4) natural mortality (M) estimates. The conch fishery mean annual commercial landings or yield (Y) was estimated from limited catch per unit effort (CPUE) data and total effort data collected by the Fisheries Division staff. CPUE figures were available for 1995 to 1999. The fishing effort for the commercial fleet was estimated as 144 days/year/boat times 5 boats/year for a total of 720 boat-days of effort per year (pers. comm, Fisheries Division, Antigua and Barbuda). The mean yield for the five years of data was then increased by 10% (liberal estimate) to reflect an unknown quantity of personal consumption and poaching (pers. comm, Fisheries Division, Antigua and Barbuda). This method was preferred over the use of the yield figure from the year of the survey (1999) due to the limited observations ($n = 3$).

The estimation of mean adult and juvenile tissue weights (including viscera) and total exploitable biomass (B) was facilitated by data included in a morphometric study by Horsford (1999). Finally, due to the range of natural mortality (M) rates that queen conch experience over the life history, from 2.12 (juveniles, Appeldoorn 1988a) to 0.433 (young adults, Rathier and Battaglya 1994), a mean natural mortality (Mmean) was estimated using a method presented by Appeldoorn (1999). The equation has the form: $M_{mean} = 4.330/(t2-t1) \ln (t2/t1) - 0.242$, where t is age in years.

Visual Survey: Density, Abundance and Yield Estimates

Density estimates for each site were made by converting numbers of conch observed/transect area to numbers of conch per hectare (ha, 10000 m^2). Estimates by site were required due to the variation (scooter time) in total area sampled per transect. These conversions were done for each size/age class and total conch. Mean densities were calculated for all 34 sites as well as for sites grouped by habitat/substrate types (S, S/A, R, CR) and depth strata (<18 m, > 18 m). This facilitated comparison of densities in other studies throughout the region. Descriptive statistics, including bootstraps, were completed using SYSTAT version 7.0.1 for Windows. The bootstrap technique (Efron and LePage 1992, Efron and Tibshirani 1993) is a powerful strategy for producing estimates of parameters, in this case standard deviations and 95% confidence intervals about the mean, in samples taken from unknown probability distributions. It is well known that conch densities do not follow a normal distribution and efforts to normalise often fail (Berg and Glazer 1995, Tewfik and Appeldoorn 1998, Appeldoorn et al. 1999). Descriptions of the population structure used the distribution of the four size/age categories.

Estimates of total abundance were calculated for the area of the identified commercial fishing grounds (23 543 ha) by multiplying mean density (conch/ha) for all size/age categories by the total area. The area of the identified commercial fishing grounds was determined from GPS co-ordinates and detailed bathymetry maps (Saint Barthelemy to Guadeloupe, Chart No. 2555050). Total exploitable biomass was calculated as the abundance of young adult (A) and old (stoned) adult (S) conch times the mean adult tissue weight (0.365 kg/conch). Several methods were used to estimate the potential or maximum sustainable yield (MSY) of the conch fishery over the identified commercial fishing grounds (23 543 ha). The use of several methods, including empirical and area-based techniques, provides some idea of the degree of uncertainty attached to any one MSY estimate.

A) Empirical Yield Estimates:

All empirical estimates were limited by the assumptions that all yields came from the identified fishing grounds.

1. Cadima's (in Troadec 1977) method was designed for exploited fisheries (level of exploitation undefined) when catch and effort time series are unavailable. It uses the equation: **MSY = X (Y + M B)**, where X is a constant, Y is the mean total catch (yield), M is the natural mortality and B is the exploitable biomass. An X value of 0.3 was found to be most useful for conch based on work by Kirkwood et al. (1994).
2. Garcia et al. (1989) developed estimates of yield based on the surplus production (biomass dynamic) models of Schaefer (1954) and Fox (1970) when catch and effort time series data are not available but estimates of Y, M and B are available. Both these

estimates assumed that fishing mortality (F) and natural mortality (M) are equal at MSY.

a) Schaefer model: **MSY = $(BM)^2/(2MB-Y)$**, where Y is the mean total catch (yield), M is the natural mortality and B is the exploitable biomass.

b) Fox model: **MSY = MB $e^{((Y/MB)-1)}$**, parameters are as stated for the Schaefer model with e = base of the natural logarithm (2.718).

B) Area-based Yield Estimates:

1. Next fully recruited year class: This estimate uses the concept that ongoing productivity of the stock is provided by the recruitment of juveniles into the exploitable (adult) portion of the population on an annual basis. In this case the next year class to enter the fishery is a combination of large juveniles and sub-adults (SA). The abundance of large juveniles and sub-adults over the identified fishing grounds is multiplied by the mean tissue weight of juveniles and sub-adults to give an estimate of production. Although natural mortality of the incoming year class was not incorporated into the abundance value used (see method 3) this should be compensated for by the use of a large juvenile/sub-adult meat weight (0.22 kg/conch). Given that the visual survey did not differentiate between sizes of juveniles 10% of all juveniles were estimated to be large by using data from Pedro Bank, Jamaica (Tewfik 1996, Tewfik and Appeldoorn 1998).
2. FAO Extrapolation: An FAO (1990) document proposed a potential yield of conch on the Antigua & Barbuda shelf of 214 MT based on **0.06 MT/km^2**. This formula was used to calculate yield for the area of the identified fishing grounds (23 543 ha) only.
3. Next fully recruited year class grow-out: This estimate again uses the concept that ongoing productivity of the stock is provided by the recruitment of juveniles into the exploitable (adult) portion of the population on an annual basis. However, In this case the next year class to enter the fishery (large juveniles and sub-adults) is grown out (incorporation of natural mortality) to adults. This is done using the exponential decay formula, **$N2 = N1\ e^{(-M(t1-t2))}$**, where N2 = population at t2, N1 = population at t1, e = base of the natural logarithm (2.718), M = natural mortality, t1 – t2 = 1 year. Due to natural mortality the abundance of large juveniles plus sub-adult year class is reduced over one year and then multiplied by the adult tissue weight of 0.365 kg. Again, given that the visual survey did not differentiate between sizes of juveniles 10% of all juveniles were estimated to be large using data from Pedro Bank, Jamaica (Tewfik 1996, Tewfik and Appeldoorn 1998).

RESULTS & DISCUSSION

Fisheries and Biological Data

The mean annual landings or yield (Y) were estimated to be 42.0 MT over the last five fishing seasons (1995-1999) (Table 1). An additional 10% was used to estimate landings for personal consumption and poaching (per comm., Antigua & Barbuda Fisheries Div.) resulting in a final yield of 46.2 MT. This is substantially lower than the 69 MT reported in OECS (1995). The stable CPUE data (Table 1) over the last five years may indicate a catch reduction due to falling market demand through the closing of exports (perhaps related to the impact of CITES regulations). However, the incomplete nature of the available data (Table 1) on catch and effort, especially over the last few years, demand caution with decreased landings possibly representing a real decrease in abundance of the stock. Finally, even very complete CPUE data can be a poor index of stock abundance due to poor estimates of fishing effort, changing catchability, and non-random distribution of fishing effort over space and time (Hilborn and Walters 1992, Arreguin-Sanchez 1996, Keesing and Baker 1997). The most reliable condition of conch stock abundance may be obtained through well designed and implemented visual surveys as best illustrated for other benthic invertebrates stocks (Hart and Gorfine 1997, Prince and Hilborn 1998, Orensanz and Jamieson 1998).

Mean adult tissue weight was 0.365 kg (N = 60, SD = 0.71) and mean large juvenile and SA tissue weight was 0.220 kg (N = 51, SD = 0.85). Mean natural mortality (Mmean) was calculated for two age ranges. The age range of 4 to 10 years old was used for the exploitable portion of the stock (adults) where younger adults predominate. The resulting natural mortality was 0.42. This seems reasonable when compared to the 0.3 used for Pedro Bank, Jamaica (Tewfik 1996, Tewfik and Appeldoorn 1998) dominated by old stone conch and 0.6 used for Belize (Appeldoorn et al. 1998) where juvenile conch dominates the catch. A second age range of 3 to 4 year olds was used for the grow-out of large juveniles and sub-adults in the exponential decay formula (see yield estimates). The mean natural mortality in this case was 1.0037. This value seems more appropriate for the Belize fishery (Appeldoorn et al. 1998) than M=0.6 especially when one considers the authors statement that “there are few adults present in the fished area”.

Visual Survey: Density, Abundance and Yield Estimates

The total area surveyed was 12.84 hectares over the identified fishing grounds of 23 543 ha. The overall density of conch over the survey area was 17.2 conch/ha (Table 2) with juveniles (J and SA) making up 78.4% of the observed population (Figure 2). Overall adult densities of 3.7

conch/ha are extremely low. Such low adult densities may be expected in a historically and currently heavily fished area and is also highly dependent on habitat type and water depth. However, such low densities may indicate a depression in the potential chance of adult conch encountering breeding partners generally referred to as the “Allee effect”. This effect results in a decrease in reproduction below that required to support the population, which may lead to local extinctions (Allee 1931). Noticeable declines in reproductive activity have been observed in conch populations when densities have fallen below 50 adult conch/ha (Stoner 1997).

Density (Table 3) and population structure (Figure 3) by habitat indicate that total conch populations are equally high in sand/algal plain (25.4 conch/ha) and coral rubble (26.1 conch/ha) with very low densities in sand plains (3.4 conch/ha) and reef (0.0 conch/ha). This is consistent with other studies, which indicate the importance of algae-covered substrates, including algal plain and coral rubble habitats, to conch feeding (Alcolado 1976, Stoner and Waite 1990, Stoner and Sandt 1992, Friedlander et al. 1995, Tewfik 1996, Tewfik and Appeldoorn 1998). It should be noted that even in preferred algae-covered substrates (S/A and CR) adult densities did not exceed 5.8 conch/ha. The oldest conch (S, stoned) were only observed in sand/algal plain (3.5 conch/ha).

Depth of surveyed sites ranged from 9.1 to 30.5 metres and were divided into two depth strata (< 18 m, > 18 m). Density (Table 4) and population structure (Fig. 4) revealed higher overall densities in sites less than 18 m in depth (20.1 conch/ha) due to higher densities of juveniles (J + SA, 16.9 conch/ha). Adults were densest within sites deeper than 18 m (4.6 conch/ha) with total densities of 13.3 conch/ha. The oldest conch (S, stoned) were densest in the deeper strata (>18 m) at 2.4 conch/ha (Table 4). This is again consistent with what is generally known about conch distributions with total densities decreasing with depth but adult densities being higher in deeper water (15-25 m) (Torres-Rosando 1987, Friedlander et al. 1994, Stoner and Schwarte 1994). Buckland (1989) observed in St. Kitts that only conch with thick, heavy shells and capable of breeding (older individuals with high percentages of gametogenic tissue) were found in waters exceeding 25 m in depth. Therefore the importance of the deep-water populations should not be overlooked and have been discussed in the literature (Stoner and Sandt 1992, Appeldoorn 1997, Stoner 1997). Such deep-water populations can potentially serve as “depth refugia” to: (1) maintain overall stock density; (2) maintain spawning stocks; (3) maintain genetic structure and (4) provide insurance against management failure (Appeldoorn 1997). However, the potential benefits of such “depth refugia” may be lost if heavy fishing pressure is exerted to depths below 25 m over the entire shelf with the use of SCUBA gear.

Abundance estimates for conch over the study area were 404 238 with a 95% confidence interval ranging from 131 629 (-67%) to 771 645 (+48%) (Table 5). It should be noted that all abundance estimates were made from limited data collected in a heavily fished area of the Southern shelf. There is a great need to expand the area of future surveys to encompass all areas of the shelf where conch populations may exist to provide a true picture of abundance and potential yield. Confidence intervals are high due to the spatial heterogeneity of conch distributions as well as the limited number of sites that were surveyed. Estimates of exploitable biomass (B) in adult meat weight (A + S) were 32 MT for the study area (Table 5). Estimates of total abundance and exploitable biomass in various habitat/substrate types and depth zones could not be made due to the lack of information on the area of these categories. The importance of habitat/substrate types and depth to conch distributions should be clear (Table 3,4, Fig. 3,4) and such information is required to fine tune total abundance and potential yield estimates whenever possible.

Estimates of potential yield for study area (23 543 ha) ranged widely (Table 6). The empirical formulas by Cadima (in Troadec 1977) and Garcia et al. (1989) (Schaefer, Fox) yielded highly variable results with 17.9, -9.45, 153.8 (unreasonable) MT respectively. It should be noted that Cadima's model performs reasonably well between fishing levels of zero and FMSY (fishing mortality at MSY) but performs poorly at fishing levels beyond (Garcia et al. 1989). It is speculated that present fishing levels in the study area are considerably higher than FMSY. It should also be noted that the Schaefer and Fox estimates by Garcia et al. (1989) depend on the assumption that F (fishing mortality) approximates M (natural mortality). Departures from this assumption will lead to serious errors in estimates of yield. Again it is speculated that fishing levels in the study area do not satisfy the assumption F=M with fishing levels thought to be much higher. At this point not much credence may be attached to empirical estimates of potential yield.

The FAO (1990) generic yield equation (0.06 MT/km^2), based on cited references Appeldoorn (1988) and FAO (1990), gives a potential yield of 14.1 MT. It is difficult to comment any further on this value due to difficulties in obtaining any information on how this generic yield equation was formulated. Finally, the area-based estimates of future production (next fully recruited year class, grow-out of that same year class) yielded the mean estimates of 8.67 and 5.27 MT. Although these estimates are based on limited samples of tissue weight (N=51,Horsford 1999) and abundance values associated with large confidence intervals (+48%, -67%) they may be the most realistic and precautionary estimates available. These estimates are quite conservative given that they only consider new biomass and therefore recent recruitment coming into the identified fishing grounds. Other estimates that use the present level of exploitable biomass (adult and stoned conch) reflect the productivity and recruitment environment of 4 to 10 years ago.

CONCLUSIONS & RECOMMENDATIONS

It must again be clearly stated that all empirical estimates of sustainable yield of the conch stock in this study area use some combination of estimates of yield (Y), natural mortality (M) and exploitable biomass (B) that have unknown levels of error associated with them. In addition all estimates of abundance have been extrapolated from a limited number of sites (N=34) over a very small surveyed area (12.84 ha) and have very large confidence levels associated with them (+48%, -67%). A high degree of caution should be used when applying the results to the management of the fishery. The present overall densities of adults (3.7 conch/ha) are well below 50 conch/ha where noticeable decreases in reproduction occur due to decreases in effective reproductive encounters (Stoner 1997). This effect may significantly contribute to a reduction in local recruitment and future fisheries production.

Recommendations for management

1) Size Restrictions

Current regulations of a minimum shell (siphonal) length of 180 mm with a flared lip and a minimum meat weight of 225 g do not limit exploitation to sexually mature individuals with as much as 23% of the catch containing immature individuals (Horsford 1999). The use of a well developed shell lip (thickness >5mm), a feature linked to sexual maturity in conch (Appeldoorn 1988b, Buckland 1989), would be a useful regulation easily identified by divers at sea. The effectiveness of a lip thickness regulation has been previously supported by Appeldoorn (1994) and Tewfik (1996). A fixed lip caliper may be easily designed and distributed to all active divers. This lip regulation would restrict harvest to only sexually mature adult conch and protect juveniles and sub-adults regardless of shell length or meat weight. In the event that conch are removed from the shell at sea, compliance with the harvest of only mature individuals could be enforced by the identification of reproductive organs, mature verge (males) or vaginal groove (females), on the conch meat.

2) Closures

The Fisheries Division may want to consider the temporary closing of historic fishing grounds (study area) on parts of the Southern shelf to facilitate quick recovery of these areas. This would benefit fishers who may be unable or unwilling to relocate their fishing efforts. This will also preserve the future potential of historic grounds in the event that future surveys do not locate suitable (productive) fishing grounds on other parts of the shelf. The use of a closed season would help protect the reproductive portion of the stock during peak breeding periods (April-Sept). The use of marine reserves or protected areas could create pockets of high density and larval production that may eventually disperse out ("spill-over effect" and "recruitment effect") to fished areas (Rowley 1994, Roberts 1997, Stoner 1997, Chiappone and Sullivan-Sealey 2000). The mobile nature of the stock would suit this plan and fishers' awareness of this mobility should aid in self-compliance. Ideally these protected areas would have a complete ban on fishing making enforcement simpler as well as allowing other living aquatic resources to benefit from protection. Areas in proximity to the shore seem the most logical for the primary establishment of such protected areas. Marine reserves are necessary components of management as they offer protection not offered by other management options (Bohnsack 1993, Roberts and Polunin 1993, Rowley 1994, Crowder et al. 2000; Nowlis 2000). These include (but are not limited to) preserving spawning stock and spawning density providing insurance against failure of other management measures, providing control areas against which effects of fishing may be gauged, and conserving biological (especially genetic) diversity.

3) Gear Restrictions

Due to the preferred use of SCUBA by fishers and the depletion of shallow water areas the banning of SCUBA gear can not be advocated as this would virtually eliminate the commercial harvest of the stock. Such a ban may however be effective in shallow areas (<10 m) in proximity to the shore where free divers may presently be out competed by SCUBA assisted divers. The preservation of shallow stocks and a traditional fishing method would be a positive result.

4) Total Effort Restrictions

The present level of fishing effort must not be applied exclusively to the identified commercial fishing areas (historic, study area). A recovery of the historic fishing grounds (study area) is quite possible given the proximity of what may be virgin conch populations to the north. However, any reallocation of fishing effort to new areas of the shelf must be proceeded by adequate habitat and population surveys.

5) Reporting and Inspections

The mandatory reporting of catch, effort, and areas fished by all commercial conch vessels is paramount to management of the stock and such information should be made available to the Fisheries Division upon request. These catches should be subject to random inspection.

6) Future Visual Surveys

A new visual survey should be carried out immediately, and every three years following, over as wide an area as possible so as to understand the full extent of the Antigua and Barbuda conch stock and its potential yield. Surveys may be limited to less than 35 m in depth, which is the reasonable limit for commercial conch harvest. Surveys should include historic fishing grounds (study area), juvenile nursery and adult spawning grounds and depth refugia as well as areas previously unexplored. All surveys should be randomly stratified by depth and habitat to best allocate sampling resources. Habitat/substrate type and depth data are critical factors affecting conch distributions and such information is required to fine tune total abundance and potential yield estimates whenever possible. Habitat/substrate type and depth data must be collected at all sites regardless of conch presence/absence. The use of underwater scooters should be continued only if reasonably accurate calculations of area surveyed can be made otherwise scooters should only be used for gross pre-survey habitat and population work. The single juvenile category used in the last survey must be expanded to include three size/age categories (3 cohorts: small, medium, large) that have been used in other conch visual surveys (Tewfik 1996, Tewfik et al. 1998, Tewfik and Appeldoorn 1998, Appeldoorn et al. 1998, Tewfik and Bene 1999). This will facilitate better predictions of future recruitment to the fishery.

7) Fisheries Data

Data collections must be continued and refined to provide accurate catch and effort (see 5) for estimates of yield in data limited models (Garcia et al. 1989) as well as the use of biomass dynamic models, including Schaefer (1954) and Fox (1970), that require long time series of catch and effort. The refinement of effort data is critical in reducing error within various fisheries models. For example, if fishers land various marine products in a single trip, then the effort measurement should be limited to that directed at conch only. Other forms of fisheries data may include details on spatial and temporal access to the overall fishing grounds by the fishing fleet (see 5). The importance of spatially explicit approaches to assessment should be emphasized in small-scale benthic invertebrate fisheries (Hart and Gorfine 1997, Keesing and Baker 1998, Orensanz and Jamieson 1998). Such information may allow warnings of overexploitation even though CPUE seems to remain stable. The lack of detail in effort data may hide the fact that fishermen must travel to more remote parts of the fishing grounds and spend more time there to maintain catches. Historical information on catch, effort and areas fished as well as poaching should not be ignored.

8) Biological data

Biological data collections should also be continued and refined. This should include the measurement of tissue weights at the landing, wholesale, and retail sites. This will facilitate the monitoring of mean harvested size (grams), maturity (external sex organs: verge & vaginal groove) and sex ratio. A limited tagging study may be used in determining growth and mortality rates as individual conch may be monitored over many years. Accurate growth and mortality data could be used in various analytical and empirical models in future. A protected or closed area would be well suited to such a study.

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Table 1: Mean annual catch/trip (kg) and yield (MT) for the Antigua and Barbuda commercial conch fishery (1995 - 1999)
* based on 5 full-time vessels operating 144 days /year

Year	Number of Trips	Mean Catch/trip (kg)	SD	Estimated Yield (MT)*
1995	86	63.3	28.2	45.6
1996	46	53.8	31.8	38.8
1997	11	48.7	14.1	35.0
1998	22	62.0	20.9	44.7
1999	3	63.8	n/a	46.0
mean		58.3		42.0
SD		6.7		4.9
CI		5.9		4.3

Table 2: Mean density of conch/hectare occurring in all sites, Antigua and Barbuda, August 1999.
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult
Habitat/substrate categories: S/A = sand/algal plain, CR = coral rubble, S = sand plain, R = reef

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A0	17002'N 62057'W	0.0	0.0	0.0	0.0	0.0	16.8	S/A
A1	17002'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
A2	n/a	0.0	0.0	0.0	0.0	0.0	19.8	R
A3	17000'N 61057'W	7.5	0.0	5.0	0.0	12.4	25.6	CR
A4	17000'N 61056'W	39.8	0.0	0.0	0.0	39.8	15.5	S/A
A5	17001'N 61058'W	0.0	0.0	0.0	0.0	0.0	24.4	n/a
A6	17000'N 61056'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
A7	17003'N 61058'W	7.5	0.0	0.0	0.0	7.5	24.4	S
A8	17001'N 61059'W	7.1	0.0	0.0	0.0	7.1	15.2	S/A
A9	17003'N 61057'W	0.0	0.0	2.5	0.0	2.5	17.7	S
B0	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	19.8	CR
B1	17007'N 61058'W	5.0	0.0	0.0	0.0	5.0	18.3	S/A
B2	17005'N 61058'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
B3	17006'N 61059'W	7.5	5.0	5.0	0.0	17.4	17.8	S/A
B4	17006'N 61000'W	0.0	0.0	0.0	0.0	0.0	21.3	CR
B5	17004'N 61057'W	109.3	5.0	29.8	0.0	144.1	18.3	CR
B6	17005'N 61056'W	0.0	0.0	2.5	0.0	2.5	9.1	S/A
B7	17005'N 61059'W	0.0	0.0	0.0	0.0	0.0	15.2	CR
B8	17006'N 62001'W	3.3	0.0	0.0	0.0	3.3	25.9	S/A
B9	17005'N 62000'W	0.0	0.0	0.0	24.8	24.8	30.5	S/A
C0	17007'N 61056'W	0.0	0.0	0.0	0.0	0.0	15.2	n/a
C1	17006'N 61056'W	0.0	0.0	0.0	0.0	0.0	13.7	n/a
C2	17007'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
C3	17007'N 61055'W	191.1	0.0	15.3	15.3	221.7	12.2	S/A
C4	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	S
C5	17007'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	CR
C6	17007'N 61055'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
C7	17007'N 61055'W	2.5	0.0	2.5	2.5	7.5	12.2	S/A
C8	17007'N 61055'W	24.8	2.5	0.0	0.0	27.3	15.8	S/A
C9	17007'N 61058'W	2.5	0.0	0.0	0.0	2.5	18.3	S
D0	17013'N 61058'W	0.0	0.0	0.0	13.3	13.3	25.0	S/A
D1	"	0.0	0.0	2.5	0.0	2.5	11.6	S
D2	"	0.0	0.0	5.5	0.0	5.5	12.8	S
D3	"	29.8	0.0	0.0	0.0	29.8	n/a	S/A
	mean	13.09	0.37	2.07	1.64	17.17	17.92	
	95% CI Lower	2.997	0.000	0.662	0.074	5.591		
	95% CI Upper	27.106	0.809	4.041	3.685	32.776		

Table 3: Mean density of conch/hectare occurring in various habitats, Antigua and Barbuda, August 1999
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult
Habitat/substrate categories: S/A = sand/algal plain, CR = coral rubble, S = sand plain, R = reef

a) Sand/Algae

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A0	17002'N 62057'W	0.0	0.0	0.0	0.0	0.0	16.8	S/A
A1	17002'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
A4	17000'N 61056'W	39.8	0.0	0.0	0.0	39.8	15.5	S/A
A8	17001'N 61059'W	7.1	0.0	0.0	0.0	7.1	15.2	S/A
B1	17007'N 61058'W	5.0	0.0	0.0	0.0	5.0	18.3	S/A
B3	17006'N 61059'W	7.5	5.0	5.0	0.0	17.4	17.8	S/A
B6	17005'N 61056'W	0.0	0.0	2.5	0.0	2.5	9.1	S/A
B8	17006'N 62001'W	3.3	0.0	0.0	0.0	3.3	25.9	S/A
B9	17005'N 62000'W	0.0	0.0	0.0	24.8	24.8	30.5	S/A
C2	17007'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
C3	17007'N 61055'W	191.1	0.0	15.3	15.3	221.7	12.2	S/A
C6	17007'N 61055'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
C7	17007'N 61055'W	2.5	0.0	2.5	2.5	7.5	12.2	S/A
C8	17007'N 61055'W	24.8	2.5	0.0	0.0	27.3	15.8	S/A
D0	17013'N 61058'W	0.0	0.0	0.0	13.3	13.3	25.0	S/A
D3	"	29.8	0.0	0.0	0.0	29.8	n/a	S/A
	mean	19.89	0.47	1.58	3.49	25.43	17.34	
	95% CI Lower	6.98	0.07	0.52	1.25	10.79		
	95% CI Upper	35.57	0.96	2.90	5.81	43.87		

b) Coral Rubble

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A3	17000'N 61057'W	7.5	0.0	5.0	0.0	12.4	25.6	CR
B0	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	19.8	CR
B4	17006'N 61000'W	0.0	0.0	0.0	0.0	0.0	21.3	CR
B5	17004'N 61057'W	109.3	5.0	29.8	0.0	144.1	18.3	CR
B7	17005'N 61059'W	0.0	0.0	0.0	0.0	0.0	15.2	CR
C5	17007'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	CR
	mean	19.46	0.83	5.80	0.00	26.09	19.8	
	95% CI Lower	7.53	0.29	2.64	0.00	10.30		
	95% CI Upper	30.48	1.47	9.07	0.00	44.21		

c) Sand

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A7	17003'N 61058'W	7.5	0.0	0.0	0.0	7.5	24.4	S
A9	17003'N 61057'W	0.0	0.0	2.5	0.0	2.5	17.7	S
C4	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	S
C9	17007'N 61058'W	2.5	0.0	0.0	0.0	2.5	18.3	S
D1	17013'N 61058'W	0.0	0.0	2.5	0.0	2.5	11.6	S
D2	"	0.0	0.0	5.5	0.0	5.5	12.8	S
	mean	1.66	0.00	1.75	0.00	3.40	17.2	
	95% CI Lower	0.88	0.00	1.13	0.00	2.63		
	95% CI Upper	2.50	0.00	2.38	0.00	4.25		

Table 3 (Continued): Mean density of conch/hectare occurring in various habitats, Antigua and Barbuda, August 1999
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult
Habitat/substrate categories: S/A = sand/algal plain, CR = coral rubble, S = sand plain, R = reef

d) Reef

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A2	n/a	0	0	0	0	0	19.8	R

e) Unknown

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A5	17001'N 61058'W	0.0	0.0	0.0	0.0	0.0	24.4	n/a
A6	17000'N 61056'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
B2	17005'N 61058'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
C0	17007'N 61056'W	0.0	0.0	0.0	0.0	0.0	15.2	n/a
C1	17006'N 61056'W	0.0	0.0	0.0	0.0	0.0	13.7	n/a
	mean	0.0	0.0	0.0	0.0	0.0	18.0	
	95% CI Lower	0.0	0.0	0.0	0.0	0.0		
	95% CI Upper	0.0	0.0	0.0	0.0	0.0		

Table 4: Mean density of conch/hectare occurring at various depths, Antigua and Barbuda, August 1999
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult
Habitat/substrate categories: S/A = sand/algal plain, CR = coral rubble, S = sand plain, R = reef

a) < 18 m

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A0	17002'N 62057'W	0.0	0.0	0.0	0.0	0.0	16.8	S/A
A1	17002'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
A4	17000'N 61056'W	39.8	0.0	0.0	0.0	39.8	15.5	S/A
A8	17001'N 61059'W	7.1	0.0	0.0	0.0	7.1	15.2	S/A
A9	17003'N 61057'W	0.0	0.0	2.5	0.0	2.5	17.7	S
B3	17006'N 61059'W	7.5	5.0	5.0	0.0	17.4	17.8	S/A
B6	17005'N 61056'W	0.0	0.0	2.5	0.0	2.5	9.1	S/A
B7	17005'N 61059'W	0.0	0.0	0.0	0.0	0.0	15.2	CR
C0	17007'N 61056'W	0.0	0.0	0.0	0.0	0.0	15.2	n/a
C1	17006'N 61056'W	0.0	0.0	0.0	0.0	0.0	13.7	n/a
C2	17007'N 61056'W	2.5	0.0	0.0	0.0	2.5	15.2	SA
C3	17007'N 61055'W	191.1	0.0	15.3	15.3	221.7	12.2	SA
C6	17007'N 61055'W	2.5	0.0	0.0	0.0	2.5	15.2	S/A
C7	17007'N 61055'W	2.5	0.0	2.5	2.5	7.5	12.2	SA
C8	17007'N 61055'W	24.8	2.5	0.0	0.0	27.3	15.8	SA
D1	17013'N 61058'W	0.0	0.0	2.5	0.0	2.5	11.6	S
D2	"	0.0	0.0	5.5	0.0	5.5	12.8	S
	mean	16.48	0.44	2.10	1.05	20.07	14.51	
	95% CI Lower	3.72	0.07	1.04	0.07	5.84		
	95% CI Upper	32.12	0.88	3.53	2.40	38.37		

b) > 18 m

Site	Location	J	SA	A	S	TOTAL	Depth (m)	Habitat
A2	n/a	0.0	0.0	0.0	0.0	0.0	19.8	R
A3	17000'N 61057'W	7.5	0.0	5.0	0.0	12.4	25.6	CR
A5	17001'N 61058'W	0.0	0.0	0.0	0.0	0.0	24.4	n/a
A6	17000'N 61056'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
A7	17003'N 61058'W	7.5	0.0	0.0	0.0	7.5	24.4	S
B0	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	19.8	CR
B1	17007'N 61058'W	5.0	0.0	0.0	0.0	5.0	18.3	S/A
B2	17005'N 61058'W	0.0	0.0	0.0	0.0	0.0	18.3	n/a
B4	17006'N 61000'W	0.0	0.0	0.0	0.0	0.0	21.3	CR
B5	17004'N 61057'W	109.3	5.0	29.8	0.0	144.1	18.3	CR
B8	17006'N 62001'W	3.3	0.0	0.0	0.0	3.3	25.9	S/A
B9	17005'N 62000'W	0.0	0.0	0.0	24.8	24.8	30.5	S/A
C4	17006'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	S
C5	17007'N 61057'W	0.0	0.0	0.0	0.0	0.0	18.3	CR
C9	17007'N 61058'W	2.5	0.0	0.0	0.0	2.5	18.3	S
D0	17013'N 61058'W	0.0	0.0	0.0	13.3	13.3	25.0	SA
	mean	8.44	0.31	2.17	2.38	13.30	21.55	
	95% CI Upper	1.42	0.00	0.15	0.39	3.66		
	95% CI Lower	17.71	0.74	4.68	4.82	25.55		

Table 5: Abundance and exploitable biomass estimates of conch over the survey area during Aug. 1999 based on density and individual adult tissue weight estimates (#)
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult

	Area	Size/Age Category					Biomass,
	(Ha)	J	SA	A	S	TOTAL	Exploitable (MT)
Mean (Table 2)	1	13.09	0.37	2.07	1.64	17.17	
95% CI Upper	1	27.106	0.809	4.041	3.685	32.776	
95% CI Lower	1	2.997	0.000	0.662	0.074	5.591	
Total Area*	23543	308135	8602	48816	38685	404238	31.9
95% CI Upper	23543	638157	19046	95137	86756	771645	66.4
95% CI Lower	23543	70558	0	15585	1742	131629	6.3
***Total Area =**	**A+B+C+D=**10751+9497+3295+N/A						

Mean tissue weight (with viscera) of Adults = 0.365 kg (Horsford 1999)

Table 6: Estimates of potential yield for the survey area (23 543 ha, see Fig. 1))
Yield (catch) = 46.2 MT (mean '95-'99 + 10%)
Tissue weights: adults (A,S) = 0.365 kg/conch, juveniles (Large/SA) = 0.220 kg/conch (Horsford 1999)
M = 0.42 (t = 4 - 10 years), 1.0037 (t = 3 - 4 years), t = age
B (exploitable biomass) = 32 MT (mean), 66 MT (upper 95% CI), and 6 MT (lower 95% CI)

Method		Formula		Area	Yield (MT)
A1) Cadima's		MSY = X (Y + MB)		Survey Area	17.89
		X = 0.3		95% CI Upper	22.23
				95% CI Lower	14.65
A2) Garcia el al.	**a) Schaefer**	MSY = ((B)M^2)/2M-(Y/B)		Survey Area	-9.35
				95% CI Upper	81.22
				95% CI Lower	-0.17
	b) Fox	MSY=MBEXP((Y/MB)-1)		Survey Area	unreasonable
				95% CI Upper	unreasonable
				95% CI Lower	unreasonable
B1) Next fully recruited year class (Large juv. + SA)					
		MSY = abundance * tissue wt.			
abundance = Juveniles* x 0.1 + Sub-adults					
*estimate that only 10% of juveniles are Large (see text)				Survey Area	8.67
Horsford (1999) mean tissue weight (with viscera) of Large/SA = 0.220 kg				95% CI Upper	18.23
				95% CI Lower	1.55
B2) FAO Extrapolation (FAO 1990)					
		MSY = 0.06 MT/km^2/yr		Survey Area	14.13
survey area	23543 Ha			95% CI Upper	N/A
survey area	235.43 km^2			95% CI Lower	N/A
B3) Decay curve and future yield for L and SA					
	step 1 (abundance)	N2 = N1EXP(-M(t1-t2))			
	Mean		14446	Survey Area	5.27
	95% CI Upper		30371	95% CI Upper	11.09
	95% CI Lower		2586	95% CI Lower	0.94
	step 2 (yield, kg)	N2 * 0.365 kg/conch			
	Mean		5273		
	95% CI Upper		11085		
	95% CI Lower		944		

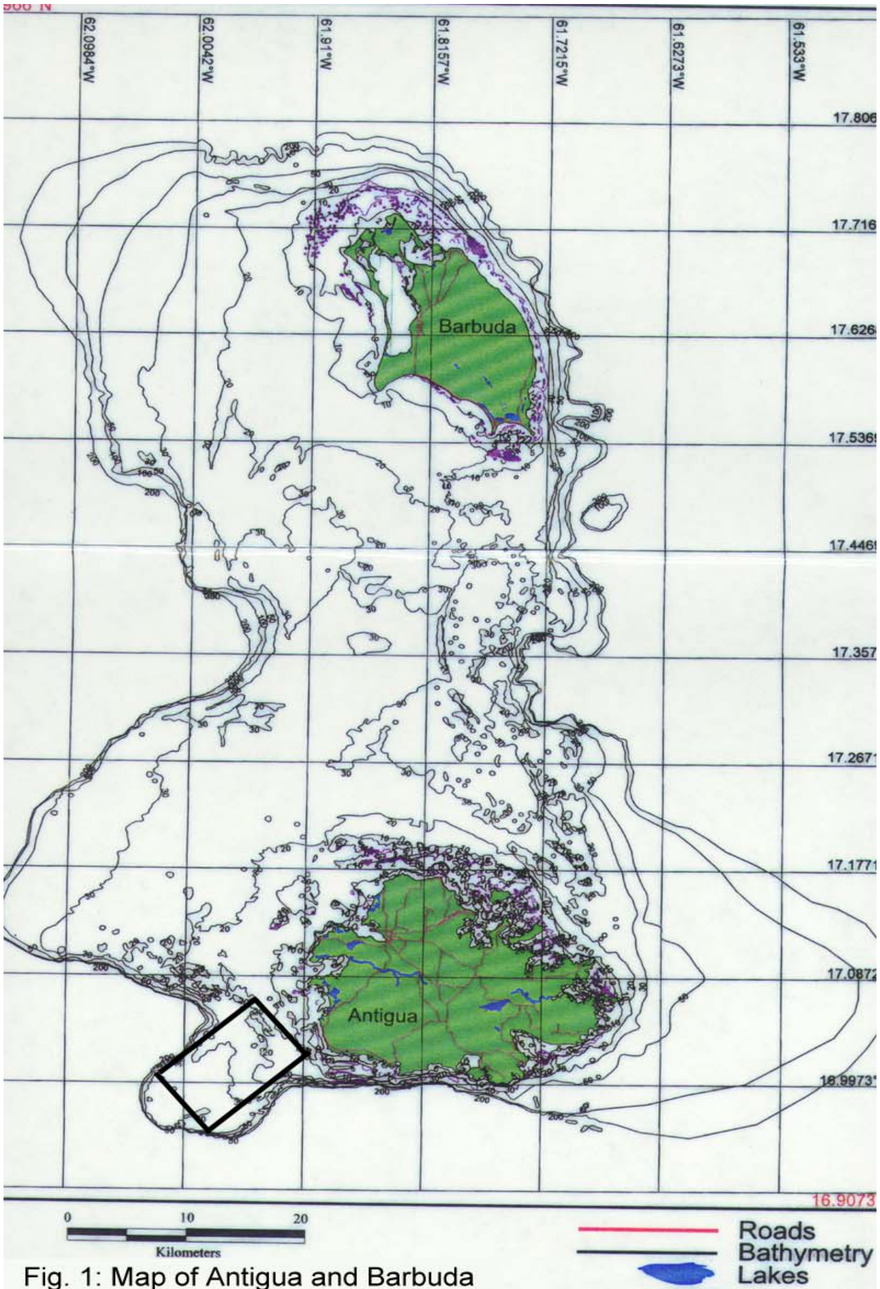

Fig. 1: Map of Antigua and Barbuda and associated shelf. Rectangle defines rough boundaries of the study area

Fig. 1: Map of Antigua and Barbuda and associated shelf. Rectangle defines rough boundaries of the conch abundance survey. Exact locations of sample sites may be obtained from Table 2.

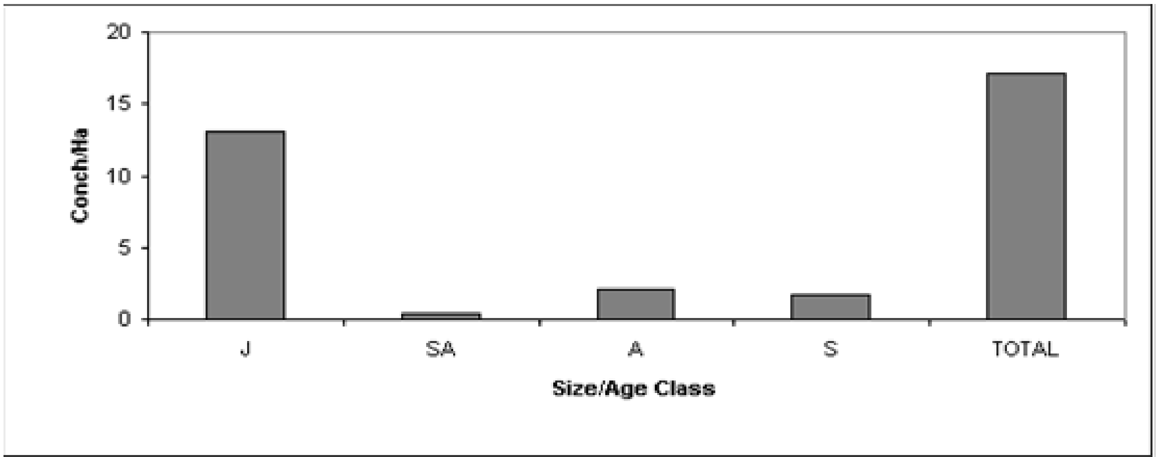

Fig 2: Population structure of conch occurring in all sites surveyed during August 1999
(see table 2 for 95% Confidence Intervals)
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult

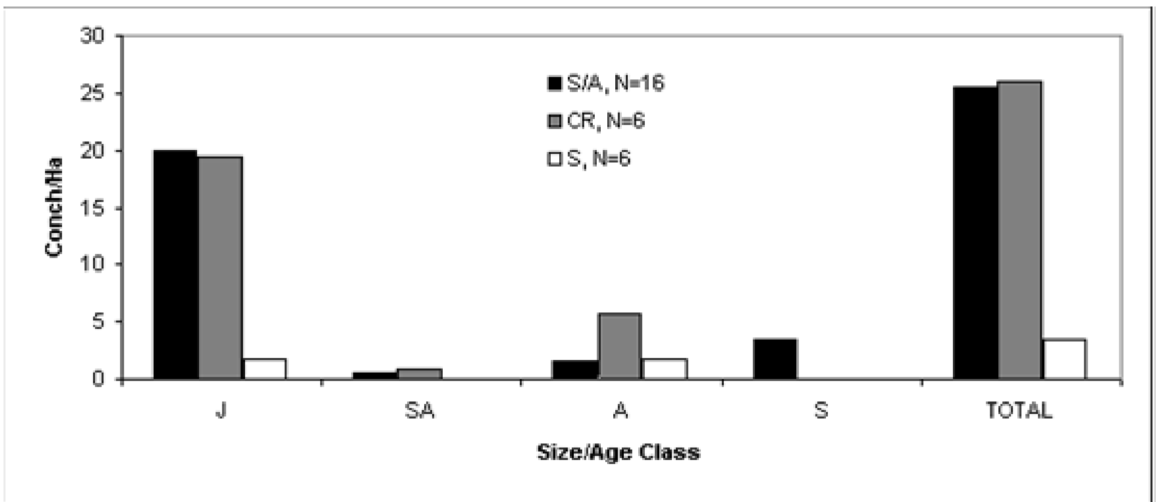

Fig 3: Population structure of conch occurring in various habitats surveyed during August 1999
(see table 3 for 95% Confidence Intervals)
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult
Habitat/substrate categories: S/A = sand/algal plain, CR = coral rubble, S = sand plain, R = reef

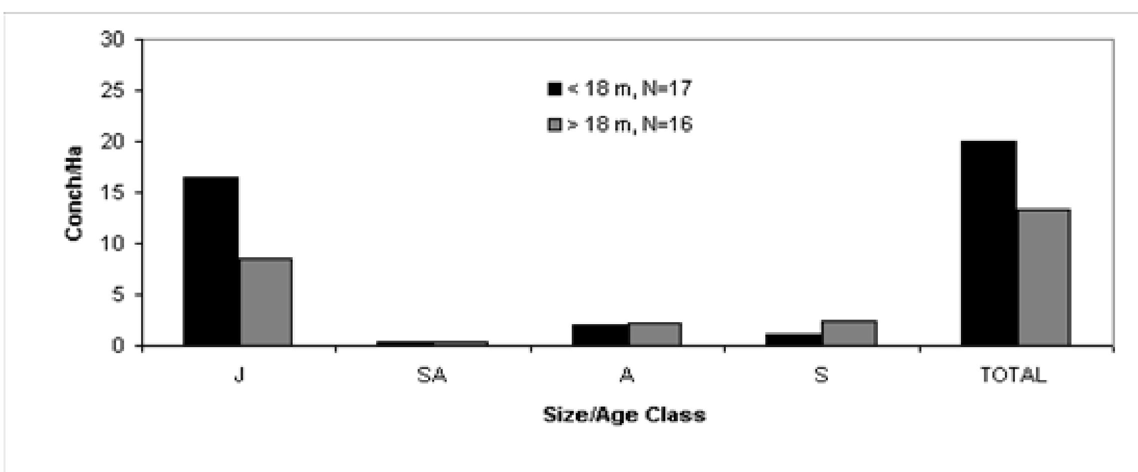

Fig 4: Population structure of conch occurring in various depths surveyed during August 1999
(see table 4 for 95% Confidence Intervals)
Size/Age categories: J = juveniles, SA = sub-adult, A = young adult, S = old (stoned) adult