Report on the

Queen Conch Stock Assessment and Management Workshop

Belize City, Belize, 15-22 March 1999

CFMC
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1999

Summary

1. Conch biology was reviewed with particular reference to stock assessment. It was emphasized that conch possessed a number of unfortunate features that made it difficult to assess. The species cannot be aged directly, and has a growth form that makes it impossible to use standard size-frequency methods correctly. Also, growth appears to vary from area to area and probably also varies with density. Natural mortality estimates vary with density, and only exist for juveniles.
2. Two stock assessment methods were presented and used with the available data. A biomass dynamic model was used where countries possessed catch and effort data. The model requires very little biological knowledge of the species, but depends on a time series of total catches (removals), effort and catches made with that effort. The Turks and Caicos Islands was used as an example to demonstrate the model.
3. The second model applied was a tuned cohort analysis based on meat weights and total catches. The method made use of a new growth model, which more accurately described observed growth rather than the standard von Bertalanffy model. The estimated fishing mortality was tuned to a weight converted catch curve. Data collected from the Bahamas were used to demonstrate the model.
4. **Bahamas**: Significant morphometric differences across the Bahamas suggest a number of stocks exist among the islands. The biomass dynamic model did not fit the available data, as there was an upward trend in CPUE. The weight-based cohort analysis indicated a low fishing mortality and a potentially large stock subject to relatively low exploitation. However this result is dependent on a relatively high estimate of natural mortality obtained from the scientific literature. Therefore, while overall Bahamas conch is probably not fully exploited, local over-exploitation of conch cannot be ruled out.
5. **Belize**: A major problem for the Belize assessment was the availability of size frequency data for only one out of the six areas which comprise Belize fishing grounds. For this area, while fishing mortality estimates are small, the assessment indicated an increase in fishing mortality over three years with increasing fishing pressure on juveniles. Both these trends are worrying. No conclusions could be drawn from the biomass dynamics model as the catch-effort time series was too short.
6. **Cuba**: Cuba lacks necessary statistics for stock assessment at this time. The fishery is largely limited to catching conch for bait, although there is some export to Europe and Asia. Discussion of this fishery was limited to the data collection program, which has recently been initiated.
7. **Grenada**: Inadequate data prevented the analyses obtaining any firm conclusions on the conch stock. Total catches were lacking and meat weights only comprised of large mature individuals. None of the available stock assessment methods could deal with this situation. Problems in the data were identified and suggestions made to improve data collection.
8. **Jamaica**: As well as catch, effort and weight frequency data, Jamaica possesses visual census surveys, which can be used as fishery independent estimates of biomass. The visual census results were used in the biomass dynamic models to obtain estimates of 700-1300 t MSY, covering the range of previous MSY estimates. The weight-based cohort analysis indicated a relatively high fishing mortality. It is generally believed that the fishery is currently exploiting a stock of old, mature individuals and it is therefore possible that the estimate of long-term sustainable yield may be of the order of some of the smaller MSY estimates. The recommendation is to continue quota reductions until the decline is CPUE is halted or reversed.
9. **Puerto Rico**: It was apparent that Puerto Rico possesses one of the longest complete time series of catch and effort data. Unfortunately not all data was available at the workshop. The available data suggested the fishery had suffered from over-exploitation. Given the full time series, it should be possible to provide a relatively good estimate of the current stock status and reference points for this stock.
10. **St. Kitts and Nevis**: In common with many countries, the available catch-effort time series does not have enough contrast to estimate all three parameters of the biomass dynamic model. To address this problem, a new Bayesian method was used which included information on parameters obtained from the Turks and Caicos assessment. The method indicated a precautionary quota (taking into account risk) of around 68 t year^{-1}.

This recommendation is consistent with subjective assessments that overfishing has taken place in the past.

11. **St. Lucia**: The short (2 years) catch effort time series could not provide estimates on reference points or stock status. A sample of meat weights gave estimates of biomass using the weight-based cohort analysis, but only large mature animals are in the catches. Improvements in stock assessment are expected as more data become available, on catch, effort and sizes of juveniles.
12. **Turks and Caicos Islands**: The Turks and Caicos Islands has the longest catch-effort time series available from 1974-1998. A biomass dynamic model was fitted to this time series to obtain an estimate of 682 t MSY. A bootstrap technique was used to obtain a probability distribution of MSY, which can be used to set precautionary quotas with MSY as the limit reference point. Problems with the stock assessment model were also identified. While they could not be solved at this workshop, the model tends to underestimate the stock size and is therefore probably not a dangerous error. The results suggest the current quota system is working well, but there is no justification to raise the quota above its current level.
13. **US Virgin Islands**: The 1993-1998 catch-effort time series for St. Croix was analyzed using a biomass dynamic model. The MSY was estimated to be 16 t year^{-1}. Conch landings have exceeded this figure on two occasions since 1993 without a noticeable decline in catch rates and it may be an underestimate. Further data is needed to obtain better estimates. Some historical data may exist and should be located if possible to improve the estimate.
14. The workshop made a number of recommendations specific to individual countries, and general recommendations to improve conch assessment and management. Most of these recommendations concerned obtaining historical data, which may have been mislaid or archived, and improvements in current routine data collection. In addition, a number of countries recommended specific research or monitoring activities, including tagging experiments and visual surveys, to support stock assessment and management.
15. Concerning methods, it was recognized that further research is needed to provide more accurate management advice. New models and estimates of growth and natural mortality are lacking. A method making use of the extensive shell length and lip thickness data currently collected by many countries is required. More work is required to incorporate properly visual census data in biomass dynamic or recruitment index models. More biological research is required on natural mortality and ageing of conch. Improved methods will result in more accurate assessments and if the assessments are heeded, greater sustainable economic returns from these resources.

Contents

1 Introduction

This report covers the methods, progress, results and conclusions of an international workshop on assessment of queen conch, (*Strombus gigas*). The workshop was held in Belize City, Belize, 15-22 March 1999. It was sponsored by the Caribbean Fishery Management Council (CFMC) and the CARICOM Fisheries Resource Assessment and Management Program (CFRAMP) as part of the International Queen Conch Initiative.

Queen conch is found throughout the Caribbean and forms an important food for many local communities. It has been traditionally fished for many years, but has come under increasing strain as an export market has developed. Demand for conch has increased in the USA, and, with the decline of the Florida fishery and its closure, has largely been satisfied by imports. This has led to concern expressed over the status of stocks in the region and to the listing of queen conch under CITES Appendix II. Among other things, this requires a fishery management plan and competent scientific authority to provide advice on each fishery which exports conch. Stock assessment has therefore become increasingly important to sustain the conch fisheries of the region.

Conch fisheries possess a number of characteristics, which makes stock assessment difficult. A significant proportion of fishing for conch may be subsistence, so recorded landings are often incomplete. In addition, the biology of queen conch makes it hard to determine relevant population parameters. It is not possible to age conch, and it is not possible to apply many size based methods due to the growth pattern during the life history, which may even exhibit some reduction in size with older age groups. There is probably a dramatic decrease in natural mortality with age, which is difficult to estimate, and while the planktonic larval phase is relatively short, stocks nevertheless are shared across the region.

The basis for management of queen conch resources should be the FAO Code of Conduct for Responsible Fisheries. It sets out the principles and standards, which should be applied in the conservation, management and development of all fisheries. The Code was unanimously adopted by the FAO Conference in November 1995. Where resources are transboundary, effective management requires that the stock is managed over the full range of its distribution (Code of Conduct, 7.3.1). The implications of this, and other requirements for responsible utilisation of transboundary resources, can be summarised as follows.

1. For transboundary fish stocks... the States involved should co-operate to ensure effective conservation and management of the resources. This should be achieved ... through a ... fisheries organisation or arrangement (Code of Conduct, 7.1.3).
2. States... should foster and promote international co-operation and co-ordination ...including information gathering and exchange, fisheries research, management and development (Code of Conduct, 7.3.4).
3. States should compile fishery-related and other supporting scientific data relating to fish stocks... in an internationally agreed format and provide them in a timely manner to the organisation... should agree on a mechanism for co-operation to compile and exchange such data (Code of Conduct, 7.4.6).

These principles require technical co-operation, which can most easily be achieved through regular workshops. Workshops allow scientific authorities to share information and assessment techniques, making better use of management resources and providing the basis for regional co-operation. This workshop aims to foster continued regional co-operation necessary for the responsible management of this species.

1.1 Participating Countries

Participants representing Bahamas, Belize, Cuba, Grenada, Jamaica, Puerto Rico, St. Lucia, St. Kitts and Nevis, Turks and Caicos Islands and US Virgin Islands attended the workshop. Information on the Mexican fishery was also made available (Appendix E).

1.2 Workshop Objectives

The overall objectives of the workshops were as follows:

1. Review available data and stock assessment needs.
2. Provide some training on two important techniques for the analysis of conch data.
3. Undertake stock assessments for each country, using the data and methods available.
4. For those countries where sufficient progress could be made in the underlying stock assessments, make management recommendations based on the precautionary approach.

The report provides a review of queen conch biology with special reference to those aspects which are directly relevant to stock assessment. There follows the country stock assessments. Assessments are separated by country rather than stock because what constitutes a stock is uncertain and the available data were almost exclusively based on national data sets. In most cases, the analyses were exploratory, and attempted two approaches using catch and effort data and meat weight frequencies. Detailed information on the three main methods applied to the available data is given in the appendices. Where other methods are used, they are documented in the text. Based on the results from the stock assessments, data collection activities were reviewed and problems identified. Finally, recommendations were made based on the results from the workshop, particularly on improvements in data collection and analytical methods.

2 Queen Conch Biology

2.1 Introduction

Stock assessment for queen conch has proved difficult. Much of this results from unique characteristics of conch biology. Conch are not fin-fish, and blind application of traditional assessment methodologies will often result in spurious results or may not even be possible. Unusual aspects of conch life history include deterministic growth in shell length, a reduction in soft tissue weight in old individuals, great morphological and life-history plasticity that is largely manifested spatially, often at small scales, and a reproductive biology characterized by repeated copulation and spawning events. Here, the biology of queen conch is reviewed with respect to stock assessment. Emphasis is given to what is known about the population dynamics of conch stocks and the applicability of stock assessment methodologies.

2.2 Movement

Conch settle in areas of soft sand and remain buried during their first year. At this time they are unavailable for assessment. At shell lengths ranging from 50 to 100 mm young juveniles begin to emerge and take up an epibenthic existence. Emergence of a year class may be protracted, with reburial often occurring, and one must be concerned about partial recruitment effects when sampling. In shallow areas, Sandt and Stoner (1993) documented a habitat shift at the time of emergence, from the area of settlement into nearby seagrass beds. General movement rates are low and size related (Miller 1972; Hesse 1979; Appeldoorn and Ballantine 1983; Appeldoorn 1987a).

Two migrations occur in conch. The first is an ontogenetic migration into deeper water. This generally becomes more pronounced in large juveniles, who leave nursery areas to move into deeper water. The second migration is related to spawning. Conch move inshore to spawn as temperatures start to increase in March (Hesse 1979; Weil and Laughlin 1984) and return to deeper water in October. This migration is manifest as a general shift in the distribution of conch, with conch in deep water migrating, but still remaining deep relative to conch in shallow water areas. For example, Coulston *et al.* (1987) reported seasonal migrations ranging from 20 to 45 m in a deep-water population. Total movement will depend on the extent of these two migrations, random movements, and the distribution of appropriate habitat or habitat barriers (e.g., reefs or shelf drop-offs). Appeldoorn (?????) reported movement of 9 km in 6 months for conch on a broad sand-algal plain 17-30 m in depth.

2.3 Growth

The most unusual aspect of queen conch biology is that growth in shell length ceases at the time of sexual maturity. At this time the flared shell lip of the adults is formed. Further shell growth occurs only in the thickening of the shell, especially of the lip (Fig. 1). In terms of shell growth, the life-history is divided into two stages: juvenile and adult. This has a profound impact on assessing age, growth and mortality using size-based techniques (length-frequency for juveniles and lip-thickness frequency for adults).

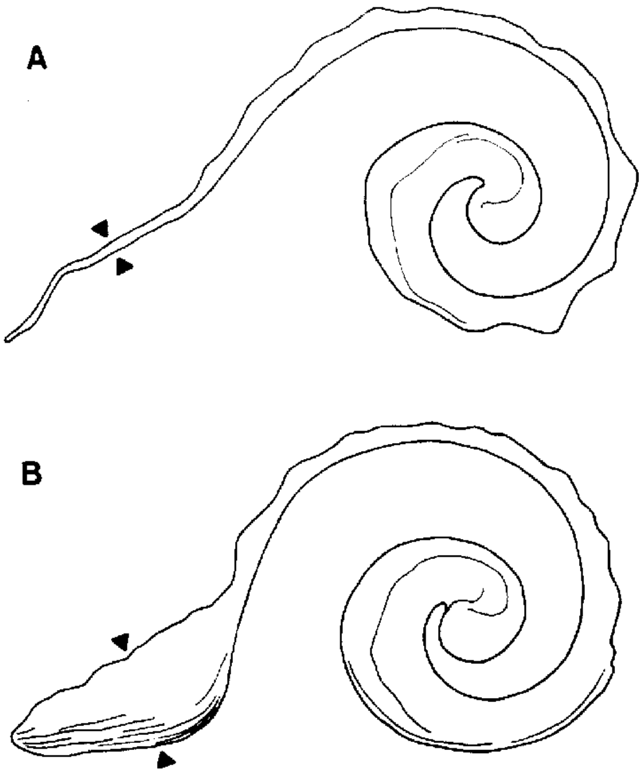

Figure 1. Cross-section of the shell of adult *Strombus gigas* showing growth in shell and lip thickness. (A) Recently matured adult, lip thickness = 5 mm; (B) old adult, lip thickness = 27 mm. Arrows represent position where lip thickness is measured. From Appeldoorn (1988a).

The reason problems arise is illustrated in Figure 2. In the first sample, the frequency mode of the large year-class is centred at 21 cm. In successive samples, this mode shifts to the right as growth continues, and the stops, with abundance progressively decreasing as conch mature and become adults. Note the correlated increase in the relative number of adults. The transition of conch from juveniles to adults affects both the location and size (height and width) of the mode on the length-frequency histogram. Changes in the shape and size of the frequency mode, as well as the transition between length-frequency and lip-thickness frequency effect the estimation of growth and mortality.

(1) The estimation of mean linear growth (for juveniles) can be affected. In Figure 2, the length-distribution of the largest year class never fully approaches that of adults. While maturation is occurring within the year-class, the observed mean size will always be less that the "real" size because larger conchs are being selectively removed (through maturation to adults) from the sample. This process is essentially the reverse of partial recruitment.

(2) The variance of growth estimates, including L_∞, will also be affected. As the shape of the frequency mode of the maturing year-class changes, so will its variance.

(3) The reverse of (1) and (2) occur when looking at adult growth using lip-thickness. This is a case of partial recruitment of juveniles into the adult population, which will affect the size and location of the first mode in lip-thickness frequency.

(4) Although growth in shell length ceases at maturation, growth in weight does not. It cannot be assumed that growth in length extrapolated to L_∞ can be used to estimate W_∞ using a length-weight conversion. (see section below on weight growth).

(5) Any process that affects the shape of the frequency modes will affect the estimate of year-class abundance, and hence mortality. For example, as conch mature, the size of the year-class length-frequency mode for juveniles decreases. Length-based techniques cannot distinguish between this loss and mortality.

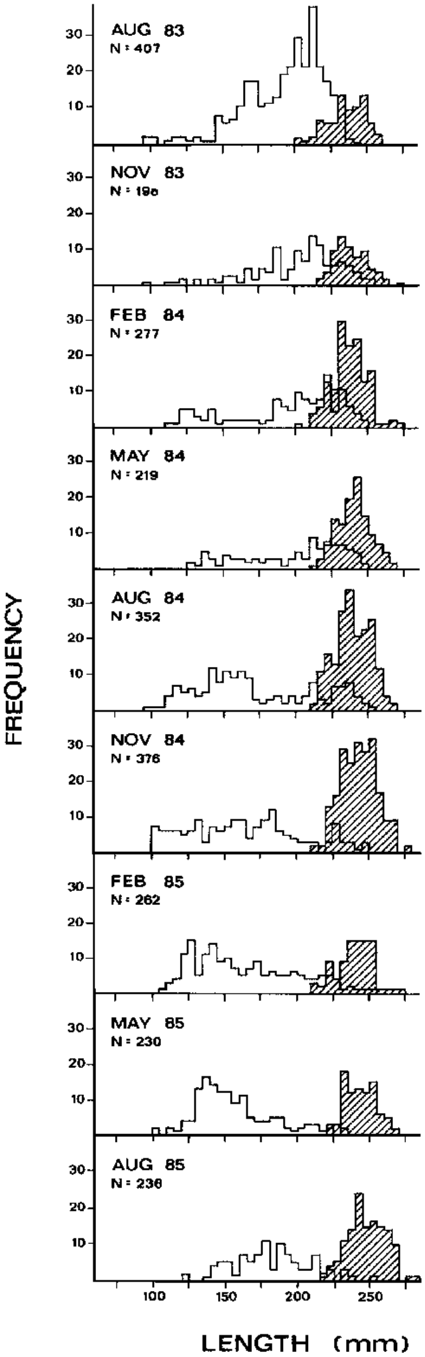

Figure 2. Length-frequency hisotgrams for *Strombus gigas* sampled quarterly off La Parguera, Puerto Rico. The open portions represent juveniles; the shaded portions represent adults. N = sample size.

As a consequence of the above, reliable results using length-frequency analysis can only be obtained if

- the sample is taken at a time of the year prior to the beginning of maturation in the largest juvenile year class (e.g., Figure 2, sample 1)
- the largest juvenile year class is ignored, or

- the number of newly matured adults is added to the largest juvenile year class.

On average, female conch are slightly larger than males. For example, reported differences in the mean size of adult females and males are 1.14 cm in St. John, USVI (Randall 1964), 1.9 cm in the Columbia offshore banks (Chiquillo *et al*. 1996), and 1.0 cm in Puerto Rico (Appeldoorn 1994a). Because weight is a power function of length, these slight differences in length may be magnified into larger relative differences when considering weight. It is hypothesized that this sexual dimorphism arises from genetic effects resulting in greater rates of production by females (Reed 1993).

Using mark-recapture data primarily from young adults (total age < 10 yr), Appeldoorn (1988a) modeled shell growth in lip thickness (LT) with the von Bertalanffy model. His resulting parameters were LT_∞ = 54.9 mm and k = 0.706 yr^{-1}, with time expressed in age since the onset of maturation. However, lip-thickness cannot be used to age old conch, and no conch were found that approach the value of LT_∞. This is because as growth rate declines it is offset by the rate of shell erosion. The latter is dependent upon the type of substratum the conch occupies, being least in soft sand and greatest on hard or rocky bottom. As a consequence, it is impossible to precisely age conch greater that about 10 years using shell measurements, about half or less of the maximum life span. At best, one can assign individuals to different age-categories based on a combination of shell thickness, color and degree of erosion (e.g. Table 1). These categories are useful for obtaining some idea of age structure from abundance surveys.

Table 1. Definitions of adult queen conch age categories.

Maturing	Flared lip starting to grow or very thin (lip generally < 5 mm thick). Periostrocum tan and clean. Often the lip is thin enough to allow the periostrocum to give color to the underside of the lip.
Young Adult	Flared lip is fully formed, with minimal to moderate erosion. Periostrocum tan, but may be sand covered or with some algal growth. Lip underside generally white with pink interior.
Old Adult	Outer lip starting to erode (as viewed from bottom). Top of shell still well formed, but periostrocum is lost and spines have rounded, with moderate erosion and fouling on the outside shell. Lip underside may have platinum color, with darker pink interior.
Very Old Adult	Lip is very thick and flared portion may be completely eroded away. Outer shell is highly fouled and eroded, often resulting in a short total length. Viewed from the underside, the lip is squared off, the white portion is often completely eroded and the interior is a dark pink.

A critical factor in analyzing growth in weight and determining production is defining precisely what the weight represents. While this is clear in terms of live weight and whole tissue weight, meat weight can range greatly depending on the level of processing. Table 2 shows the relative number of conch per kg for different levels of processing in the Jamaica fishery. These values have changed over time, reflecting both changes in the age structure of the exploited population and the increasing skill in processing among workers as the fishery developed.

Table 3 gives the relationships between weight and shell size for juvenile and adult conch from La Parguera Puerto Rico. It is clear that shell length is an excellent predictor of weight for juveniles, but this is not the case for adults. The best predictor for adults uses a combination of length and lip information. The reason for this is illustrated in Figure 3. After maturation, growth in weight continues, but growth in length does not. Thus, the length-weight relationship for adults is shifted up and from that for juveniles. Adult weight is determined both by the size (length) at maturation and the adult age of the individual.

Table 2. Number (N) of individuals per kilogram (and pound) of queen conch from Pedro Bank by degree of processing.

Processing	N/kg	N/lb
Unprocessed	6.6	3.0
50% Cleaned	7.7	3.5
65% Cleaned	9.9	4.5
85% Cleaned	12.1	5.5
100% Cleaned	14.3	6.5

Table 3. For juvenile (J) and adult (A) *Strombus gigas*, regression equations for meat weight (MW), wet-tissue weight(TW) and shell weight (SW) as a function of shell length (L) and/or shell-lip thickness (LP).[a]

Group	Regression Equation $y = a + b(x)$	r^2	N	mean x^b	mean y^b
Meat Weight					
J	Log (MW) = -2.535+3.486 Log (L)	0.926	94	1.838	1.254
A	Log (MW) = -1.510+2.804 Log (L)	0.494	130	2.393	1.392
A	Log (MW) = 2.212+0.163 Log (LP)	0.274	131	2.394	1.117
A	Log (MW) = -1.357+2.571 Log (L) + 0.135 Log (LP)	0.684	130		
A	Log (MW+100) = 1.797+0.232 Log (LP)	0.354	130	2.101	1.117
Tissue Weight					
J	Log (TW) = -2.286+3.459 Log (L)	0.925	94	2.053	1.254
A	Log (TW) = -1.444+2.928 Log (L)	0.524	130	2.632	1.392
A	Log (TW) = 2.469+0.147 Log (LP)	0.214	131	2.633	1.117
A	Log (TW) = -1.294+2.726 Log (L) + 0.118 Log (LP)	0.659	130		
A	Log (TW + 100) = 1.764+0.403 Log (LP)	0.321	130	2.121	1.117
Shell Weight					
J	Log (SW) = -1.786+3.517 Log (L)	0.878	94	2.626	1.254
A	Log (SW) = -0.286+2.530 Log (L)	0.347	130	3.237	1.392
A	Log (SW) = 2.952+0.256 Log (LP)	0.579	131	3.237	1.117
A	Log (SW) = 0.013+2.129 Log (L) + 0.273 Log (LP)	0.822	130		
A	Log (SW+1000) = 2.793+0.293 Log (LP)	0.633	130	3.720	1.117

[a] All weights are in g; length is in cm and lip thickness is in mm. N is sample size. Logs are base 10.

[b] For simple regressions, mean x and y values are given to permit conversion to functional form ($y = u + vx$) where v = b/r and u = (mean y) – v (mean x).

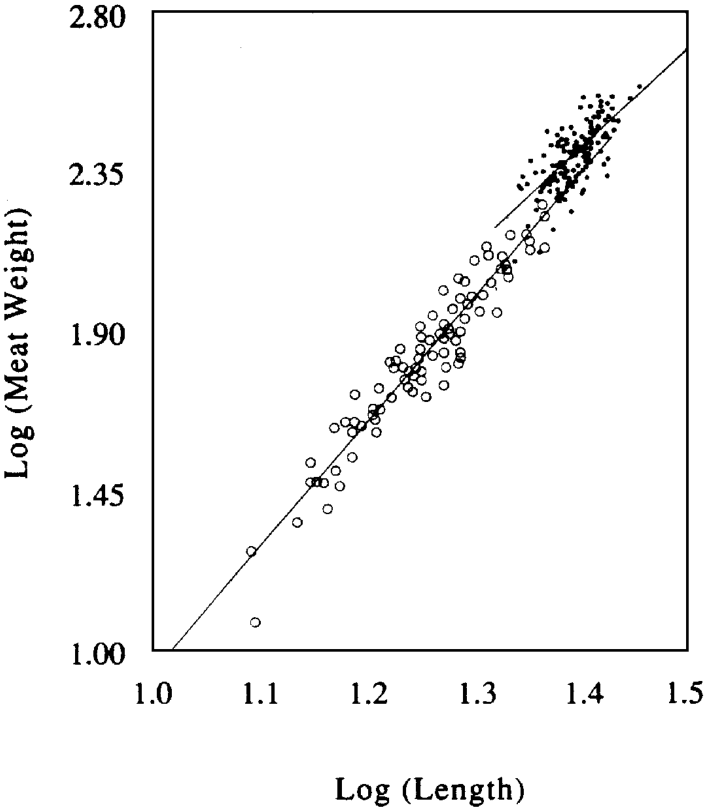

Figure 3. Length-weight relationships for juvenile (open circles) and adult (closed circles) *Strombus gigas* from La Parguera, Puerto Rico. Regression equations are given in Table 3. From Appeldoorn (1994a).

Appeldoorn (1988a) modeled final weight (FW) as a function of juvenile weight (= size at maturation) and adult weight (= growth after maturation):

$FW = a\,Len^{b} + c\,Lip^{d}$

The estimates of a and b come from the length-weight relationship for juveniles (Table 3: note that parameter *a* here is the antilog of parameter *a* as expressed in the table). The parameters c and d come from the following expression:

$Log_{10}(FW - a\,Len^{b}) = Log_{10}(c) + d\,Log_{10}(Lip)$

In practice, for young adults, the parenthetic expression on the left side of the above equation is often less than zero, for which logarithms are undefined. To avoid this problem, a constant can be added to all values of observed final weight prior to running any regression (e.g. 100 g for meat or tissue weight). To obtain proper predicted weights using these equations, the appropriate constant (e.g. 100g) should be subtracted from the antilog of the predicted value.

Once c and d are known, an equation for in adult weight as a function of lip-thickness can be developed (Table 3). Using the growth function of lip-thickness over time, adult growth in weight can then be estimated. Because weight is a function of both size at maturation and subsequent adult growth, these results can only be depicted graphically for a single representative size at maturation, which in this case was the mean length of adults (24.5 cm). Figure 4 shows the expected weight growth of 24.5-cm adults compared to observed values for adults between 24 cm and 25 cm in length.

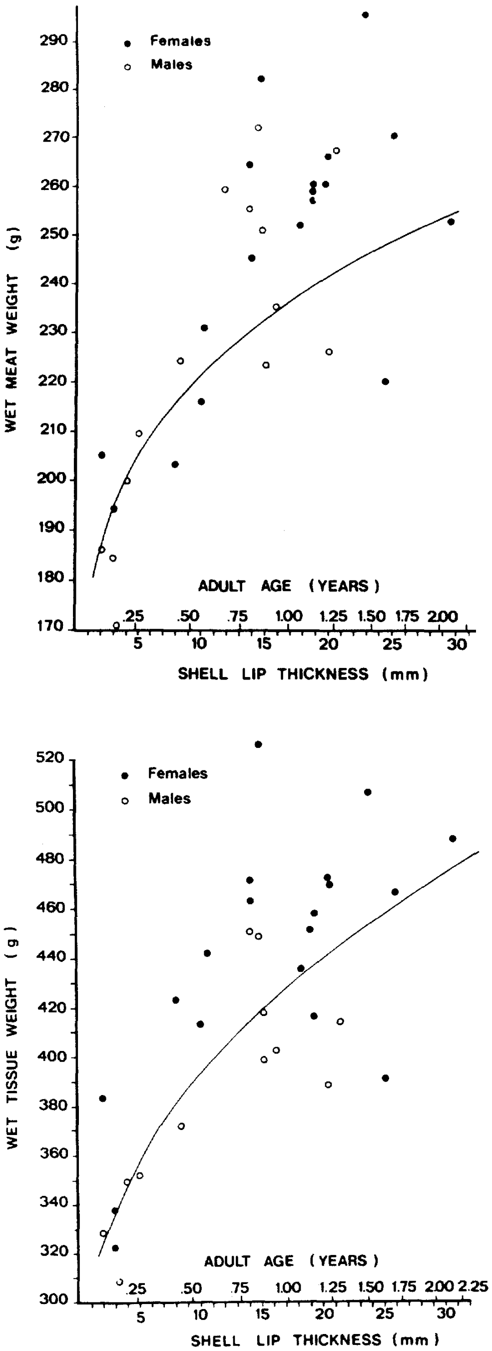

Figure 4. Predicted wet meat weight (top) and wet tissue weight (bottom) of adult *Strombus gigas*, averaging 245 mm in length, as a function of shell-lip thickness. Origin of the x-axis is at the start of lip formation. Individual points represent observed values of weight and shell-lip thickness for adult conch between 240 and 249 mm in length. From Appeldoorn (1988a).

Appeldoorn (1992a) combined growth in weight for juveniles and adults for an average size individual (24.5 cm). Estimates of weight at age were then fitted to a Gompertz model, with the resulting equations for meat weight (MW) and whole tissue weight (TW):

$$MW = 4.394\,10^{-7}\, e^{20.12\left(1-e^{-1.275t}\right)}$$

$$TW = 1.263\,10^{-5}\, e^{17.44\left(1-e^{-1.126t}\right)}$$

These are depicted in Figure 5. The resulting curves, and the use of the Gompertz model in the first place, indicate that the growth rate in weight declines much more rapidly that expected if growth followed a more typical von Bertalanffy model. This emphasizes another unique aspect of conch biology. As the shell thickens in older adults, there is increasingly less space inside the shell to accommodate the animal. In fact, body size decreases significantly in very old individuals. Theoretically, one would thus expect a disproportionally large amount of energy to be diverted from growth to reproduction in conch.

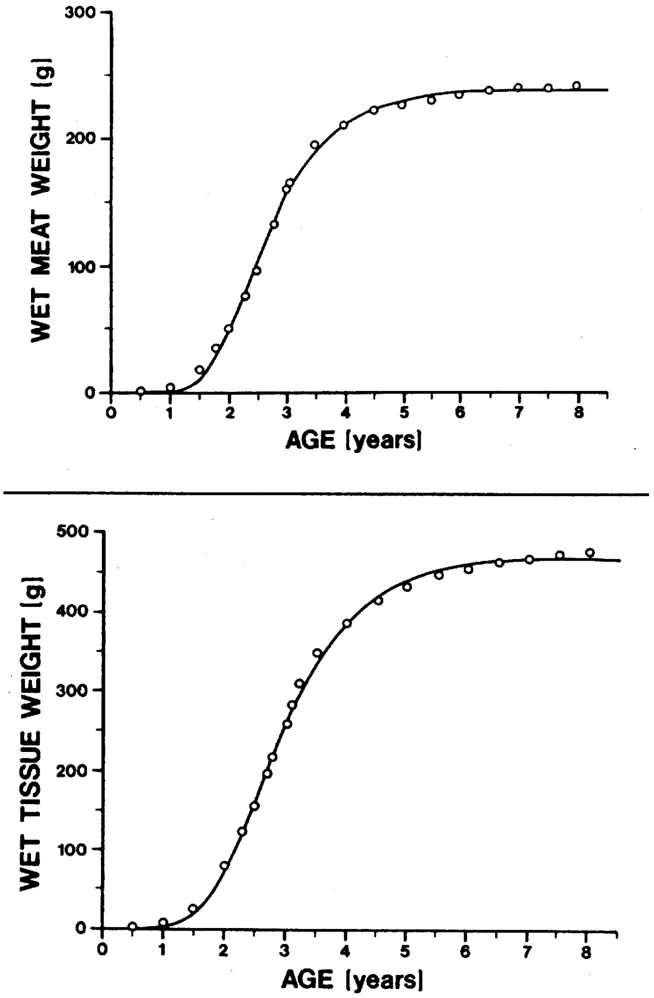

Figure 5. Growth in meat weight (top) and tissue weight (bottom) for *Strombus gigas* of average length (24 cm) from La Paguera, Puerto Rico. Points represent data used to determine parameters of the Gompertz function. Solid line represents the fit of the resulting model. From Appeldoorn (1992a).

2.4 Patchiness

Conch morphology is largely controlled by habitat characteristics, operating directly or mediated through control of growth rate. Factors such as depth, substrate type, food quality and quantity, and density are known to affect growth and morphology. For example, Alcolado (1976) found that with increasing depth conch were characterized by longer but fewer spines, slower growth in length but a wider shell (i.e., tighter coiling of the shell), and a thicker shell. The result of this plasticity is great spatial variability in terms of growth rate, length-weight relationships, mortality, and maturation. As an example, Figure 6 shows the relationship between growth rate and size and age at maturation. Populations characterized by rapid growth tend both to reach a larger size before maturation and to mature at an earlier age.

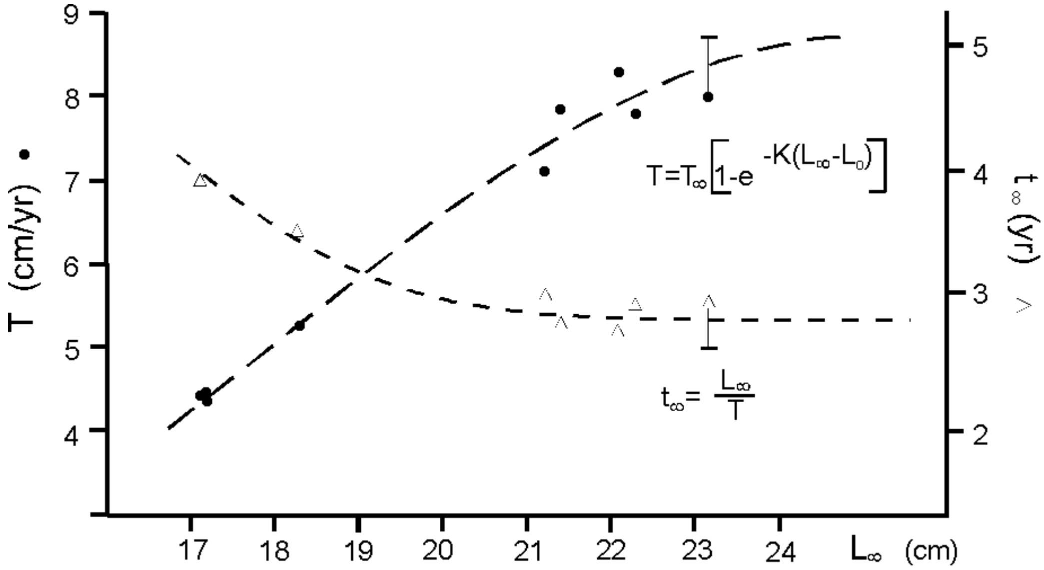

Figure 6. Relationships between the final average shell length (L_f) and the mean growth rate (T) (long dashed line) and the age at maturation (t_f) (short dashed line) for *Strombus gigas* from 9 locations in Cuba. The line crossing vertically in 6 gives the probable range of T and t_f for that location. In the equation, $T_{¥}$ = 9.7, K = 0.208 and L_o = 14.39. From Alcolado (1976).

Because of these differences, growth and mortality functions developed for one specific area are not likely to be representative of conch over a broad area. Table 4 and Figure 7 show the reported values of von Bertalanffy growth parameters for shell length. The variability among parameter estimates is great and is a result of variable application of different methodologies as well as the effects of spatial variability in growth and morphology. This spatial variability makes typical dynamic-pool models, such as yield-per-recruit, difficult to apply even if an appropriate growth function could be developed. However, such models are useful in a heuristic sense, to explore the possible effects of potential management measures. In the particular case of juvenile growth, variability in growth parameters may not be critical as long as the function can predict juvenile size at age (Figure 8). Different growth parameters may fit data equally well because of the negative correlation among k and L_∞, and the fact that L_∞, is an extrapolation well beyond the length at maturation.

Table 4. Estimates of von Bertalanffy parameters for queen conch for growth in shell length.

Location	L_∞	k	t-zero	Phi'	Source
San Andres & Providencia	329.4	0.720		1.536	Garcia 1991
Providencia & Santa Catalina	375.0	0.250		1.114	Marquez 1993
San Bernardo, Columbia	365.0	0.290		1.171	in Gallo *et al*. 1996
San Andres & Providencia	350.0	0.270		1.127	Gallo *et al.* 1996
Boca Chica, Belize	268.0	0.223	-0.050	0.967	Strasdine 1988
Tres Cocos, Belize	332.0	0.207	-0.330	0.997	Strasdine 1988
Water Caye, Belize	269.0	0.209		0.940	Strasdine 1988
Quintana Roo, Mexico	341.7	0.580			Valle-Esquivel 1998
Pedro Bank, Jamaica	221.0	0.580	0.155		Tewfik 1996
Cabo Cruz, Zone A, Cuba	383.4	0.330	-0.050	1.241	Alcolado 1976
Cabo Cruz, Zone B, Cuba	380.6	0.287	-0.120	1.178	Alcolado 1976
Diego Perez, Zone A, Cuba	232.7	0.429	-0.090	1.210	Alcolado 1976
Diego Perez, Zone B, Cuba	207.6	0.442	-0.090	1.190	Alcolado 1976
Cayo Anclitas, Cuba	259.8	0.571	0.090	1.366	Alcolado 1976
Rada Inst. Oceanol., Cuba	334.0	0.360	0.130	1.239	Alcolado 1976
Berry Islands, Bahamas	300.0	0.200	-0.650	0.952	Iversen *et al*. 1987
Six Hill Cay, Turks & Caicos	256.0	0.563	-0.160	1.356	in Appeldoorn *et al*. 1987
La Parguera, Puerto Rico, tagging	460.0	0.250	0.244	1.173	Appeldoorn 1990
La Parguera, Puerto Rico. LFA	340.0	0.437	0.462	1.328	Appeldoorn 1990
St. John, USVI	260.4	0.516		1.323	Berg 1976
St. Croix, USVI	241.7	0.420		1.212	Berg 1976
St. Kitts	331.9	0.347		1.221	Buckland 1989
Martinique, tagging	338.6	0.388			Rathier & Battaglya 1994
Martinique, LFA	339.0	0.392			Rathier & Battaglya 1994

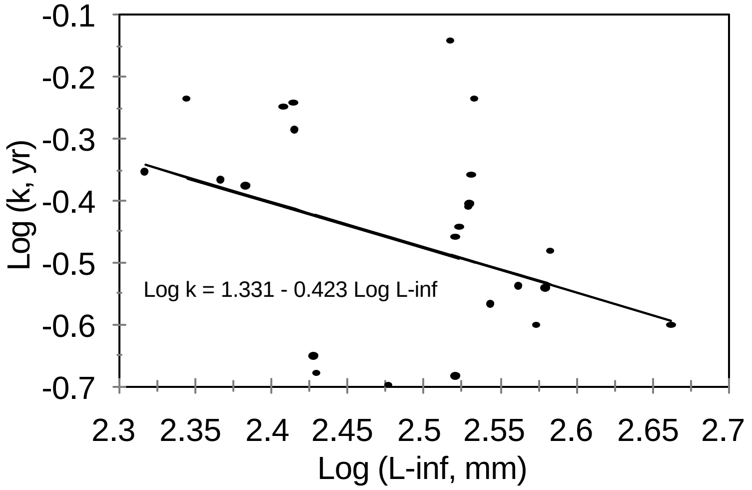

Figure 7. Log-log plot of the von Bertalanffy parameters for juvenile shell growth of *Strombus gigas*. Values and literature sources are given in Table 4.

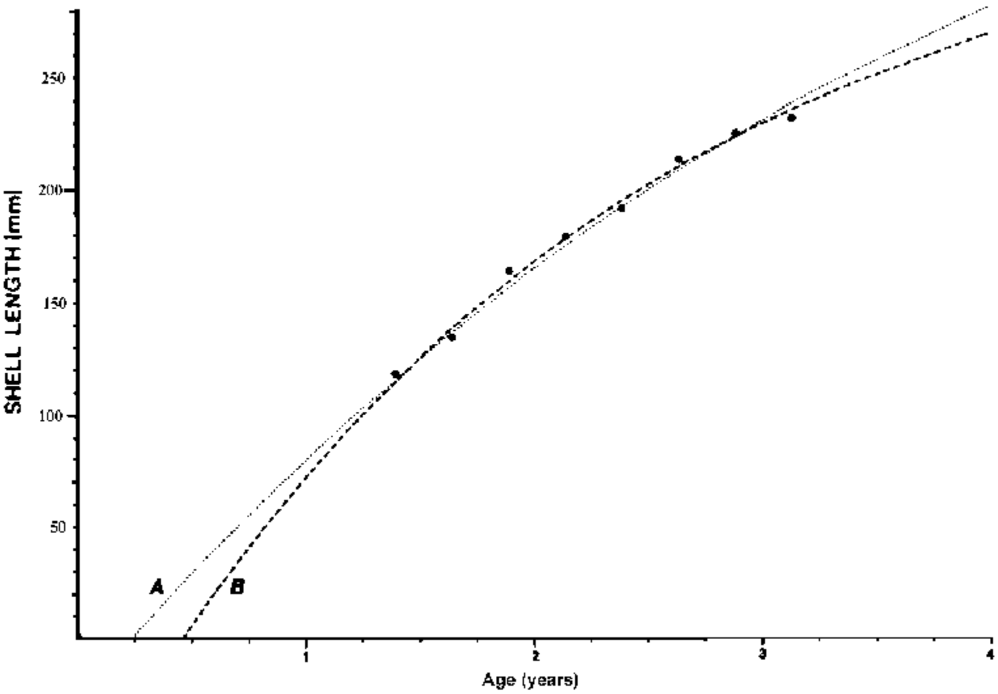

Figure 8. Length at age and von Bertalanffy growth curves for juvenile *Strombus gigas* from Puerto Rico. A: growth curve derived from growth-increment data, B: growth curve derived from age-length data. From Appeldoorn (1990).

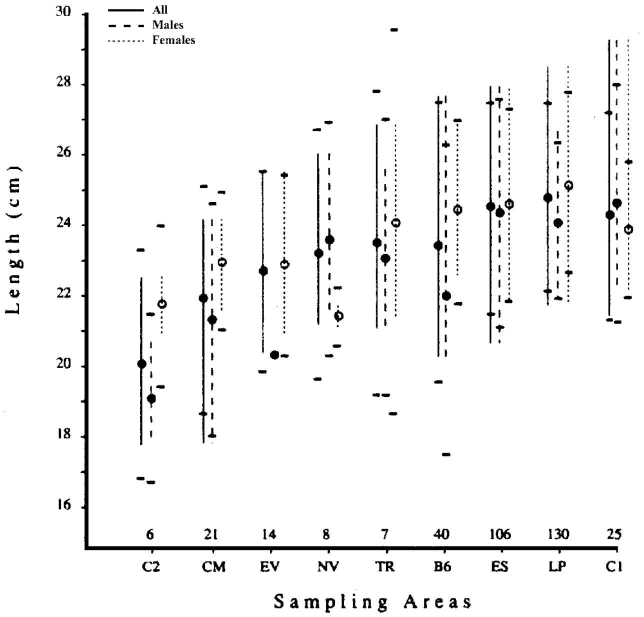

Figure 9. Length distributions of adult *Strombus gigas* from different areas of Puerto Rico. Numbers at bottom = sample size, Circles = mean, Lines = range, dashes = ± 1 standard deviation. From Appeldoorn (1994a).

Figure 9 illustrates the potential variability in length among adult conch from different sites. The range of sizes in the areas characterized by small conch shows little overlap with those from areas characterized by large conch. Appeldoorn (1994a) showed that the length-weight relationships for different populations could vary significantly. Nevertheless, he was able to show that a general function could be used to predict meat weight among populations differing significantly in mean length, by using both length and lip information. This implies that the combination of length and lip measurements could be used as a metric for assessing population structure and stock status from samples taken over a broad area containing populations differing in morphology and size at maturation.

2.5 Natural Mortality

Conch have a maximum longevity of 20 to 30 years (Berg and Glazer, pers. comm., in Appeldoorn 1994a). Mortality is thought to be very low in conch once they have matured and thickened the shell. However, no direct estimates of natural mortality have been made for old conch. In fact, no estimate has been made for conch greater than 4.25 yr (M=0.52), representing only the first 20-25% of the potential life span (Appeldoorn 1988a).

Estimates of mortality on juveniles have shown that mortality decreases significantly with increasing size (Appeldoorn 1988b, Ray *et al*. 1994). Appeldoorn (1988b) derived a relationship between natural mortality (M) and age (Fig. 10). This was further modified by (1) omitting the data point representing the youngest juveniles (representing a stage prior to becoming epibenthic and potentially available to the fishery), (2) adding the one estimate for adult mortality, and (3) fitting the relationship with the inverse model of Caddy. The latter was chosen because the extrapolated survival rates for old individuals were more consistent with the known life span of conch. The final form of the equation is

$$M_t = -0.242 + 4.330/t$$

where t is age. Calculation of the mean value of M between any two ages can then be determined by the following equation:

$$M_{mean} = \frac{4.330 \ln (t_2/t_1)}{(t_2-t_1)} - 0.242$$

However, this model yields negative values of M at older ages. It is therefore recommended mortality be restricted to a minimum of M = 0.1, i.e. the Caddy model is used until M declines to 0.1, then M remains constant as age increases.

Despite the general relationship between size/age and mortality, actual mortality can vary widely due to season, habitat, and other factors (Stoner and Glazer, 1998). Thus, the estimation of natural mortality remains problematic and is the most limiting factor in attempting to model population dynamics.

An approximation of natural mortality can be obtained from the empirical equation of (Hoenig 1983), which predicts total mortality (Z) from the maximum age in the population (t_{max}). For mollusks, his equation is as follows:

$$Ln(Z) = 1.23 - 0.832\ Ln(t_{max}) \qquad r^2 - 0.78$$

In the absence of fishing, Z equals M, and the maximum age in the population should approach the maximum longevity for the species. Thus, for a longevity of 20 to 30 years, the estimates of Z = M are 0.28 and 0.20, respectively. This equation assumes that mortality is constant over the life span, which is not the case for conch. Because the adult stage covers the vast majority of the maximum life span, the resulting estimation of M more closely corresponds to the expected mortality for adult conch, and specifically would not be applicable for juveniles.

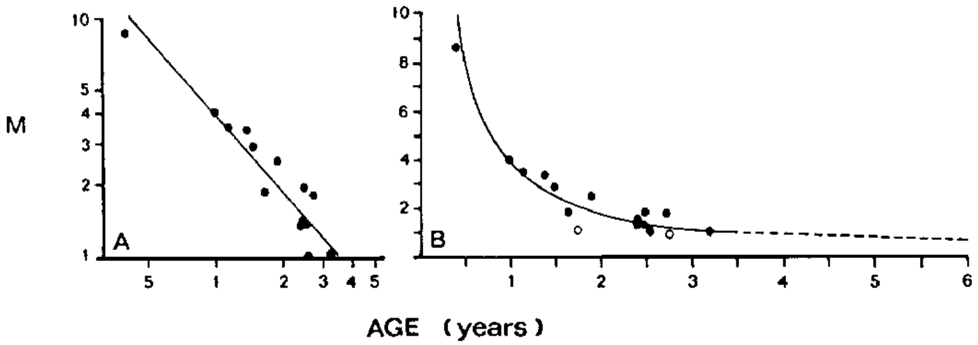

Figure 10. Log-log (A) and back-transformed (B) regression of instantaneous mortality (M) against age in *Strombus gigas*. From Appeldoorn (1988b).

2.6 Reproduction and Recruitment

2.6.1 Maturation

Conch begin to mature when the flared lip starts to form. The mean age and size at which this occurs among areas is a function of growth rate (Figure 6). Table 5 shows estimates of size at maturation for various areas within the region.

Table 5. Reported age when growth in length of queen conch ceases and the flared-lip begins to form.

Location	Age (yr)	Source
St. John USVI	3	Berg 1976
St. Kitts/Nevis	2.3-2.8	Wilkins *et al*. 1987
St. Kitts	4	Buckland 1989
Bermuda	4	Wefer & Killingley 1980
Puerto Rico	3.6	Appeldoorn 1988a
Cuba	3-4	Alcolado 1976
Belize	3.5-4	Calculated from Strasdine 1984
Turks & Caicos Islands	2.8	Hesse 1976

The proportion mature (both sexes) was modeled against shell lip-thickness (LT) for conch in Puerto Rico:

$$\text{Proportion Mature} = 1 - e^{-0.14\,(LT-1.9)}$$

This relationship is shown in Figure 11. The figure shows that no conch were mature until the lip reached a thickness of 4 mm, that 50% maturation was reached at a lip thickness of 7 mm, and that 100% maturation did not occur until on year after lip formation. This agrees with Egan (1985) who found no ripe gonads in conch with lips less that 5 mm. Chiquillo *et al*. (1996) reported that 18.5% of adults with lip-thickness greater than 5 mm were still immature, while Buckland (1989) reported that gonads of significantly greater cross-section occurred in conch with lips that were “thick, eroded, bulged”.

The above relationship can be converted to an age function using the relationship between lip thickness and adult age (T) from Appeldoorn (1988a):

$$LT(\text{mm}) = 54.9\,(1 - e^{-.0706\,T})$$

where adult age is the time since the formation of the flared shell lip. In Puerto Rico, this age must be added to 3.2 yr to obtain total age.

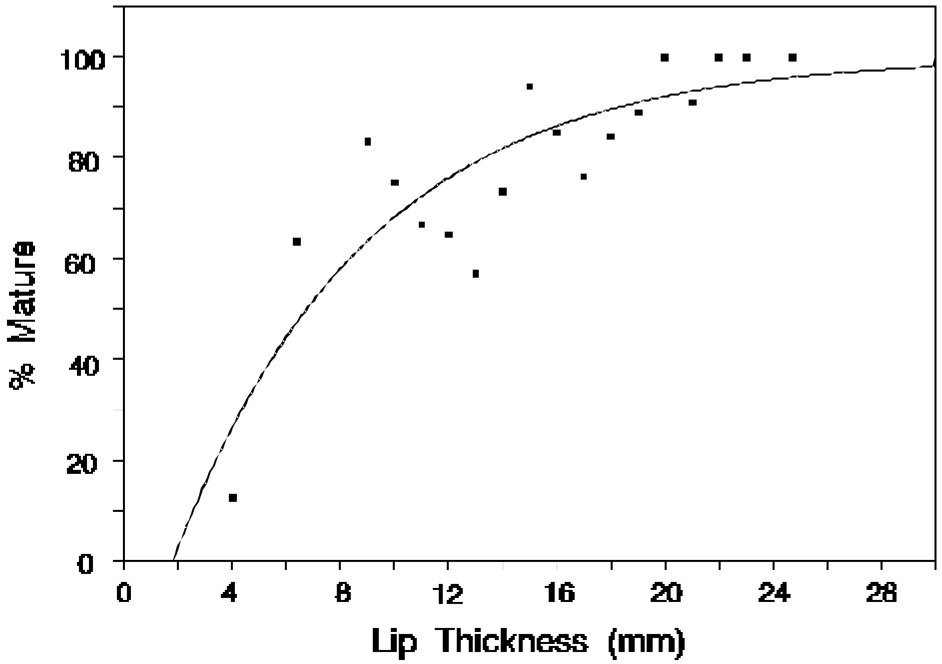

Figure 11. Percent full maturation as a function of lip-thickness for *Strombus gigas* off La Parguera, Puerto Rico. All individuals had a fully flared shell lip.

2.6.2 Spawning Season

The spawning season for queen conch is broad (Table 6) and can be variable depending on temperature, turbulence (winter storms) and perhaps density. Egan (1985) reported that gametogenesis occurred year round in Belize, but he did not document actual spawning activity, which may have been more limited. Despite the long duration of the season, production peaks over a narrower time period of approximately three-months, typically from July to September (Figure 12).

Table 6. Observations of spawning season for the queen conch, *Strombus gigas*.

Location	Spawning Season	Source
Jamaica	Pre-July - late Nov	Sally 1986
Florida	late May – Sept	D'Asaro 1965
Bahamas	April – Oct	Stoner *et al*. 1992
Turks & Caicos	mid-March - mid-Nov	Davis & Hesse 1983
Puerto Rico	mid-May - mid-Nov	in Appeldoorn *et al.* 1987
St. John, USVI	Feb-March - Nov-Dec	Randall 1964
St. Kitts/Nevis	late-April - late Sept	Buckland 1989
Venezuela	early July - mid-Nov.	Brownell 1977
Venezuela	late April - late-Nov.	Weil & Laughlin 1984

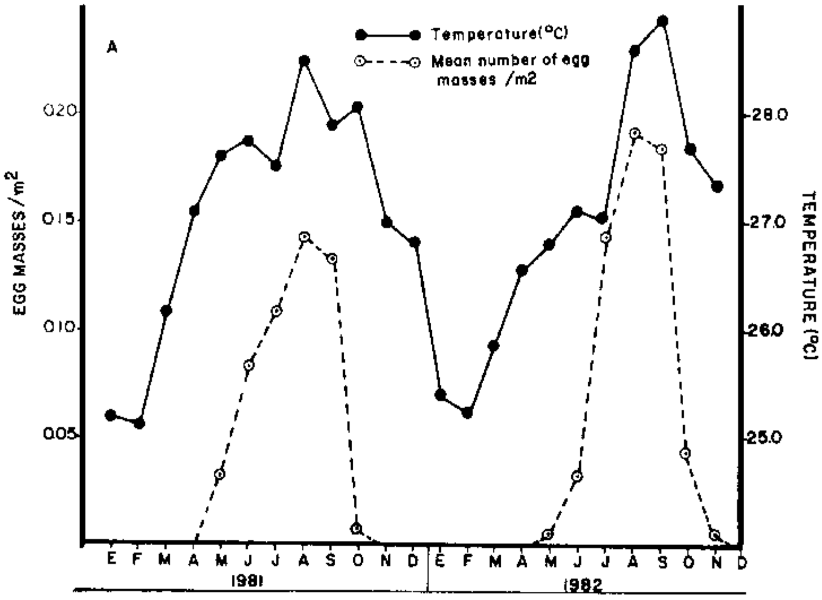

Figure 12. Mean monthly variations in density of *Strombus gigas* egg masses and water temperature in Los Roques, Venezuela. From Weil and Laughlin (1984).

2.6.3 Egg Deposition and Fecundity

Queen conch females produce demersal eggs, generally in areas of clean sand with low organic content. Females take 24-36 hours to lay a complete egg mass (Randall 1964; D'Asaro 1965). Females will repeatedly deposit egg masses over the course of the spawning season. The number of eggs/egg mass is variable and ranges for 300 000 to 1.5 million. Factors affecting this include temperature and other weather conditions, food availability and condition of the individual, genotype make-up, the frequency of egg mass deposition, and any other factor that may disrupt egg deposition (Appeldoorn, 1993).

The effect of food availability and genotype were demonstrated by Appeldoorn (1993), who followed individual reproductive activity over an entire spawning season in conch kept in enclosures at densities of 1/5 m^2 and 1/70 m^2. There was noticeable food limitation at the higher density despite supplemental feeding. Females in the high-density treatment spawned an average of 6.7 egg masses containing 500 000 eggs for a total fecundity of 3.36 million eggs. The average rate of egg mass formation and size of egg mass are comparable to those reported from conch enclosed in an egg farm at similar densities in the Turks and Caicos Islands (Davis and Hesse 1983; Davis *et al*. 1984). Females in the low-density treatment spawned an average of 13.6 egg masses containing 750 000 eggs for a total fecundity 10.2 million eggs. Maximum rates observed were 25 egg masses, a single egg mass of 1.5 million eggs, and a total fecundity of 22 million. Much individual variability occurred. For example, all the above maxima were recorded for a single female, which was also the first and last to spawn over the season.

In the same study, a significant relationship was found between age (from lip-thickness) and total fecundity for conch in the low-density treatment:

$$\mathrm{Log}_{10}(\mathrm{Fecundity}) = 4.157 + 2.012\ \mathrm{Log}_{10}(\mathrm{Age}) \qquad r^2 = 0.672; \qquad N = 10$$

A similar relationship was found for the high-density treatment, although with a lower intercept, but the result was not statistically significant, primarily due to a smaller sample size and narrower range of ages. The results indicate that fecundity increases with the square of age. However, this relationship cannot be extended into older ages where lip (and weight) growth ceases. In partial support of the above, Buckland (1989) found no relationship between number of eggs/egg mass and shell length, but found a weak linear relationship with total shell weight (SW) in grams:

$$\text{Number of eggs/ egg mass} = 0.83 + 2.31\,(\text{SW}) \qquad r^2 = 0.26$$

Given evidence of a relationship between fecundity and age, Appeldoorn (1993) developed another approach to develop an age-fecundity relationship. For this, it was assumed that fecundity was proportional to wet tissue weight. Under this assumption, it was possible to use as a guide the Gompertz function predicting weight from age for the average adult in the La Parguera population. The upper portion of this function approximates a decreasing exponential, such that, in terms of fecundity, the following equation was developed:

$$E_t = E_{max}(1 - e^{-K(t-3.2)}),$$

where E_t is fecundity at age t, E_{max} is the average maximum fecundity for an individual, K is the instantaneous growth constant, and 3.2 is the age (years) at the onset of maturation. From the tissue growth equation it was determined that 95% of the adult growth occurs by age 6, or 2.8 years after the onset of maturation. The parameter K was thus estimated from $t_{.95} = 3/K$, or K = 1.07. Estimation of is more problematic as in the experiment this was clearly affected by the density treatments, and older females were not well represented. Estimation of E_{max}, however, is not necessary for assessments based on spawning potential ratio (SPR); because SPR is a ratio, maximum fecundity, as a constant, can be set equal to 1. This model is still limited to those ages for which tissue weight increases. The relationship between fecundity and age cannot yet be determined for very old conch in which meat weight is known to decrease.

2.6.4 Copulation, Stock Density and Reproductive Output

Males transfer sperm to females through copulation, whereby the verge is extended under the shell of the female and into the genital region. Males and females copulate many times during the spawning season and copulate with multiple partners. Females can store eggs for several weeks prior to spawning (D'Asaro 1965). Since many males can copulate with one female, sperm from several males can fertilize a single egg mass (Steiner and Siddall, pers. comm). Because physical contact with females is necessary for copulation and hence egg production, and because conch are slow moving, the maintenance of populations at high density is necessary for successful reproduction. At low densities, reproductive opportunities are lost to the time searching for mates.

The importance of maintaining stock density was further argued by Appeldoorn (1995a), who hypothesized that the cycle of repeated egg-laying and copulation stimulated reproductive productivity such that a positive feedback relationship forms. Support for parts of this hypothesis were observed in other species (Appeldoorn 1995a) and from reproductive experiments (Appeldoorn, unpublished data). Under this hypothesis, maintaining stock density is important in maintaining the positive feedback relationship that enhances reproductive output. If density falls (as abundance falls) this relationship breaks down and overall reproductive output will decline at an increasing rate.

The potential result of these two relationships to stock density is illustrated in the alternative stock-recruitment relationships shown in Figure 13. Curve A represents a typical expected stock-recruitment relationship. Curve B shows what might be expected if reproductive output is dependent upon stock density, and not just stock abundance. Here, there is a threshold abundance below which recruitment declines rapidly, such that recruitment failure can occur at stock sizes significantly above zero. In support of this, Stoner (199) found in the Exuma Cays Land and Sea Park, that reproductive activity (% conch egg laying) decline noticeably when density fell below 50 conch ha^{-1}. While measured density is a function of both area surveyed relative to appropriate habitat and stock abundance, it is clear that many areas within the region have low stock densities (Table 7).

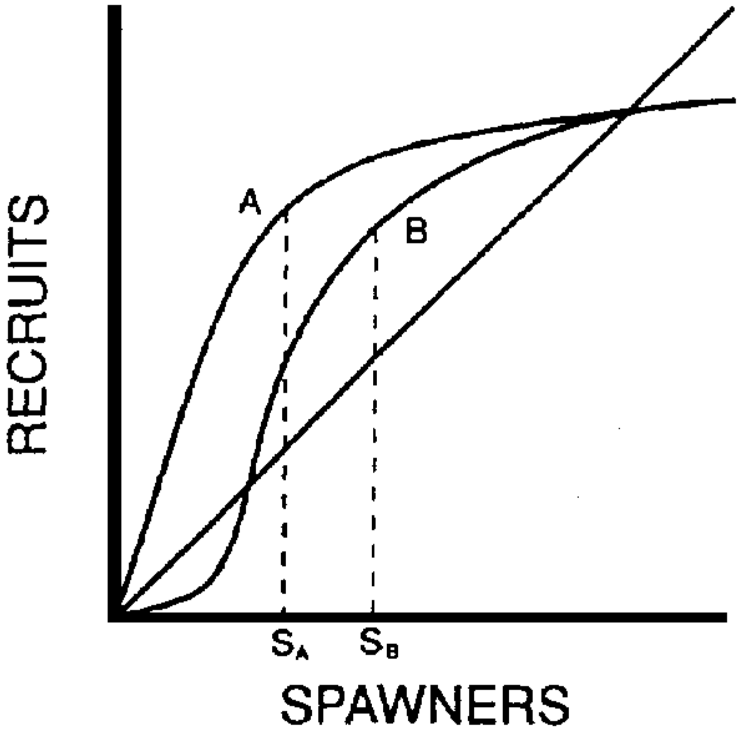

Figure 13. Theoretical stock-recruitment relationships (a) without incorporating, and (B) incorporating hypothesised spawning-stock density-dependent mechanisms. Line at 45° represents replacement values. Distance from any point on a curve down to the replacement line represents surplus recruitment. S_A and S_B are the respective points of maximum surplus recruitment for the two curves.

Table 7. Average densities of *Strombus gigas* determined by resource surveys.

Location	(No./ha)	Source
Belize		
Sublegal (< 15 cm)	14.3	Appeldoorn & Rolke 1996
Legal (≥ 15 cm)	14.9	Appeldoorn & Rolke 1996
Mexico		
Cozumel (1989)	89.0	Martínez Vasquez 1995
Cozumel (1995, after closure)	830.0	Martínez Vasquez 1995
Pedro Bank (1995)		
Artisanal Zone (0-10 m)	89.09	Appeldoorn 1995b
Industrial Zone (10-20 m)	144.46	Appeldoorn 1995b
20-30 m	276.97	Appeldoorn 1995b
U.S. Virgin Islands		
St. Croix (1981)	7.60	Wood & Olsen 1983
St. Thomas/St. John (1981)	9.70	Friedlander *et al*. 1994
St. Thomas/St. John (1990)	12.25	Friedlander *et al*. 1994
Puerto Rico		
Southwest (1985/86)	8.11	Torres Rosado 1987
West (1995)	4.19	Mateo *et al*. 1998
East (1996)	7.20	Mateo *et al*. 1998
Little Bahama Bank		
1983/83	28.50	Smith & Neirop 1984
Great Bahama Bank		
Unprotected Bank (1983/83)	20.79	Smith & Neirop 1984
Protected Bank (1991/94)	53.6	Stoner & Ray 1996
Protected Shelf (1991/94)	96.0	Stoner & Ray 1996
Florida Keys		
1987-88	2.4	Berg & Glazer 1995
1990	1.54	Berg & Glazer 1995
Bermuda		
1988	0.52	Berg *et al*. 1992a
1989	2.94	Berg *et al*. 1992b

2.7 Larval Dispersal and Recruitment

The demersal eggs of queen conch hatch in approximately 5 days, releasing planktonic veliger larvae. The exact length of larval life is not well known, although larvae can be aged using daily rings deposited in statoliths (Grana-Raffucci and Appeldoorn 1997). From mariculture an expected larval life is 2 – 3 weeks, while Davis *et al*. (1996) recorded a larval period of 14 days for larvae reared in field enclosures with natural assemblages of phytoplanktonic food. The maximum age of larvae sustained in culture is 60 days (D'Asaro 1965). Observations by Posada and Appeldoorn (1994) and by Stoner and Davis (1997) indicate that the average extent of larval dispersal is in the range of 10's to 100's km. However, conch larvae have been found in the middle of the Eastern Caribbean (Posada and Appeldoorn 1994) and in the North Atlantic Drift (extension of the Gulf Stream) (Sheltema, pers. comm.), indicating that some long-distance dispersal is possible. Despite this potential, it is likely that dispersal is limited within sub-regions, and therefore populations within different countries should be managed as separate stocks.

Recruitment of conch into shallow-water nursery areas has been found to be directly proportional to the density of late-stage larvae sampled over nursery areas the year before (Stoner *et al*. 1996). However, the relationship differs among areas (Figure 14). Nevertheless, these results clearly point to the necessity of maintaining egg and larval production if recruitment is also to be maintained.

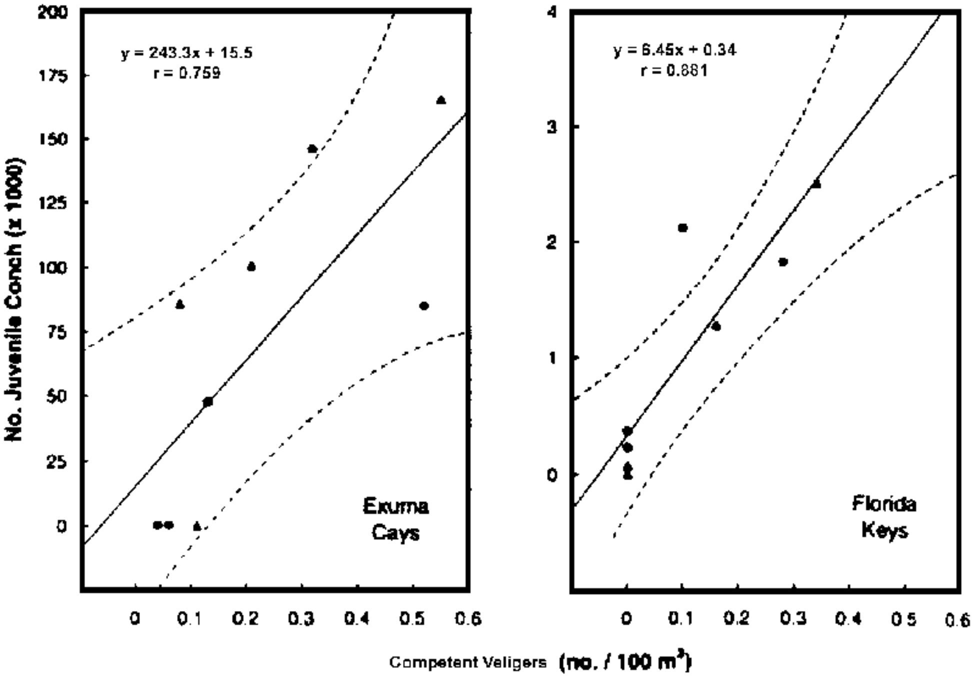

Figure 14. Relationship between the mean density of late-stage queen conch larvae at a nursery ground and the size of the benthic juvenile population in the subsequent year. The relationships are shown for nurseries in the Exuma Cays, Bahamas and Florida Keys. Circles represent the larval collections for 1992 and juvenile surveys in 1993. Triangles represent larvae in 1993 and Juveniles in 1994. Linear regressions and 95% confidence intervals are shown. From Stoner *et al.* (1996).

2.8 Discussion

The primary stumbling block in developing quantitative stock assessments of queen conch is the absence of a reliable method for ageing individuals. Size-based methods are useful during approximately the first seven years of life, although their application is difficult due to the split pattern of growth, and limited in extent due to significant patchiness in shell growth and morphology. The degree of general shell erosion is a further indicator of age, but it lacks accuracy and precision. As such, assessments can only be reliable for younger conch, whose rates of shell and meat growth are rapid enough to indicate approximate age.

The most important process in understanding the potential productivity of queen conch, as with most other species, is a firm understanding and quantification of natural mortality. With one exception, all estimates of natural mortality are for juvenile stages, yet it is known that conch have an extended longevity. Thus, most of the life history has not been studied with respect to natural mortality, although the potential longevity of conch argues that natural mortality must be very low in older conch. To date, there have been two studies that have summarized mortality information. Appeldoorn (1988b) used data from juveniles to show that M declines significantly during the first few years. More recently Stoner and Glazer (1998) used similar data to show that short-term variability in M can be high. However, neither study was specifically designed to determine the mean level of M, even among juveniles. Both studies dealt with variations in M, for which systematic errors in estimation would be less problematic. What is needed are more studies, involving both juveniles and adults. These studies need to be of sufficiently long duration to factor out short-term variability.

The general biology of older conch remains enigmatic, yet because of assumed low mortality this period may be potentially important. The decline in meat and tissue weight in older, thick-shelled conch has not been quantified. There are several ramifications to this decline. Where meat weights are the metric available for assessment and old conch are abundant (e.g. Pedro Bank, Jamaica), very old conch may be indistinguishable from young conch; also, a significant decline in meat weight would result in an overestimation of potential yield. Furthermore, the reproductive potential of these older conch is unknown. Is fecundity related to biomass (typically the case in fishes) or is there an increase in spawning frequency and total fecundity as tissue weight ceases to grow or even decline? If the latter is true, then older conch would represent a disproportionally important component of the spawning stock.

Although the potential for long-distance dispersal of conch larvae is evident, it is more probable that populations are self-recruiting on a sub-regional basis. However, the scale of this is unknown, and the determination of stock structure may be critical for some important fisheries. Two examples are Pedro Bank (Jamaica) and Belize. Pedro Bank sits in the central axis of the Caribbean Current and appears to have limited upstream sources for recruitment (see Roberts 1997). The fishery behind the Belizean barrier reef is based on the harvest of juveniles, with too few adults to support observed recruitment (Appeldoorn and Rolke 1996). Thus determining the location of, and conserving the spawning stock for this fishery is critical.

The current difficulties in quantifying stock status in queen conch preclude the use of many otherwise standard approaches (e.g. yield-per-recruit) in anything other than a heuristic sense. Nevertheless, where applicable, such exercises offer valuable insight on the potential response of conch populations to exploitation. Alternatively, there are a number of management measures that may be undertaken to conserve stocks and maintain production in the absence of target production reference points. These would include seasonal closures during periods of peak spawning (when conch are most vulnerable to fishing), prohibiting the capture of juveniles or thin-lipped (> 5 mm) adults, and protecting juvenile nursery areas from environmental degradation. Most importantly, the biology of conch suggests that a critical fishery management tool is the establishment of networks of marine reserves. While marine reserves offer a variety of specific benefits to both fisheries management and production extending beyond single species (Ballantine 1997, Bohnsack 1998), their specific use for the management of conch is further warranted by the following considerations: (1) the uncertainty in, but likely local stock structure, (2) the importance of maintaining the continuity of abundance in nursery areas, (3) the importance of maintaining spawning stocks at high density, (4) the potential reproductive importance of older conch, and (5) the small-scale spatial patchiness of conch morphology and growth, which renders stock-wide assessments and some management measures (e.g. minimum length) problematic. While stock assessments can result in more effective and flexible management strategies, there exists significant information on the biology and ecology of queen conch, as well as the consequences of overfishing, to enact effective management in the absence of quantitative assessments on local stocks.

3 Stock Assessments

3.1 Bahamas

3.1.1 Background

The Bahamas EEZ covers an area greater than 343 450 km^2. Of this, 154 553 km^2 comprise shallow waters (up to 200 m depth). The length of the shallow water shelf has been estimated to be 4 633 km (2 500 nm).

The commercial fishing industry mainly targets shallow water species. The most important of these are: spiny lobster, *Panulirus argus*; stone crabs, *Menippe mercenaria*; snappers, *Lutjanus* spp. and *Ocyurus chrysurus*; and queen conch (*Strombus gigas*). Of these, spiny lobster is by far the most important, accounting for more than eighty percent (80%) by weight of the total annual catch in live whole weight. The total conch landings usually account for approximately 10% of the weight of all fishery products landed in the country.

The Fisheries Department considers that conch stocks in The Bahamas are generally in a healthy condition. This is partly due to the fact that the conch fishery mainly represents a supplementary income for fishermen during the closed season for lobsters, 1st April through 31st July. It is mainly during this period that conchs are landed in large quantities. However, the conch fisheries are highly localized, in areas close to population centers and therefore the potential exists for localized stock depletion, especially during the closed season for lobster.

The Department of Fisheries, within the Ministry of Agriculture and Fisheries, is responsible for the administration, management and development of fisheries in The Bahamas. The Department of Fisheries is currently governed by the Fisheries Resources (Jurisdiction and Conservation) Act, 1977, and is responsible for the issuing of licenses for all commercial fishing vessels, compressor (hookah) permits, trapping permits and vendors permits. The Department is also responsible for the enforcement of all fisheries regulations. There is an enforcement unit whose responsibility is to assure that fisheries laws are not violated. Further, there is a public education section that serves to share information with the fishermen and the general public about the Department, the fisheries resources and other information regarding developments within the fishing industry.

3.1.2 Description of Data

Fisheries statistics and data collection is carried out and compiled by the technical staff of the Department of Fisheries. The Department uses a Daily Landing Form to collect catch and effort statistics from fishing vessels. These forms collect information on the catch, trip duration, crew, gears and number and type of vessels used in the harvesting of all fisheries resources.

The Department also requires all licensed processing facilities to submit a Monthly Purchase Report that details by species, source and cost all purchases made for the month. Since the majority of fishery resource landed is actually bought by the processing plants, this information adds to the total fishery resource landed within the country.

The widely dispersed state of the Bahamian islands make it difficult and expensive to collect the fishery catch and effort statistics required for management purposes. There is insufficient fisheries technical staff and therefore there are islands or parts of islands where there is no fishery officer present to collect the data. Fortunately, most islands with major fishing communities also have processing plants that purchase most if not all of the fishery products landed in those communities. Therefore, information on the fisheries catch for such islands is obtained from the Monthly Purchase Reports of those islands.

During 1995 the Department of Fisheries conducted a Fisheries Census to assess the fisheries activities in The Bahamas. This census is used to generate expansion factors for the various regions for The Bahamas.

The inability of the Department of Fisheries to collect comprehensive statistical data on fish catches and fishing effort continues to be a major hurdle for sustainable fisheries management. Such data is needed for the planning, implementing and subsequent monitoring of fishery management and development efforts. The Department's capacity to collect statistical data and other information, and to properly analyze it, needs to be substantially improved.

The Department of Fisheries initiated a conch stock assessment project during 1996 to determine the effect of the current level of harvests on the sustainability of the local stocks. The data required for the project included meat weight frequency by area, and individual conch measurements on shell length, shell weight and lip thickness, meat weight, and tissue weight. The project also required a comprehensive literature search for any publications on conch biology and stock assessments.

3.1.3 Catch and Effort Data Analysis

A biomass dynamic (Schaefer) model was fitted to the catch and effort data collected for The Bahamas. The model did not fit the data well. The data were separated by fishing areas to see whether there were any area-specific differences for the exploitation of the conch stocks. However, the model was still unable to provide a good fit to the data. The model requires some significant variation in the catch and effort time series, but this requirement is not being met. In general, the catch is relatively constant and the catch per unit effort (CPUE) data collected gives an upward trend for most of the individual fishing statistical areas and for The Bahamas as a whole. Therefore the model could only be fitted with any statistical validity if particular key parameters were fixed. There are also questions over whether CPUE in this case is proportional to stock size, as effort directed at harvesting only conch is not recorded within trips.

However, because the areas of the Great Bahama and Little Bahama banks are so large and the number of fishermen diving for conch are small, it seems unlikely that the whole resource is being fully utilized. In addition, because the costs involved in traveling long distances would exceed the returns earned for conch, much of the resource is not threatened. This would suggest any assessment should be carried out, concentrating on areas around population centers where local depletion may occur, rather than try to assess the resource as a whole.

3.1.4 Morphometric ANCOVA

An Analysis of Covariance (ANCOVA) was used to test for significant differences in the morphological relationships between the different fishery statistical regions for The Bahamas. The parameters tested were the log meat weight and the log siphonal length for conch in each of the fishing areas of New Providence, Grand Bahama and Abaco. (Abaco data excludes the Sandy Point conch, which are distinctly different. This increased the power of comparison between the other sites). The results of the ANCOVA indicated the null hypothesis, that there were no significant differences in the conch morphology between the fishery regions, should be rejected at the 5% level.

The data set were sufficiently large (greater than 2000 observations each) so that bootstrap resampling could be used to test the robustness of the results obtained. The resampling was conducted via 1000 repetitions of 50 observations each. The results obtained from the bootstrapping produce significance difference 36% of the time for the slope and 100% for the intercept. Therefore, it can be safely concluded that there are significantly different relationships between the log of meat weight and the log of siphonal length for conch in each of the fishing areas. Thus, separate and individual stock assessments are required for each of the areas defined.

3.1.5 Weight-based Stock Assessment

The Tuned Weight-based Cohort Analysis requires data on total conch meat weight frequency, the total catch statistics. Also the asymptotic meat weight for the area being assessed (W_∞), the juvenile growth parameters, the asymptotic shell length for the area being assessed (L_∞) and an estimate of the growth parameter k are required. These data are actively being collected for the purpose of conducting a stock assessment on conch. The W_∞

value was obtained by averaging the largest 10% of the mature conch for the area being considered. The juvenile growth parameter was obtained for The Bahamas from work conducted by Iversen (1980 - 82) and from reanalysis of the data by the ongoing conch research program sponsored by the Department of Fisheries. The Natural Mortality (M) values were obtained by averaging the values found in the literature.

The ANCOVA results show that the various fishing areas are significantly different from each other and therefore require individual assessments for their resources. Therefore, the data for Grand Bahama Island were used to conduct a specific area assessment. The F_{tuned} used for the analysis was obtained using the graphed regression range for the weight converted catch curve analysis. The value selected corresponded to a meat weight range between 90 to 130 grams. The F_{tuned} value obtained was 0.3435 $year^{-1}$. The calculations on abundance at weight for the stock obtained from tuned weight cohort analysis show that the catch numbers are at least an order of magnitude less than the abundance. The total conch biomass for the Grand Bahama fishing area is calculated to be over 881 600 kg of conch meat. The catch removed from the area is estimated to be about 117 335 kg. The F values for the exploited stock was found to be a relatively low 0.154 $year^{-1}$. All of these factors would indicate, according to the preliminary results of the model (Table 3.1.1), that the stock in the Grand Bahama area is not yet being fully exploited. This is further supported by the substantial calculated recruitment weight for the area. However, it must be noted that the natural mortality is certainly much higher at the initial life stages for conch than later in life and also, as discussed during the Workshop, that the M adopted for use during the exploitable phase for conch may be too high.

Table 3.1.1 Summary of results from the weight based cohort analysis.

RESULT	
F – exploited stock	0.154
Total abundance	21 142 378
Total biomass	881 600

The mortality due to fishing is lower in the smaller size classes than in the larger size classes, which are fully recruited to the fishery (Fig. 3.1.1). This exploitation pattern suggests there is some selection by fishermen for the larger and more mature conch. The trend in the abundance in numbers of conch by meat weight categories shows that there is a rapid loss of conchs due to the high natural mortality rate selected (Fig. 3.1.2), reaching almost 50% between the first and second recorded meat weight categories. The graph also suggests that the conch catch could be increased for this specific area.

The improvements that can be made to this model include refinement of the area specific data needed for input to the model. The k and L_∞ values ought to be determined specifically for the areas being assessed. This is especially important because the various areas of The Bahamas are proven to be significantly different from each other. Therefore any parameters determined in one area may not be safely transferable to another. There is also significant variability in the conch stock within the particular areas. Perhaps a method of classifying the conch types according to the morphometric attributes needs to be designed.

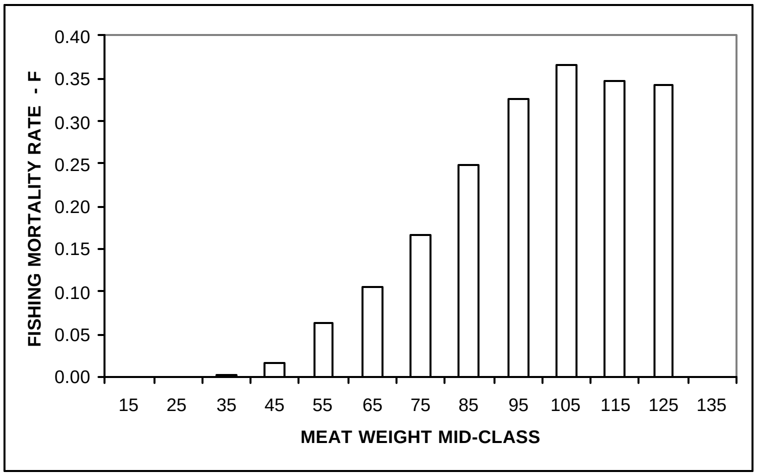

Figure 3.1.1. F-estimates by mid-class weight from applying the calibrated weight cohort analysis technique to the 1997 weight frequencies and total conch landings in the Grand Bahama fishery, based on M of 1.19 year^{-1}.

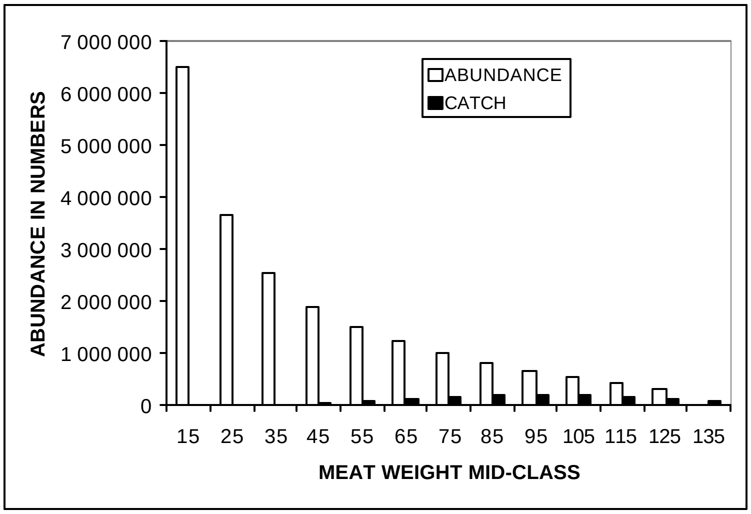

Figure 3.1.2. Stock abundance and catch in numbers estimated from applying the calibrated weight cohort analysis technique to 1997 weight frequencies and total landings in the Grand Bahama conch fishery, based on an M of 1.19 year^{-1}.

3.2 Belize

3.2.1 Background

The fishing industry in Belize is mainly an artisanal industry and is carried out within the shallow protected waters of the main barrier reef (reef flat and reef slope), as well as the atolls. It employs approximately 4 000 fishermen and 500 processing and market workers. It consists of two large very active co-operatives (Northern and National Fishermen Cooperatives) and three smaller co-operatives.

The fishing industry is a major contributor to the Belize economy, primarily in respect to foreign exchange earnings. The seasonal conch fishery earned approximately BZ$3.3 million from 212 t of processed product and 11 t of conch shells in 1998. Produce is landed at the co-operatives like lobster, and a similar policy exists for local sales. During the season, the fishermen who had previously targeted lobster, target conch, and when the seasons are running concurrently they fish for both. Conch is caught along the fore-reef, and the inner lagoons, and is fished exclusively by free diving. The different type of fishing vessels used is reflected in the different ethnic groups, but the main vessel used is the sloop.

The conch fishery is governed by size restrictions and by a closed season. No conch should be caught which does not have a total shell length of 7 inches and no landed meat should be less than 3 oz. The closed season extends from 1st July to 30th September. No conch should be caught in Belize using SCUBA or hookah equipment.

3.2.2 Description of Data

The Belize data set comprised the following: Total annual conch production per area, morphometric data, juvenile growth parameters and an estimate of the natural mortality rate. A brief description of these data follows.

Total catch data was available from the late 1970s. This was the total queen conch catch per year and was compiled from sales slips records from the co-operatives. This figure, however, is not a true representation of total catch annually. It does not include what is sold on the local market and the conch caught illegally and taken across to neighboring countries.

Effort data and total production data was only available for three years (1996, 1997 and 1998) for all five fishing areas. Effort is recorded as number of days fished and is obtained from a copy of the sales slip given to fishermen as they land their catch at the co-operatives. The sales slips were modified to include the area fished, number of days fished, total catch per trip and gear.

Although most of the conch harvested is landed at the co-operatives, the small amount consumed by the local market is not unaccounted for. There is also the problem of illegal fishing in Belize. As a result, production data underestimates the total catch since it does not include the catch being harvested illegally and taken out of the country.

Morphometric data was only available for three years (1996, 1997 and 1998). The data were collected once a year and was limited to only one area. From this area, measurements were obtained from 300 individuals collected per year. The measurements recorded in each occasion were:

- Shell length (mm)
- Lip Thickness (mm)
- Total weight (g)
- Meat weight (g)
- Maturity
- Sex

For the years 1996 and 1997, the data was obtained by placing a data collector on one of the sloops. The data collector then collected morphometric information on a sample of the total catch of that vessel. As a result, these data represented only individuals that were over the legal size limit of 7 inches.

The 1998 data was fisheries independent. As a result, these data correspond to individuals that are above and below the legal size limit. Since biological data was only available for one area, size-based stock assessment could only be done for that area.

3.2.3 Catch and Effort Data Analysis

Belize only possesses three years data, so results are preliminary and cannot be used until more data become available. To estimate the unexploited stock size (B_{∞}) and catchability (q), the rate of increase (r) had to be fixed. A value of 0.53 year^{-1} was chosen as an approximate value derived from the Caicos Bank stock assessment. The resulting estimates are very unreliable (Table 3.2.1) as there is also little contrast in the data (Fig. 3.2.1).

Table 3.2.1 Parameter estimates from fitting the dynamic Schaefer to the catch and effort data

r (year^{-1})	B_{∞} (kg)	q (fishing day^{-1})	MSY (kg)	Effort at MSY (fishing days)	Fishing mortality (year^{-1})
0.53	2146400	4.03 10^{-06}	284398	65720	0.307885

It was believed that the conch stock in Belize is overexploited. However, with only three data points estimating two parameters, it does not show a true representation of the exploitation of the fishery. The MSY value is just above the total catch caught in 1998 (253 t). Given the very small amount of data, the only conclusion that can be drawn is that the catch and effort recording needs to be continued.

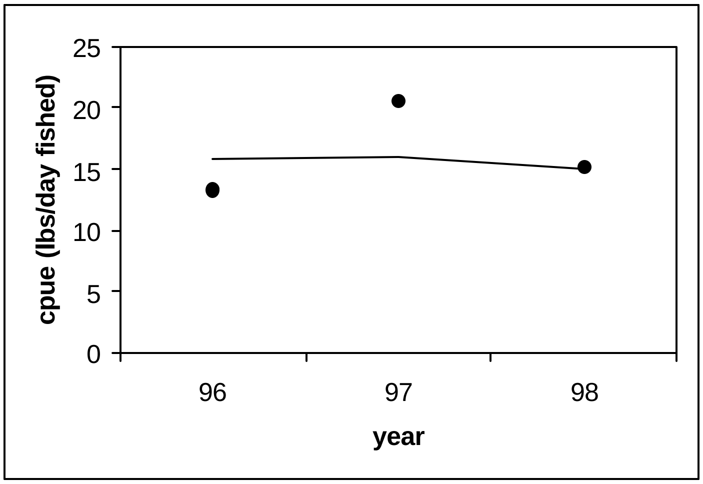

Fig 3.2.1 Observed (·) and expected (¾) CPUE for the available three years data.

3.2.4 Weight-Based Stock Assessment

The method is a tuned weight cohort analysis (See Appendix C). The tuning is achieved by changing the initial F/Z required in the new weight cohort analysis until the average weighted fishing mortality for a given weight range equals an externally supplied fishing mortality rate for the same weight range as above. The external Ftune value is calculated by means of a new weight converted catch curve also provided.

The juvenile growth parameters were obtained from Strasdine (1984). There were estimates for three areas in Belize and an average of the three areas was calculated for the growth parameters. Parameters used are: L_∞ = 300 mm, K = 0.22 yr^{-1}, and t_0 = -0.19 yr.

An asymptotic weight (W_∞) for the edible meat was required by the new growth model used in the stock assessment. This W_∞ was obtained by determining the mean meat weight of adult individuals (individuals with shell length greater than or equal to 230 mm). This was done for each year covered in the assessments (1996, 1997 and 1998).

The average M for the queen conch given in the literature was used (1.19 yr^{-1}). This value may be higher than the true M as it includes estimates for the very young conchs, which are subjected to much higher natural mortality than adult conchs due to predation.

The F_{tune} values used for tuning the weight based cohort analysis were obtained using the graphed regression ranges for the annual weight converted catch curve analysis (Table 3.2.2). The tuned weight cohort analysis results indicate that the fishing mortality values for the exploited weight categories in the stock are generally small (Table 3.2.3).

Table 3.2.2 The F_{tune} values obtained for each year used for tuning the weight based cohort analysis.

Year	F	Valid Weight Range
1996	0.685	260 - 290
1997	0.270	200 - 300
1998	0.328	120 - 230

Table 3.2.3 Fishing mortality, meat (edible) biomass and abundance estimates for the exploited stock.

Year	F exploited stock ($year^{-1}$)	Biomass (kg)	Abundance (N)
1996	0.209	163 839	1 087 719
1997	0.222	352 643	2 244 922
1998	0.318	524 762	3 675 659

These estimates, however, were obtained with an uncertain natural mortality rate that may be overestimated, in which case these values will be underestimated. In spite of this, it is important to note that the fishing mortality rate estimates for the exploited stock show an increasing trend from 0.209 in 1996 to 0.318 in 1998 (Table 3.2.3). These estimates are indicative of large changes in annual population abundance expressed in meat weight. These estimates correspond to one relatively small area of the entire fishery and the abundance levels are considered to be high for that reason.

Looking at the results by-weight-class, it is observed that for the three years considered in the analysis (1996, 1997 and 1998), the larger animals were being exploited more intensively than the juveniles, although juveniles were also being targeted (Fig. 3.2.2). Larger animals show very high fishing mortality rates well in excess of the natural mortality rate used in the computations. This is especially conspicuous in the last two years. Also, the figures show that the fishing mortality for the juveniles have shown a marked increase over the three years. This may be the result of the increased fishing pressure observed on the adults and the possible depletion of the larger individuals in the stock.

The abundance by meat weight classes (Fig. 3.2.3) showed that the juvenile catch was well below their abundance. However, the larger animals were being exploited at considerably high levels. This may be a clear indication that in the area analyzed, fishermen are targeting the larger animals to meet the size requirements, which governs the fishery. So, the largest animals are being fished out at relatively high exploitation rates as observed in all the previous figures. This may be forcing the increased utilization of the juveniles as their fishing mortality rates have also increased, especially in the last year of the analysis.

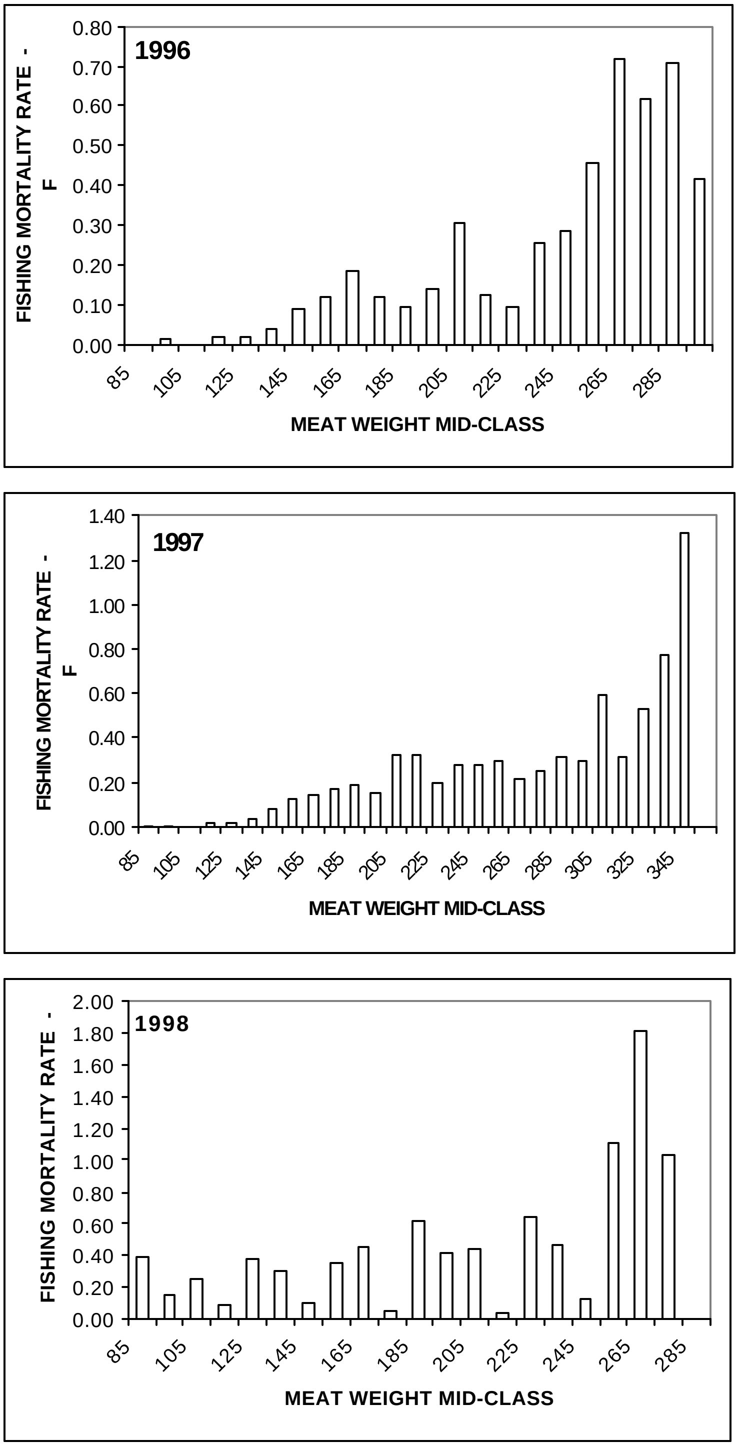

Figure 3.2.2 Estimated fishing mortality by weight class for the years 1996-1998.

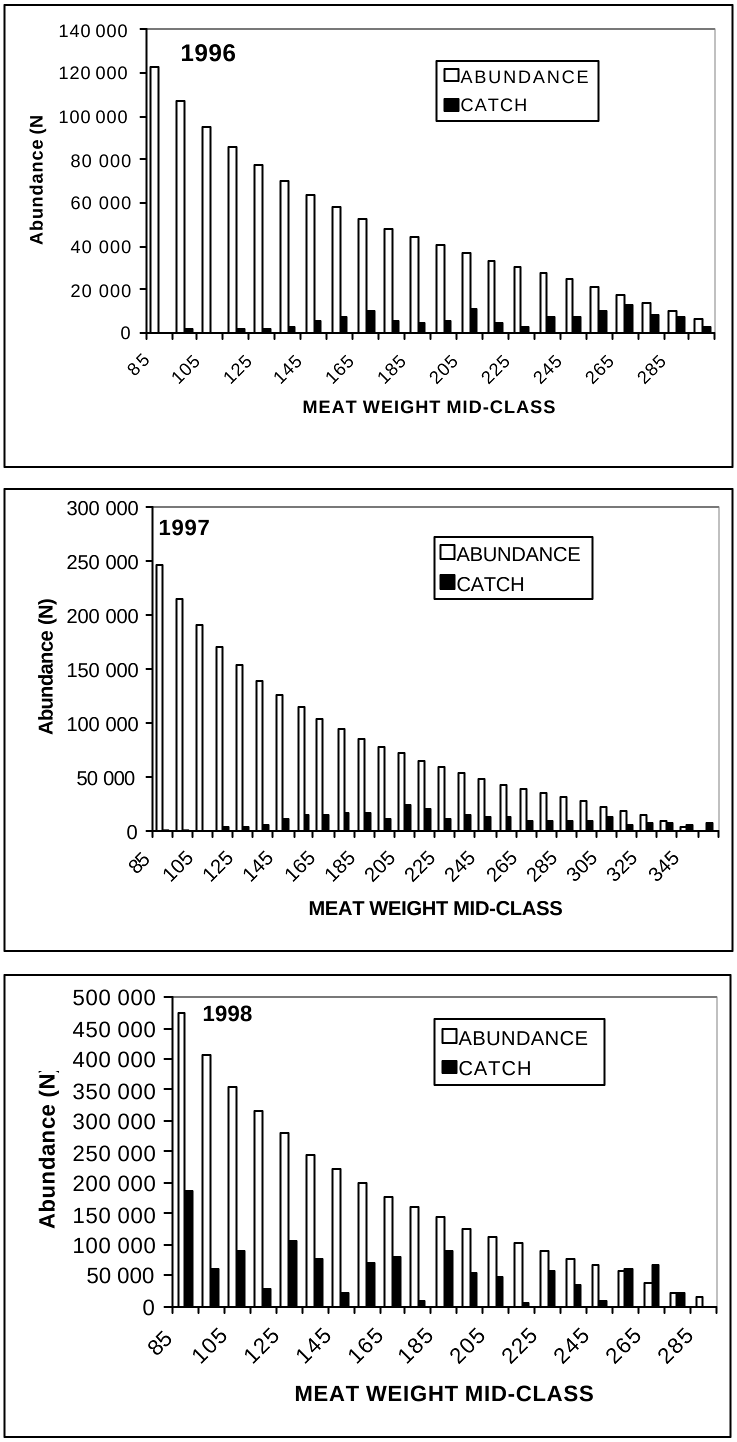

Figure 3.2.3 Abundance and catch by weight class for the three years analyzed.

3.3 Grenada

3.3.1 Background

Grenada, a small country of only 344 km^2, is located in the Southern Caribbean, between St. Vincent and the Grenadines (North) and Trinidad and Tobago (South). Grenada has a total shelf area of 900 km^2, within which there are large areas of sand and coral rubble that support conch populations.

The conch fishery is important to Grenada as conch meat is used extensively by local people and as a delicacy in the tourist industry, as well as an export product. Most fishermen harvest conch using SCUBA and free diving from small wooden boats with outboard engines. The catch is landed at many landing sites throughout the island. On occasions, the fishermen save their catches in 'crawls' until ready for market (the Grenadines) and only meats are landed.

3.3.2 Description of Data

As a participant of CFRAMP, conch data collection began in late 1996 and went on through 1998. Generally, fish production data is collected at seven primary and two secondary landing sites. However, conch data collection presents a number of problems.

(i) Conch is landed at only two primary landing sites and at a number of secondary sites, directly to hotels and restaurants and to traders who export them to Trinidad and Tobago. This creates a problem in determining total production.

(ii) Another problem presented to the data collectors is the question of effort. Fishermen diving for conch do not target exclusively conch, but other species like lobsters, fish, etc. The problem then arises, how do you estimate the effort time actually spent in the harvest of conch?

(iii) Conch are not usually landed in shells. This is because the fishermen try to avoid the excess weight and special arrangements have to be made with the fishermen to be able to sample conch shells.

3.3.3 Description of Data

Mostly biological data were available at the workshop and that data included:

- Total weight (shell and meat)
- Shell length
- Lip thickness
- Meat weight
- Sex
- Effort data on the fishing activity for a number of boats sampled on a given day. However, this effort data cannot be applied exclusively to conch as the divers also target other species such as lobsters and fish on the same trip.

Historical data on catch and effort were not available.

3.3.4 Weight Based Data Analysis

The weight-based stock assessment technique was tried. However a number of problems were found. Firstly, the data set provided no information on juvenile conch. This resulted from the fact that the data collectors sampled only conch landed by local fishermen which consist of only mature conch due to Grenada's size limits. Secondly, when attempting to input total catch numbers into the module, it resulted that the meat weight increments (classes) recorded in the data were not sufficiently accurate resulting in gaps (zeros) in the data set. This did not permit the continuation of the exercise.

3.3.5 Conclusion

Based on the problems encountered while trying to use the methods presented at the workshop, there are a number of concerns, which need to be addressed.

1. The size-based method presented at the workshop takes into consideration only meat weights. Other data, total weight, shell length, lip thickness and sex, were not used, but are collected.
2. The average weights of conch from different areas differ considerably. It was not clear whether the size-based method at the workshop would give robust results despite this problem.
3. Meat weight records need to be standardized (percentage processing).
4. 'True effort' in the conch fishery needs to be determined, as the divers do not target only conch on a fishing trip, but also other species such as lobsters and fish.

The answers to these concerns would decide what recommendations would be made for future conch assessment.

3.4 Jamaica

3.4.1 Background

Jamaica is located approximately 145 km south of Cuba and 161 km west of Haiti. The island is 236 km long, between 35 and 82 km wide, with a total area of 10 940 km^2 and a coastline of approximately 885 km. Numerous coastal features, such as harbors, bays, beaches, estuaries mangrove, rocky shores, cays, coral reefs and lagoons, punctuate the coastline. Jamaica has a tropical maritime climate, which is modified by northeast trade winds and land sea breezes. Average temperature is 27°C, with seasonal variation from 23 to 28°C.

There are over 11 000 registered fishermen and 3 500 registered vessels, although it is estimated that there are in reality about 20 000 fishermen and 9 000 vessels. Jamaica has presently 187 fishing beaches, including 3 offshore cays. Of these there are presently 152 active beaches (i.e.fishing activities are presently occurring on these beaches). The fishing areas in Jamaica can be divided into two main areas; (i) Near shore – north and south shelves, (ii) Offshore – Pedro and Morant Banks.

The conch fishery, mainly queen conch (*Strombus gigas*), plays an important role in the economy of Jamaica. It is the largest fishery in the region, and has landed a maximum of 3 000 t in one year (Fig. 3.4.1). It is also a major earner of foreign exchange for the country, earning between 8 – 12 million US dollars every year for the country. The industry employs many Jamaicans especially in the processing sector.

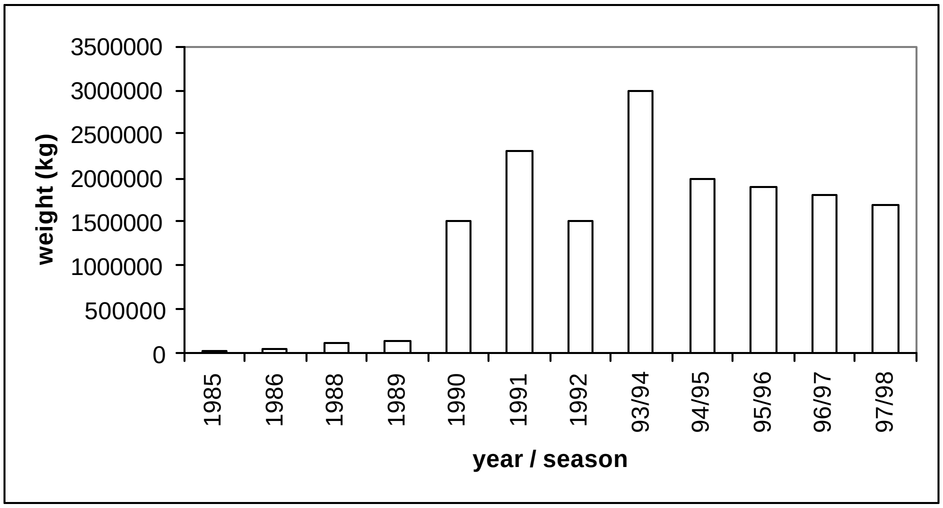

Figure 3.4.1 Jamaica conch landings 1985-1998. In 1993, statistical recording switched to fishing season rather than calendar year.

Before 1992, the Jamaica conch fishery was unmanaged. Despite the exponential increase in effort and production since the expansion of the industrial fishery in the middle 1980s, the fishery was allowed to continue without regulation or management plan.

The fishery comprises 3 categories of fishermen:

- **Industrial fishermen** are large producers who process conch for the export market. They operate vessels with a mean size of 23m LOA, which average 10 divers per vessel. They fish all over Pedro Bank exploiting depths to approximately 25m. The fishermen use SCUBA and hookah to capture conch. Of the National Total Allowable Catch, 80% is allocated to the industrial fishermen (i.e. the Industrial Total Allowable Catch).
- The **offshore artisanal** sector consists of small-scale fishermen based on the offshore cays using hookah and free diving to exploit near-shore areas on the Pedro Bank (artisanal zone), up to depths of approximately 15m. Carrier vessels, such as "packer boats", which travel from the mainland to the cays, buy 'dirty conch' (50% processed) and sell directly to processing plants. Other fishermen generally fish using SCUBA and free-diving. They sell the conch to processors, local traders and to a lesser extent, on the local market, primarily to the hospitality industry. The offshore artisanal fishermen harvest 20% of the National Total Allowable Catch (i.e. the Artisanal Total Allowable Catch).
- **Mainland artisanals** are small-scale fishermen who dive for conch on the island shelf (north and south). Conch is mainly harvested for local consumer demand (conch is not exported or supplied to processing plants). Little conch is harvested on the south shelf (Table 3.4.1). Conch landed not only includes queen conch, but other species as well. Industrial fishing is not allowed on the island shelf.

Table 3.4.1 Landings of conch on the island shelf, 1996– 1997

Year	Landings (t)
1996	1.22
1997	21.20

The number of vessels licensed for fishing conch on the Pedro Bank varies from year to year. Industrial size vessels range from 20-35m and are usually operated by processing plants. Most vessels are leased from countries such as the USA, Nicaragua, Honduras and the Dominican Republic. The crew consists of about 36 individuals including divers and dorimen (canoe operators). Dominican divers use hookah (air compressor and air hose and regulator attached for breathing under water) for fishing conch. Hondurans and some others use SCUBA. Conch is picked up, shelled and only the meat taken to the surface. Further processing to different levels (Table 3.4.2) may take place on board the vessel. Each trip can return with about 24 000kg meat, with trips averaging 1 per month.

Table 3.4.2 Conch processing classification as defined for the Jamaican fishery.

Process Level	Tissue Loss
"Dirty" – unprocessed	None, animal simply removed from shell
50%	Operculum ("claw") and viscera ("bag")
65% "semi-fillet"	"head" (eyes, stalks, and proboscis), "claw" "bag" and part of mantle ("skirt")
85%	all of the above plus verge, "skirt" and most of skin
100% "fillet"	only pure white meat remains

By 1990, the Fisheries Division of the Ministry of Agriculture became very concerned that the level of conch exploitation was beyond sustainable levels. Mahon, Kong and Aiken (1992), predicted that the fishery would collapse within three years if the then high level of exploitation was not reduced.

In 1992, *Strombus gigas* was added on Appendix II of the Convention of the International Trade of Endangered Species of Wild Flora and Fauna (CITES). The convention requires that all international trade in the species involving CITES countries (Parties and Signatories) be accompanied by a valid CITES permit, or comparable documentation, and is reported to the

CITES Secretariat. CITES permits must be issued by the authorized national CITES Management Authority and endorsed by the Scientific Authority. The Jamaica CITES Management Authority is currently the Natural Resources Conservation Authority (NRCA), Ministry of Environment and Housing.

As a result of the predicted collapse of the fishery and CITES, several meetings were convened with conch industry members. A draft fisheries management plan was discussed and formulated.

In 1993, Jamaica established a quota system for the queen conch Fishery. There were several factors that led to this decision, including the fact that 95% of conch was exported, the requirement that importers have CITES certification, and in preparation for ratification of CITES by Jamaica.

In 1994, CITES became concerned about the high level of export meat from Jamaica (estimated at 3 893 t) and requested the conch management plan for Jamaica. During this time the plan was in a developmental stage and highlighted the need for an abundance study on the Pedro Bank to determine the sustainable quota levels for the fishery. CITES ruled that the research work must be carried out and a sustainable quota determined for the Jamaican conch fishery before it would authorize its member states to allow any more imports. Consequently, all export of conch was discontinued. This position by CITES forced conch industry members to fund a research project that would determine the abundance of conch on the Pedro Bank.

There are five management objectives laid out in the fisheries management plan:

(i) To monitor and control the conch capture fishery to maintain optimum sustainable yields;
(ii) To promote the rehabilitation of overexploited stocks;
(iii) To monitor and control all current activities relating to the processing of conch, with a view to optimizing the value of the conch resources by the establishment of processing standards and legal minimum levels of processing;
(iv) To obtain optimum foreign exchange earnings from the export of conch; and
(v) To obtain an optimum yield for local consumption by residents and tourists.

The major elements of the conch management strategy include:

- **Limited entry** licensing for the industrial conch fishery (restrict the total number of conch motor fishery vessels) and a maximum number of divers (depending on the specific gear utilized) and fishing vessels per “Mother” Boat.

- An annual four-month **closed season** for conch, which commences on 1st July and ends 31st October. It is enforced through inspection of conch to enforce the legal minimum size and weight of conch, a mandatory declaration of conch during the closed season and prohibition of the processing or importing of conch during the closed season.

- A **Quota Management System** provides for the Minister to set an annual National Total Allowable Catch (NTAC) based on the best available scientific information. The NTAC is divided among industrial and artisanal processors using a formula to be agreed upon by the Fisheries Division and conch industry members.

- Provision for an **Exclusive Fishing Zone for artisanal conch fishermen** is made in the plan for the Minister to declare any area on the Pedro Bank and any near shore or offshore bank an Exclusive Artisanal Fishing Zone. Under the plan, the Island shelf of Jamaica and the waters extending five nautical miles should be declared an Exclusive Artisanal Fishing Zone.

- The plan allows for restrictions on the **importation of SCUBA and hookah fishing gears** is pro

Setting appropriate controls depends upon timely and accurate scientific advice from stock assessment.

In 1996, a survey was conducted on the Morant Cays, to determine the abundance of conch and whether this area could also be commercially exploited. Although the density of conch was found to be similar to the Pedro Bank, the isolated nature of the cays and difficult conditions make the development of a commercial fishery unlikely.

In 1997, the major export markets (the European Union and the United States) have established stringent quality control conditions (Hazard Analysis and Critical Control Point - HACCP) for the importation of seafood into their country. Among other things, basic minimum standards are set for seafood processing plants. All seafood plants must satisfy these standards and must be certified by the authorized government departments (Veterinary Division, Ministry of Agriculture and Mining and the Jamaica Bureau of Standards). In compliance to the European Union regulations, the Veterinary Division drafted the “Marine and Aquaculture Products and By-Product Inspection Act, 1997”. This Act was submitted to the Parliamentary Counsel for review. In addition, the relevant EU Directive is currently in force and the USA will begin to enforce this new requirement in 1998. Also, in 1997, the second conch abundance survey was conducted on the Pedro Cays.

In 1998, the Natural Research Conservation Authority, in compliance with the CITES regulations drafted “The Trade in Endangered Species (Convention) Act, 1998”. This Act deals with the regulation of trade in endangered species, which relates to the Queen Conch. This document has also been submitted to the Parliamentary Council and is awaiting review.

3.4.2 Description of Data

Catch and Effort Data

Data log sheets are issued to industrial operators and the vessel captains who return completed sheets to the Fisheries Division. No direct data collection program has been designed for the offshore artisanal fishermen. With an expected increase in the artisanal fishermen in the 1998/99 conch season it is important that data, especially effort, are collected from each fishermen. For offshore artisanal fishermen, it is assumed that the processing plants collect most of the conch brought in by the packer/carrier vessels, so landings are available from this source. Catch and effort from near shore artisanal fishermen are collected in the regular data collection program. Total landings are cross-checked with export certification forms from NRCA. There is no estimate of the level of poaching on the Pedro Bank.

Landings data for the Pedro Bank extend back to 1985, although records changed from calendar year to season in 1993. Effort data extends back to 1993/94 season.

Biological Data

The biological data collection program aims to detect changes in the meat weight in each fishing ground, refine growth parameters (i.e. k, L_∞) and detect changes in the spawning stock biomass and patterns of reproduction. Biological data is collected monthly from the processing plants during the fishing season. A sample size of 1000 individual conch meat were sampled per processing plant per month, but the sample size was reduced to 500 individual meat weights. Quarterly trips are planned to Pedro Cays to obtain information on length-weight relationships. No biological data is being collected from offshore artisanal or mainland artisanal.

Visual Surveys

The area of Pedro Bank has been surveyed twice. The survey divided the bank into four strata defined by depth measurements, three of which were assessed in the survey. A total of 58 stations were randomly chosen from a grid set over the bank, with the majority of the stations allocated to the second stratum where exploitation mainly occurs. Commercial divers were used to collect data with the aid of a scientific diver to ensure that sampling methods were adhered to and to describe the general bottom characteristics. A GPS was used to locate each station, which had 20 sub-sites each.

The results showed an increase in density with depth. Therefore artisanal stratum (0-10m) had the lowest density of conch while the deepest stratum surveyed had the highest observed density.

An abundance survey gives a snapshot of the resource. However, several approaches are available for examining the potential production of stock based on its abundance and rate of mortality. The data from the survey were:

1. Description of the morphometrics and population structure

2. Estimates of growth rates and age using size frequency distribution
3. Estimates of population density and overall abundance

MSY was estimated at 1800 t for Pedro Bank for 1995. Samples taken from the processing plants suggest that the potential meat yield per conch seems to be below that sampled from the three major sites, and may indicate the small overall size of conch in the deeper areas of the Bank, which constitutes the majority of the conch habitat. Males and females examined morphometrically were found to be significantly different. From the results and awareness from the study, Jamaica now has a temporary strategy in place for monitoring, control, and protection of the stocks although funds are limited.

For the second survey the Pedro Bank was again stratified into three zones, but only the 10m and 10-20m zones were sampled due to a lack of resources. 22 of the original 47 sample sites were revisited, with 5 sites from the 0-10m zone and 17 10-20m zone. Two teams of two divers each was used to collect data.

Large standard deviations were seen in the range of densities among sites although living conch was seen consistently at all sites. High densities of dead conch was also found at nearly all sites, accounting for a ratio of live to dead exploitable size/age categories in the artisanal zone of 1:6.4, and in the second zone a ratio of 1:1.8 live to dead conch.

The overall density and abundance of conch on Pedro Bank even with the significant decrease from the first survey, are at least 10 times that reported from areas in the region and are on the same order of magnitude as reported in the first survey. Analyses are based on a comparison between all stations sampled in 1994.

Based on all available scientific data the exploitation rate is beyond the sustainable capacity of the stock given the significant changes that have occurred in population densities, overall abundance and population structure over the last three years. Another observation is that the level of fishing mortality (catch) has not been equally distributed over the area of the Bank (0-30m) on which earlier (Appeldoorn 1995b; Tewfik 1996) estimates of MSY were based. Also the problem of poaching has not been addressed and thus accounted for when calculating MSY.

3.4.3 Catch, Effort and Visual Census Data Analysis

Catch data extends back to 1990, effort data to 1993/94. Two methods were used to estimate the maximum sustainable yield limit reference point (MSY). A standard Schaefer model (see Appendix B) was fitted to the data. However, because the data series was very short, the rate of increase (r) was fixed at a level close to that obtained for Turks and Caicos Islands model, which possesses a much longer time series. The alternative method was to fix the 1994/95 population size in the time series to the estimate obtained from the fishery independent visual census, but allow the rate of increase to be estimated (Fig. 3.4.2). The total number of adult conch in 1994/95 was estimated to be 108 558 000 from the visual census. Dividing this number by the number of conch in one kg (8.14; Tewfik 1996), it was estimated that the conch biomass at that time was 13 336 t. This figure was used as a fixed population size in the time series.

Table 3.4.3 Results from fitting the Schaefer model with and without using the visual census stock size estimation.

	r	B_{∞}	q	Initial	MSY (t)
Catch Effort Only	0.50	10287716	$6.59\,10^{-6}$	0.9	1297
Visual Census	0.24	12007394	$2.23\,10^{-6}$	NA	715

The two analyses gave quite different results (Table 3.4.3), with the two MSY estimates spanning the range of previous estimates (Table 3.4.4). This underlines the uncertainty in the results and the need to identify some reliable target figure for the catch quota. The most important difference in parameter values was between the assumed and fitted rates of increase (r). The fitted rate of increase was much smaller because the decline in CPUE has been steeper than that expected with a higher rate of increase value, hence producing a smaller estimate of MSY.

Table 3.4.4 Potential yield calculations (MSY) for the Pedro Bank Conch Fishery based on November 1994 survey data (Source, Tewfik, 1996; this report)

Method	MSY (t)	95% C.I.
Gulland (1971)	830	265 – 1742
Cadima	970	731 – 1044
Fully recruited year class (L+SA)	1184	359 – 1954
Caicos Bank comparison	739	683 – 776

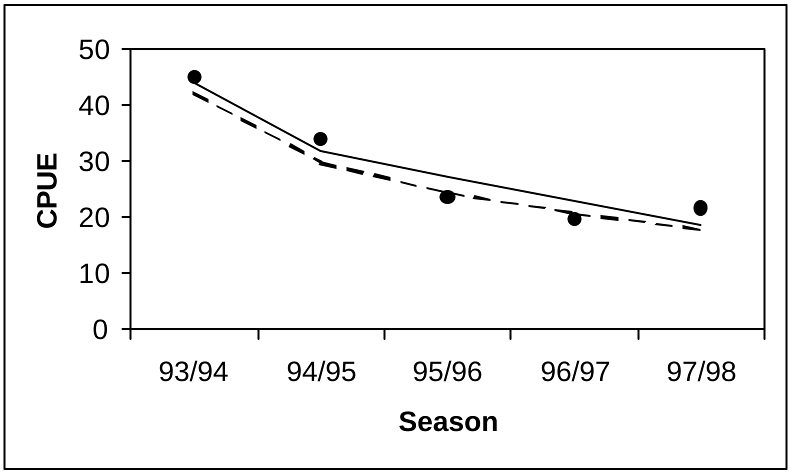

Figure 3.4.2 Observed (·) CPUE and expected CPUE for the Schaefer with (– –) and without (¾) fixing the population size in the 1994/95 season to the visual census estimate. It is not possible to choose between the two models as the data does not possess enough contrast to provide a test. The visual census is probably the most reliable as it uses an independent assessment of the population size, but little confidence can be placed in any of the estimates with only 5 data points and declining CPUE.

An alternative method was to use the visual census age categories to model the age structure of the population. When conducting the visual census survey, abundance was recorded in broad size/age classes (juveniles, mature and stoned). Two classes of juveniles could be considered as future recruits, whereas mature and stoned were the exploited stock. These categories allowed for the construction of a simple recruitment model, where the initial population size and subsequent recruitments were derived from the visual census directly. This left two parameters, natural mortality and catchability, to estimate from 4 data points. Again, the lack of data will give unreliable results. Not surprisingly, the catchability estimate ($2.23\ 10^{-6}$) was similar to that for the Schaefer model using visual census data (both population models were scaled to the same estimates). The natural mortality estimate (0.24 year^{-1}) may not be unreasonable for adult conch (Appeldoorn 1995b), but there is no independent support available in this study. Without a stock recruitment relationship, MSY is an inappropriate reference point for this model. However, with a longer time series, the model may be used to set quotas to the replacement yield so that the estimated population size remains stable (Table 3.4.5).

In general, the results were tentative due to the short time series of data available. The visual census data proved particularly valuable in considering alternative assessment techniques and making the most of the short catch and effort time series available. This may be further improved if not only a longer time series, but also more detailed data, such as catch and effort by trip and individual census samples, were to become available. In the meantime, results suggest the Pedro Bank MSY may well be below 1000 t. Given that MSY is a limit reference point, quotas may need to be continuously reduced until there are signs that the stock size is stable.

Table 3.4.5 Results from the visual census recruitment model suggests the population has declined throughout the period and fishing mortality has risen above natural mortality (M = 0.24 year^{-1}). However, the population model is not necessarily in full agreement with the CPUE time series, perhaps because recruitment is higher than that indicated. More visual census data is required to test the model and improve parameter estimates.

Year	Total Catch	CPUE	Recruitment	Population	F
94/95	16280000	277		108569510	0.18
95/96	15466000	193	9643840	80139158	0.24
96/97	14652000	161	20672910	65149523	0.29
97/98	13838000	176	7831605	44108175	0.43

3.4.4 Analysis of Gear Types

There are three different gear types being used in the fishery; hookah, SCUBA and free diving. Although, all the methods can be grouped as diving, each method exerts different effort. The two gears used in the industrial fishery were compared using ANCOVA (Appendix D). Two analyses were done. Firstly it was tested whether changes in gear type had occurred over the different seasons. There had been a significant shift from 73% hookah in 1995/96 to 81% hookah in 1996/97. Hookah is becoming prevalent in the industrial fishery. Secondly, gear catch rates were compared to see whether gears should be separated in the analyses.

Table 3.4.6 Gear performance as percentage of catch rate measured against catch based on catch and effort by season

Season	Hookah	SCUBA
1995/96	8% (+/-)	80% (-)
1996/97	43% (-)	98% (-)
1997/98	8% (+/-)	14% (-)

(-) not significant; (+) significant; (+/-) border-line significance

There are significance differences in catch rates by gear types between seasons (Table 3.4.6), which suggests gear type should be separated by fisheries management area in the analyses. Another factor to consider is the experience of the divers, as more experienced divers enter the fishery, the catchability may change.

3.4.5 Weight-Based Stock Assessment

The weight of landings and growth parameter estimates for juvenile conch were used to estimate abundance and the fishing mortality of conchs in the exploited population. The following average growth parameter estimate for juvenile conch were used in the simulated growth equation: L_∞=221.25, K=0.58 and t_0=0.1545. These values were estimated from an average of two sites surveyed by Tewfik (1996). The parameters a=0.00388 and b=1.959, used in the juveniles siphonal lengths - meat weight model, were taken from a re-analysis done by Iversen (unpublished data) on data collected in the Bahamas, 1980-1982. These values from the Bahamas were used, as the other juvenile growth parameters were similar to those estimated by Tewfik (1996) for Jamaica. W_∞ was estimated from the catch data using the last 25% or higher mass of the meat weight landings, by taking the average meat weight of the lower classes over 3 seasons and averaging them. W_∞ = 182.45. Two alternative natural mortalities (M) of 0.62 and 0.3 year^{-1} were assumed, as estimated by Appeldoorn (1995b).

Table 3.4.7 Results of the weight-based stock assessment applied to queen conch landings in Jamaica from 1995-1997.

Year	W¥	A3	F_{tuned}	F/Z	Abundance t	Biomass t	$F_{exploited\ stock}$
1995/96							
M=0.62	182.45	0.848	0.444	0.528	42 393	5 139	0.179
M=0.3	182.45	0.848	0.45	0.663	23 898	2 744	0.327
1996/97							
M=0.62	182.45	0.848	0.406	0.400	54 754	5 595	0.248
M=0.3	182.45	0.848	0.51	0.516	30 546	3 173	0.423
1997/98							
M=0.62	182.45	0.848	0.476	0.549	40 729	4 342	0.319
M=0.3	182.45	0.848	0.69	0.563	29 497	3 022	0.490

The results obtained for the 1995/96 season of an abundance of 42.39 million when M=0.62 was very low (Table 3.4.7) in comparison to that obtained by Appeldoorn (1995b) of 102.48 million. Also in 1996, Tewfik estimated total abundance at 146.2 million, while the value obtained in the weight-based stock assessment was 54.74 million. The significant differences in abundance estimate for the respective years could be attributed to the fact that landings have been affected by poaching, which was not accounted for in total landings.

The figure used for natural mortality may have been too high. Adult conch has a predicted maximum M of 0.62, and M=0.3 is the expected value for a mid-aged adult conch (Appeldoorn 1995b). The population size will be biased if M is incorrect. Also, the estimated abundance available for fishing is heavily dependent on the tuned F-values.

3.4.6 Conclusions

Reductions in Total Allowable Catch (TAC) which must be harvested over the entire area open to fishing at any given time should continue. Although the stock assessment results remain uncertain, the possibility that the sustainable yield may be below 900 t should be seriously considered and its implications assessed. Monitoring will require mandatory reporting of catch and effort information to the Fisheries Division prior to the off-loading of the catch which should be subject to random inspection of meat size and sexual maturity. In addition, some further restrictions, which may be considered in the future based on scientific assessment, include:

- **Size restrictions** to protect juveniles and sub-adults.
- **Closed areas** to create pockets of high conch productivity.
- **Gear restrictions** to ban the use of SCUBA and hookah gear in the artisanal zone (<10m depth).
- **Vessel restrictions** limiting the size of the commercial scale vessels (mother boats), therefore indirectly limiting the number of divers per vessel.

3.5 St. Kitts and Nevis

3.5.1 Background

St. Kitts and Nevis is a member of CARICOM States and therefore takes part in the projects initiated by the CARICOM Fisheries Resource Assessment and Management Programs. The islands' area is 269 km^2 and they have a coastline of 135 km. The fishing area inclusive of the Exclusive Economic Zone is 20400 km^2 with a shelf area of 845 km^2.

The shoreline features of Nevis include sandy beaches, fresh water lagoons, rocky shores and sea cliffs. The main coastal habitats are coral reefs, sea grass beds and fresh water lagoons. All three habitats are of critical importance to the marine ecosystem of Nevis.

The queen conch fishery has been a very important to St. Kitts and Nevis. The conch populations are considered overfished within the Federation, especially on the leeward side of the islands (Fisheries Management Plan 1997). However, conch are beginning to reappear in near shore areas in response to the concentration of fishing effort in deeper waters and the reduction of exports to the French islands due to CITES restrictions. In addition, Nevis appears to be a regional settlement area for larval conch. The conch is particularly susceptible to over fishing because it aggregates in specific habitats.

Conch inhabits the sea grass beds and coral rubble areas. It is harvested by free diving and SCUBA. Most of the fishing is done from small wooden open fishing boats with outboard motors ranging from 25 to 40 hp motor and an average length of 5 meters. The average number of boats operated in this fishery for 1998 was six with a crew of three persons per boat. The conch is landed at one landing site and sold to two intermediaries who in turn store, export and sell locally to the hotels, restaurants and the public.

3.5.2 Description of Data

Prior to the data collection sub-project initiated by CFRAMP, the Fisheries Division on Nevis collected data from the monthly export forms, which gives an estimate of the landings. The effort was collected by interviewing the fishermen involved in the conch fishery and is a subjective estimate of the annual average (see Table 3.5.1).

The conch sub-project was implemented on Nevis in 1997. It was then recommended to the Division to collect the following data: lip thickness, meat weight, shell length and a sample of the catch i.e. number of conch within the sample catch. These data are being compiled for 1998. The Division experiences difficulties in getting this information. Fishermen are unwilling to provide the Division with shells since the conch is not landed with the shells.

3.5.3 Catch and effort Data Analysis

Least-Squares Model

The estimated landings data presented were used in the dynamic Schaefer model to estimate the population size and expected catch time series. The results were uncertain for to a number of reasons. An important problem was the poor estimates of fishing effort. Because the estimated catch rates have changed little over the time series, it was not possible to estimate all parameters. Therefore the rate of increase (r) was fixed to the TCI estimate (0.53 $year^{-1}$), and only K and q were estimated, to give least-squares estimates of 2987 t and 3.01 10^{-6} respectively, giving an MSY of 395 t. The fit was poor, and unreliable. For example, different estimates resulted from different parameter start positions. The MSY result seems wildly optimistic as anecdotal reports suggest overfishing at a tenth of this value. This suggests the results are too unreliable to be used.

It is evident that reliable parameter estimates can not be obtained for the Schaefer model using this catch-effort time series alone. There is a distinct lack of contrast, with the only decline in catch rates occurring when landings have been reduced (Fig. 3.5.1). Although the dynamic aspect of the time series is unreliable, the series may still be useful to estimating catchability (q) if we had a better idea of the values of the population model parameters and therefore the underlying population changes.

Table 3.5.1 Nevis catch and effort data for conch. Landings were taken from export forms and effort is derived from annual interviews with fishermen. Total landings in 1991 and 1994 are missing data, but are provided as subjective estimates for fitting the biomass dynamics model.

Year	Landings lbs	Effort	Average # boats	Average divers/boat	Average hours/day	Average days/year
1979	115246	7488	9	1	4	208
1980	114789	7488	9	1	4	208
1981	114550	8320	10	1	4	208
1982	112420	8320	10	1	4	208
1983	178310	9152	11	1	4	208
1984	262515	10816	13	1	4	208
1985	243293	10816	13	1	4	208
1986	214385	10816	13	1	4	208
1987	178130	9984	12	1	4	208
1988	230284	9984	12	1	4	208
1989	200273	9984	12	1	4	208
1990	98256	5824	8	1	4	182
1991	*90000*					
1992	90648	3640	5	1	4	182
1993	49950	2496	4	1	4	156
1994	*35000*					
1995	34440	4680	5	2	3	156
1996	43650	4680	5	2	3	156
1997	19620	4680	5	2	3	156
1998	130225	7020	6	2	3	195

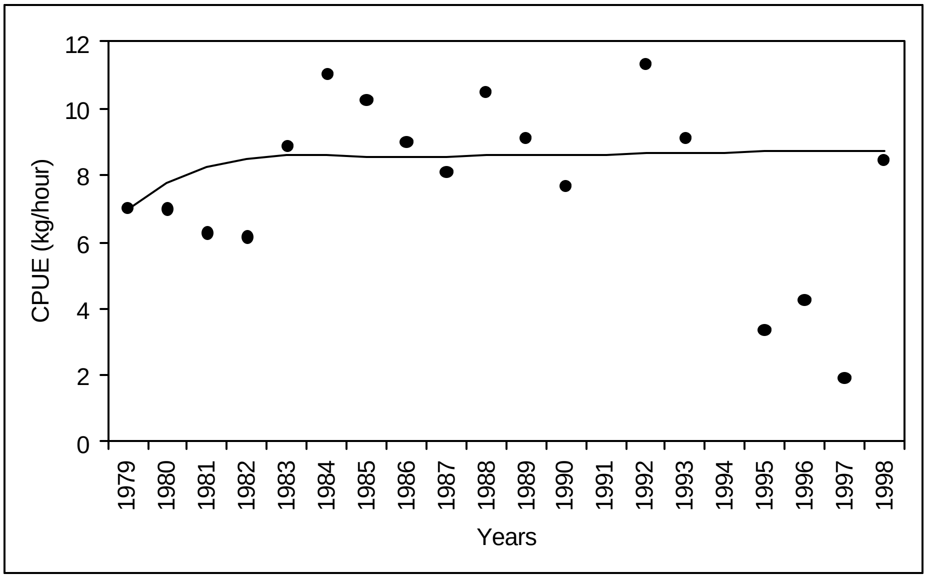

Figure 3.5.1 Observed (·) and expected (¾) CPUE obtained from fitting the Schaefer model with the rate of increase parameter (r) fixed at 0.53 year^{-1}. With the exception of years 1995-1997, the time series is flat. The decline in CPUE in these last three years makes little sense as landings had decreased, so there should have been some recovery in catch rates in this period.

Bayesian Assessment

Bayesian assessment is more complex than maximum likelihood and more difficult to do in practice. It offers some significant advantages, however, in terms of decision analysis and a simple way of combining information from different sources. The method and results presented here are preliminary. An important aim of this analysis is to show the potential value of sharing data even if stocks may not be shared, and hence the value of regional working groups on the main exploited species in the region. The methods are briefly described in Appendix B.

The aim of a Bayesian analysis is to calculate the full probability distribution of the parameters of interest. This is done here by combining a prior probability (based on the Caicos Bank model) and likelihood (based on the Nevis catch-effort time series) to produce the posterior probability density function (pdf). The posterior is then used itself to generate the probability distributions of values of interest, such as MSY, as well as in decision analysis. Decision analysis is used to find a control that maximizes some measure of expected gain ('utility', in this case sustainable catch). The expected gain is found by calculating the gain resulting from a particular set parameters multiplied by the probability that combination of parameters is correct, all summed up over all possible parameter combinations.

In both cases, risks of making the wrong decisions are accounted for explicitly. There is no guarantee that any particular answer is somehow the right answer. The emphasis is much more on rational choice rather than hoping to be being correct. This should deal with risks, which can never be eliminated. The only way to reduce risks is to gather more and better data.

In the first case, the probability distributions of two limit reference points were obtained from the posterior pdf of the r, B_∞ and q parameters. The cumulative frequency of MSY (Fig. 3.5.2) and effort at MSY (Fig. 3.5.3) based on random draws from the pdf indicate that MSY may well be attained by levels of catch and effort higher than those observed. This is extreme in the effort case, and is almost directly a result of the lack of a decline evident in the CPUE even with the higher catches. A precautionary approach would be to set catch and effort levels so that there is a low, say, 20% chance, of exploiting the resource beyond MSY (i.e. the 20th frequency percentile = 200; 180 000 lbs or 17000 boat days).

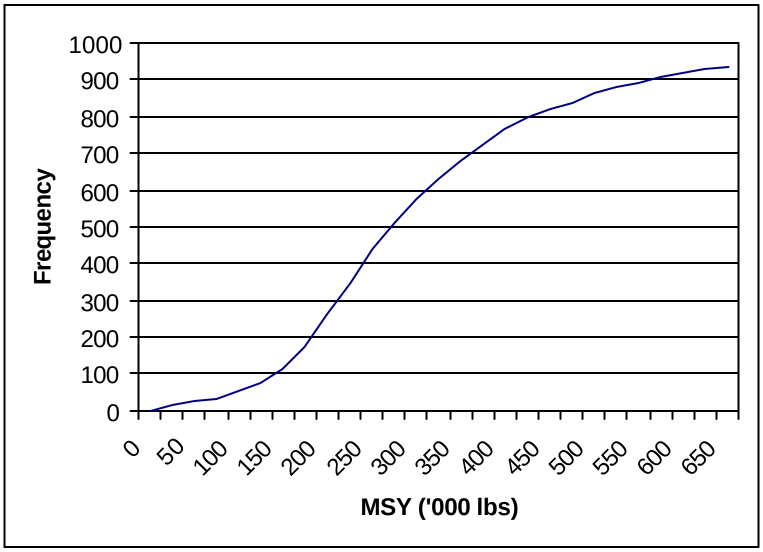

Figure 5.2 Cumulative frequency distribution for MSY based on random parameters drawn from the posterior pdf.

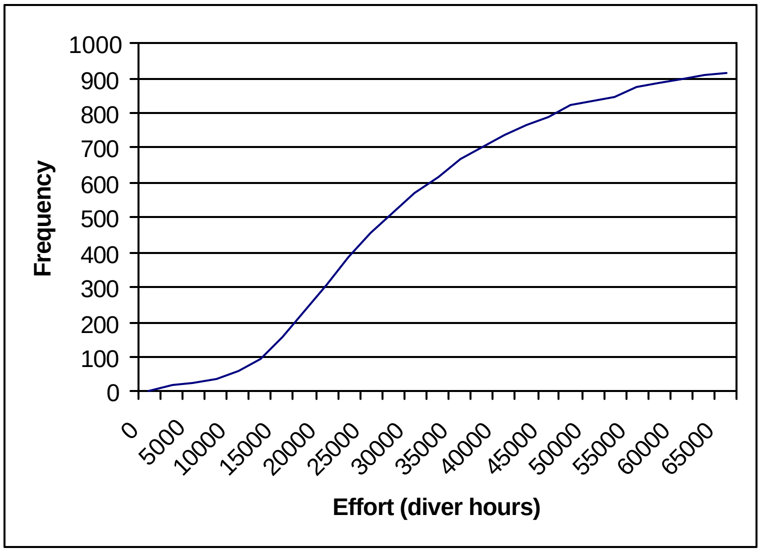

Figure 3.5.3 Cumulative frequency distribution for fishing effort to reach MSY based on random parameters drawn from the posterior pdf.

For the purposes of this analysis, utility was defined as the long term sustainable catch for fixed quotas of catch and effort. Where overfishing would occur (quota exceeds MSY or fishermen exceed those required to reach MSY), the 'utility' is set to zero.

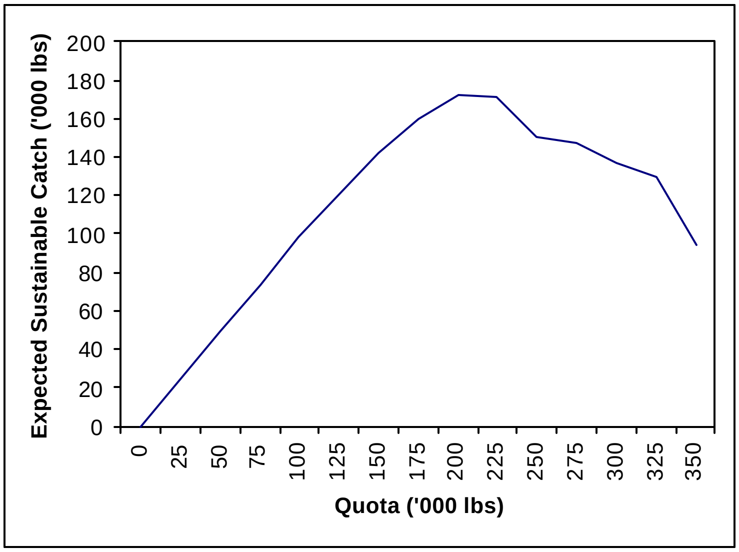

Figure 3.5.4 Expected long term catch from different quotas based on the posterior. The expected sustainable catch (utility) for each quota was calculated as the size of the quota or zero if the quota exceeded the MSY. The decision theory optimum quota would be set for the point where the maximum utility is attained, around 200 000 lbs in this case. The utility used (sustainable catch) is fairly risk indifferent, and including any level of risk aversion would move the maximum to the left. However, there is only a very low chance of overfishing below a 150 000 lbs quota, so this would only have a small affect unless unrealistic utility curves were chosen.

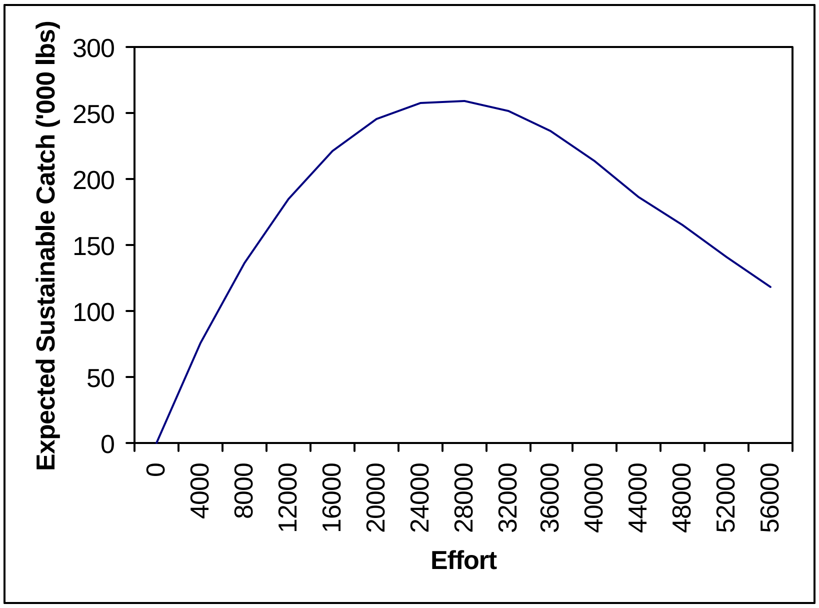

Figure 3.5.5 The expected long term sustainable catch obtained from different levels of effort (diver hours) for the posterior pdf. The observed effort has not exceeded 11000 (Table 3.5.1), but the optimum suggested from this analysis more than doubles this to around 28000. The effort analysis is more optimistic than the analysis on catch (Fig. 3.5.4), with higher expected sustainable catches. No economic parameters are used in the utility, and in particular, effort costs are ignored. Including costs would reduce optimal effort levels.

Conclusion

It is important to note that without the reliance on the TCI data, it would be impossible to use these data at all. Data series, such as that from the TCI, are valuable not just for the local assessment, but to provide additional information for the assessment of the same species elsewhere.

Superficially the analysis suggests there is a potential for higher yields and, accepting some risk, quotas around 200 000 lbs and much higher effort levels could be allowed (Fig. 3.5.4). There are three reasons why this view is probably optimistic.

The problems with the TCI model and with the Nevis catch-effort data set apply also in this case. The lack of a decline in the Nevis CPUE time series would be interpreted by the model as no significant change in population size, although overfishing is thought to have occurred at this time. Also the measures of utility (i.e. catch) are crude and based on equilibrium results. No economics is included, so although the MSY may indeed be as high as 200 000 lbs per year, this may still reduce catch rates to a level at which vessels make very little profit.

Walters and Ludwig (1994) and Punt and Hilborn (1997) caution against the extrapolations from one population to another as used here. One suggestion is to use additional data to estimate density, such as visual census, to apply a correction to the unexploited biomass estimate (McAllister and Kirkwood 1998a). This would be certainly useful and is recommended. However a similar argument would also apply to the rate of increase parameter (r) which would be difficult to estimate directly. What is clear is that such a prior should represent both the uncertainty of the original population parameters and additional uncertainty regards the extrapolation from one population to the other. The use of a prior in this way is only unsatisfactory if the full uncertainty is not represented (McAllister and Kirkwood 1998b). In this analysis, uncertainty was represented in an *ad hoc* way by increasing the spread of the prior through a smoothing parameter (see Press 1989), which to some extent addresses this problem. As more and better data becomes available, reliance on the prior is reduced and will eventually be eliminated altogether.

Can any recommendation be made besides those related to improved data collection? Given the model uncertainty, it is difficult to strike a balance between extreme caution and the needs of supporting a fishing industry. A Bayesian approach can rationalize this uncertainty. For example, we could introduce another unknown parameter representing the St. Kitts and Nevis conch density as a proportion of the TCI, which may take any value between 0 and 1. The uninformative prior for this parameter is uniform over the parameter range, so (approximately) integrating over this nuisance parameter would lead to results which suggest optimal levels of control to be 50% of those assuming equal density, hence a recommended quota of 100 000 lbs. This is unduly pessimistic as too low densities would assume fewer conch than has been already caught. Strictly speaking such a parameter should be included in the full analysis. In summary, a maximum catch of 100 000 - 200 000 lbs should be set. Based on the decision analysis, an interim precautionary maximum quota around 150 000 lbs would suffice until more information becomes available.

Preliminary results obtained so far are not robust, but probably the best that can currently be obtained. Improved collection of fishing effort and biological data (to establish morphometric relationships) is necessary in order to make better informed management decisions. Visual census counts in both the Turks and Caicos Islands and Nevis would allow the Bayesian assessment to make better use of the TCI data. In the interim, the precautionary approach suggested above is recommended.

3.6 St. Lucia

In St. Lucia like many of the other Caribbean countries, the meat of the queen conch (*Strombus gigas*) is considered a delicacy. With significant expansion of the tourist industry during the past two decades as well as a high demand from the neighboring island of Martinique, there has been a steady rise in demand for conch. This demand is expected to continue rising given the current focus on tourism development.

Previously the export of conch was prohibited, but a study on conch consumption in Martinique revealed that illegal exports to Martinique during the late 1980s were in the region of 5 tons annually. Exports have been permitted since 1993 under careful control through CITES. Vessels are required to export whole animals and are only allowed to operate through procedures required by CITES and following careful examination of the conch to be exported. However, exports to Martinique decreased significantly after the re-opening of the Martinican fishery in 1997 and trade restrictions imposed until St. Lucia gain EU compliance with regards health and sanitary controls for fishery exports into the EU territories.

Conch is exploited commercially by twenty to thirty divers who operate out of two landing sites in the North of the island (Gros Islet and Marisule). Fishermen operate out of ten open, wooden canoes and fiberglass pirogues ranging in length from 25-30 ft and powered by 115-250 hp engines. Harvesting occurs at least three times a week, alternating harvesting and rest days. The nearshore stocks have been depleted thus most fishermen use SCUBA to gather the conch, however some fishermen use gill nets and free diving for the conch resources that occur on the west and south-west coast. Commercial dive depths range from 24-36m (80-120ft), however some divers exceed this and may even reach depths of up to 60m (200ft). Conch are usually penned in wire meshed cages in shallow areas close to shore prior to sale. Conch currently sells at US$3.00-$4.00 per pound (US$6.60-$8.80 per kilogram). Conch stocks in the northern and southern areas are most targeted, with landings of 300-700 animals per trip.

Current fisheries regulations comprise a minimum size (shell length 18cm) and a minimum weight (total weight of 1kg and meat weight not including digestive glands of 280g). There is provision in the law for a closed season, but none has been put into practice as yet. However research show conch vary in growth rate and form between areas. Because conch cease growing in length at sexual maturity, differences in length become fixed in time. Where conch mature at a large size, most of the adults may be above the legal minimum size, and therefore subject to harvest; in areas having smaller conch, the opposite may be true. It is possible that in some areas whole populations of conch will remain protected whereas in others entire populations could be harvested before maturation (Appeldorn 1992b).

At present in St. Lucia only the presence of a flared lip is used as an indicator of sexual maturity and an informal policy stipulates that conch is landed in its shell. Very little research had been carried out on the population status of the queen conch and the fishery has scarcely been monitored, catch data being limited to some landing information and CITES export permits to Martinique. Therefore, it is very difficult to determine whether the regulations for conch are suitable for the existing local populations. However, with financial and technical assistance from CFRAMP, the Department of Fisheries put measures in place to resolve this constraint. A two year biological study of local conch populations was conducted from 1996 to 1998. The purpose was assess the queen conch fishery in order to refine the existing data collection system, to better understand the status of the resource and to determine whether existing regulations are suitable.

3.6.1 Description of Data

Conch were sampled from two sites off the island of St. Lucia, one in the North and one in the South. Fishermen made all collections using SCUBA and bottom gill nets. Conch samples were assessed by a data collector at a landing site in the north of the island. All conch were measured for shell length and lip thickness. Shell measurements were made to the nearest 1mm using calipers, and included length for all individuals and lip thickness for adults. Total length was defined as the maximum distance from the tip of the spire to the edge of the siphonal canal; shell lip thickness was defined as the thickness of the lip measured in the mid-lateral region approximately 35mm in from the edge of the shell. Weights including total and meat weight were sampled on one occasion only for a sample from each site. This was done making a hole in the spire with a hatchet and removing meat with a knife. Meat weight measurements comprised wet-meat weight, (defined as the weight of the intact animal including viscera, without the shell) and total weight (defined as the weight of the intact animal including the shell). Conch were also sexed when meat weights were take for each site. The location of conch grounds was determined using a Global Positioning Device (GPS). For analysis all conch landed were grouped into the north and south sites and not by diving area.

All data were stored and manipulated in the Trip Interview Programme (TIP), however data was analyzed in MS Excel.

3.6.2 Analysis

The total number of conch sampled from the north and the south from 1996-1996 were 4390, of which 144 were identified as male and 173 as female, 4065 were mature and 325 were immature (i.e. that the lip thickness was less than 5mm). The average size and lip thickness for all the conch sampled was 241.42mm and 19.83mm respectively. It was observed that females were larger both in shell length and lip thickness, with an average shell length and lip thickness of 235.21mm and 26.18mm respectively, as compared to males, which had average shell lengths and lip thickness of 229.43 mm and 25.47 mm respectively. This was observed in both sample sites (Table 3.6.1). Females were also heavier in meat weight in the northern sample, however the opposite was the case for the southern population. Overall the conch from the south had a heavier average meat weight than the northern region (Table 3.6.1). T-tests and ANCOVA tests showed that was a significant difference between the northern and southern populations for both males and females for shell length and meat weight.

Table 3.6.1 Summary statistics for length, weight and lip thickness by sampling area. (N= Number of individuals, S.D.= standard deviation, F = Females, M = Males)

Area	Shell Length			Meat Weight			Lip Thickness		
	N	Mean	S.D	N	Mean	S.D	N	Mean	S.D
North									
All	3114	239.44	26.95	149	283.28	100.31	3114	19.19	8.42
M	72	225.26	13.65	78	295.51	102.07	77	22.58	7.91
F	77	230.99	18.89	71	270.07	96.80	72	23.51	7.51
South									
All	1276	246.25	27.03	49*	331.63	132.50	1276	21.37	8.27
M	73	233.53	13.87	13	370.17	146.18	73	28.32	9.64
F	96	238.59	24.92	34	322.68	84.64	96	28.33	10.01

*Three conch in this sample were unidentified.

It was observed that the majority of conch landed fell in lip thickness class range of 21-23 mm for both the north and south sites and for all three years (Table 3.6.2). For shell length the majority of conch sampled fell in to the class 24 mm and 25 mm for the north and the south respectively. The largest conch was 330 mm shell length and the smallest was 147 mm.

Table 3.6.2 Summary of total lip thickness frequency by year

Interval (mm)	**Frequency**			
	1996	**1997**	**1998**	**Total**
0-2	36	44	41	121
3-5	60	103	41	204
6-8	56	90	80	226
9-11	77	83	41	201
12-14	144	117	93	354
15-17	162	161	135	458
18-20	40	116	123	279
21-23	282	403	394	1079
24-26	139	225	315	679
27-29	54	104	187	345
30-32	49	91	66	206
33-35	41	51	60	152
36-38	8	11	17	36
39-41	3	5	13	21
42-44	7	3	9	19
45-47	3	3	2	8
48-50	0	0	2	2
Total	1161	1610	1619	4390

There was insufficient data to fit the Schaefer model. Results for the weight cohort analysis model showed that total animal abundance was 2850 626 with a total biomass of 117 954. However more weight data is required for this model to obtain any reliable results, in particular juvenile data. Furthermore the **L¥**, **k** and **to** values were values for Martinique and not St. Lucia.

3.7 Turks and Caicos Islands

3.7.1 Background

The Turks and Caicos Islands are a group of low-lying, arid islands located on the south-eastern end of the Bahamas archipelago and north of the Dominican Republic. Its shallow banks are separated by deep-water (1500-2000 m) passages defining three distinct banks, with the largest; the Caicos Bank (6110 km^2), supporting a significant fishery for conch (*Strombus gigas*) and spiny lobster (*Panulirus argus* (Latreille))**.**

Conch has been fished in the Turks and Caicos Islands for many years and used as a local food, dried and bartered for fresh produce from Haiti, and as bait in the spiny lobster trap fishery (Hesse and Hesse 1976; Doran 1958). Free diving fishermen, operating small fiberglass dinghies powered by outboard engines, target this resource, second only to spiny lobster in value.

The conch fishery dates back to the last century when the catch was mainly exported to Haiti. With the establishment of the Middle Caicos Corporation in 1973 and the Atlantic Gold fishing Corporation, live conchs as well as process frozen conch meats were shipped to the United States (Hesse and Hesse, 1976; Brownell and Stevely, 1981).

The fishery has traditionally been characterized by peaks and troughs in landings, coinciding with World War I and II which disrupted the salt export industry, and emigration to the Bahamas in the late 1950s to the mid 1960s (Ninnes 1994). However, peaks observed in the last two decades (1977-1980, and 1984-1987) also partly reflect the status of the lobster fishery, when fishermen were inclined to switch to conch as a result of poor lobster catch rates. These factors, exacerbated by unsustainable levels of fishing, have led to wide fluctuations in landings.

3.7.2 Description of Data

Export data from 1901 to the present has been recorded on Customs export sheets. Since 1974, a system of processing plant pay slip receipts was established which recorded pounds landed per boat day. These data allowed for the calculation of effort from 1974 to 1998.

Generally, fishermen leave the dock around 0700h in search of known fishing grounds and return by 1600h, although the length of the fishing day will depend on weather conditions. Each boat usually carries a boat driver and 1-2 divers. The divers collect the conch by free diving (using only mask, fins and snorkel) while the boat driver removes the conch from the shell. The processing has little effect on the catch rate, so search time dominates a conch fishing day. Therefore, catch per unit-effort (CPUE), measured as kg boat-day^{-1}, is likely to be inversely related to conch density, and therefore approximately proportional to the stock size (Medley and Ninnes 1999).

The catch data are recorded as pounds of meat landed in the processing plants at the end of each fishing day by each fishing boat. Additional data such as number of fishermen per boat are also recorded which are available on the pay slip receipt. However, numbers of fishermen per boat is thought to be unreliable, so effort is measured in boat days.

In this assessment of the conch stock, available catch data for the period 1974-1998 was used, with the exception of a small sample from 1975-76 data for which effort is questionable and 1984-85 when effort was not recorded.

3.7.3 Catch and Effort Data Analysis

The Schaefer model was fitted to the catch and effort time series using the same method as that described by Medley and Ninnes (1999), but using additional data. The standard least-squares fitting method was used, but with separate weights between the two periods 1974-1985 and 1985-1998 based on monthly CPUE series variance. The weighting improved the estimates as the variance of the data is not constant, but appears to be higher in earlier years (Fig. 3.7.1). It is suspected that this has more to do with the data collection method, which was less reliable in early years, than a reflection of true catch rates.

All the data used was reassembled from original daily catch records and carefully checked for errors. The data assembled was a significantly longer time series than that used by Medley and Ninnes (1999). The initial population size was assumed to be 90% of the unexploited stock size. This takes into account previous fishing, which is not included explicitly in the model. It was found the model was not sensitive to reasonable changes to values of this parameter.

The model did not fit the CPUE time series well (Fig.3.7.1), with evident discrepancy particularly since the introduction of the quota in 1992. While overall the fit seems reasonable (Fig. 3.7.2), the model has consistently failed to predict the CPUE in recent years, forecasting a decline which has never materialized. An alternative model, the generalized production model of Pella and Tomlinson (1969), was also fitted, but could do no better than the simpler Schaefer model in explaining the current catch rates.

Probably the best way to improve the assessment would be to begin modeling the population structure rather than assuming a homogeneous biomass. However, it is also possible the model is incorrect because not all catches are accounted for. Either changing local consumption or illegal catches could be an important source of discrepancy between the model and observed CPUE.

From the fitted model parameters, a number of values were estimated with confidence intervals generated from bootstraps (Table 3.7.1). The main aim of the stock assessment is a safe export quota for the 1999-2000 season. The MSY itself is not appropriate. Even if the model was correct, the least squares MSY estimate would have an approximately 50% chance of being an overestimate, so using it to set the quota could well result in overfishing (Fig. 3.7.3). Using the lower 90% confidence limit would have only a 5% chance of overfishing (Note that this is not a precise interpretation of confidence intervals and should be only attempted with larger data sets). Based on the lower 90% confidence limit for MSY, a maximum sustainable quota for the season 1999/2000 could be set at 1.50 million pounds of landed meat, which converts to the export quota of 601000 pounds process meat weight. This is to say that after the meat is cleaned, 60% of the landed weight is waste meat and the remainder is exported.

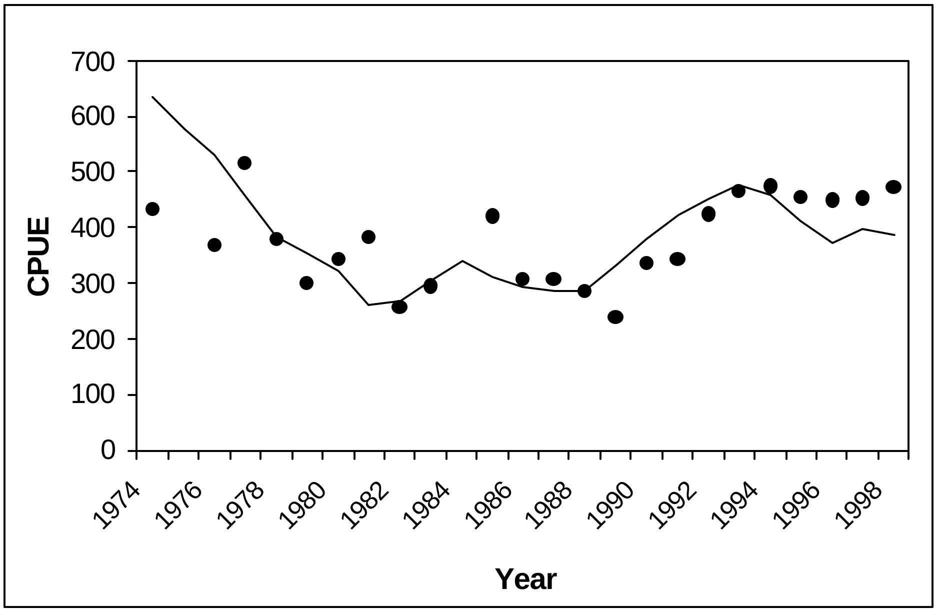

Figure 3.7.1 The observed (·) and expected (¾) catch-per-effort (CPUE). Since 1994 the expected CPUE is gradually declining, which is in contrast to the observed CPUE. It is also apparent that since the implementation of the quota that catch rates have stabilized and have remained high, suggesting the management regime has been successful.

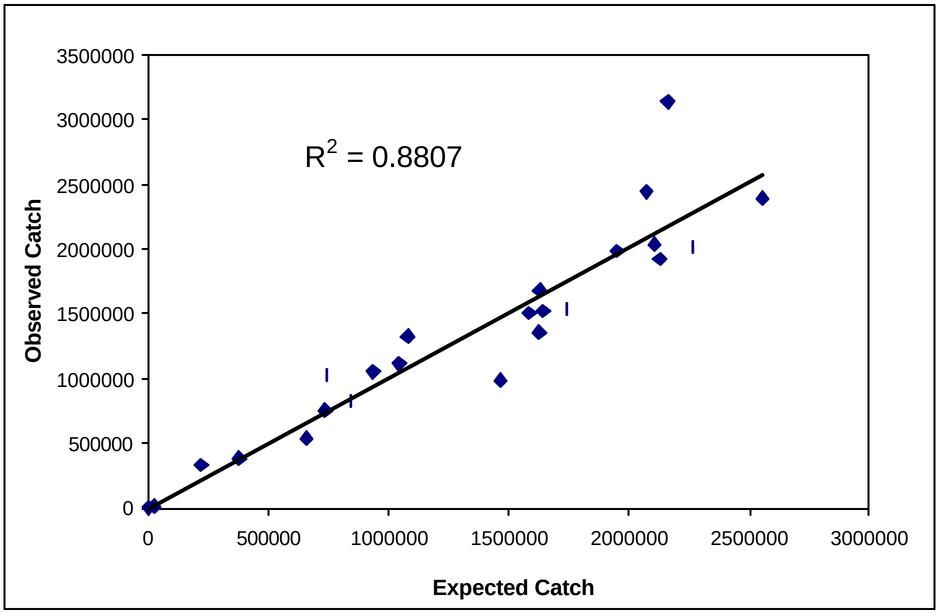

Figure 3.7.2 The expected catch plotted against the observed catch with a linear regression trend line.

Table 3.7.1 Parameter estimates for the Schaefer model from the least squares fit. Maximum sustainable yield (MSY), effort at MSY (f_{MSY}) and fishing mortality at MSY (F_{MSY}) and the export quota are calculated from the fitted parameters (r, K and q).

Parameter	Estimate	Lower 5% bound	Upper 95% bound
K (kg)	4632740	3819278	6524365
r (year^{-1})	0.64	0.428	0.806
q (boat day^{-1})	6.54 10^{-05}	4.58 10^{-05}	8.82 10^{-05}
MSY (kg)	739340	683244	776322
f_{MSY} (boat days)	4879	3694	5579
F_{MSY} (year^{-1})	0.384	0.277	0.454
MSY Export Quota (lbs)	650619	**601254**	683163

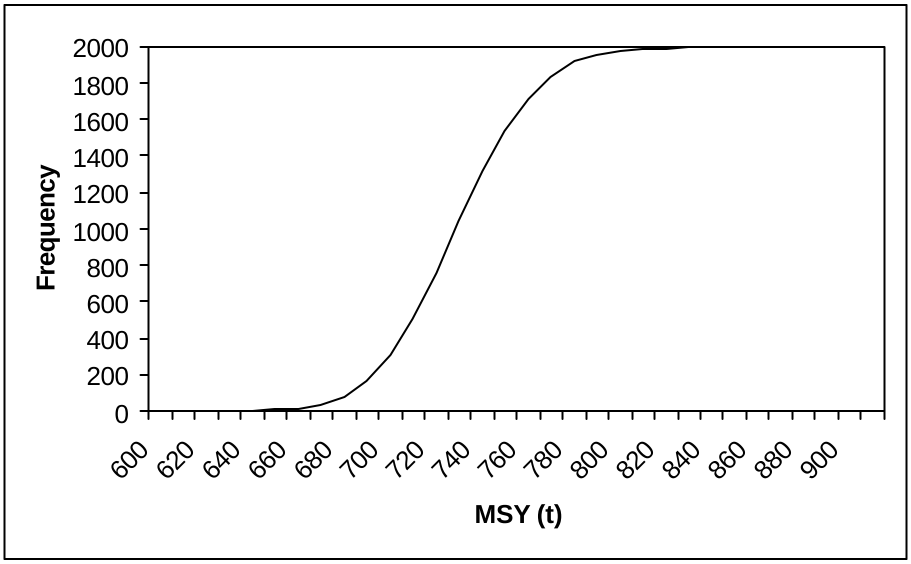

Figure 3.7.3 Cumulative frequency distribution for the bootstrap estimates. For any quota (x axis) the frequency can be read off from the curve to provide the approximate odds of overfishing (quota exceeding the MSY). For example, a quota of around 730 t gives a 1000:1000 (= 50%) chance of overfishing.

3.7.4 Discussion

The 1995 Schaefer model, which was used by Medley and Ninnes (1999), gave the best fit to the catch and effort data time series, and it was as used to forecast the CPUE for 1996-1999. The model is not a good predictor as it has consistently underestimated the CPUE (stock size) in recent years. The results are robust, however. For example, the recommended quota is insensitive to unrecorded catches destined for local consumption (Medley 1997). Empirically, the quota, which was set in 1996, seems to be maintaining the stock size at a sustainable level, and appears to have stabilized catch rates (Fig. 3.7.1). This suggests the current management system has been very successful and should continue.

As the model is not effective at forecasting, a model based on, for example, a biological recruitment index needs to be developed. Thus, alternative sources of information, which can be used to model the stock population structure, are needed and research should be conducted to identify these. This research is urgent as it may indicate a slight increase is possible in the quota that would not endanger the stock.

Nevertheless, it is advisable that the quota be set based on these results until improvements can be made to the model. The model suggests a risk-averse quota very close to the current 600000 lbs export, and so the result largely reinforces the current management policy.

3.8 U.S. Virgin Islands

3.8.1 Background

Available conch habitat to support the conch fishery in the U.S. Virgin Islands is limited to waters of the surrounding shallow insular shelf platform. The approximate size of this habitat is estimated to be 34 300 ha for St. Croix and 162 925 ha for St. Thomas and St. John. Wood and Olsen (1983) determined the standing stock for ST. Thomas/St. John and St. Croix was 1 550 372 and 260 680 individuals, respectively. Maximum sustainable yield (MSY) was calculated to be 364 000 pounds annually for the St. Thomas shelf and 60 000 pounds for the St. Croix shelf. With a harvest of 59 000 pounds of conch in 1978-79 for St. Croix, the fishery was believed to be fully exploited.

The conch fishery, concentrated around St. Croix, is artisanal in nature and consists of approximately 25 commercial fishermen fishing from outboard-powered, fiberglass vessels < 8 m in size. Each vessel has a minimum of one diver plus a boat operator. Larger vessels may accommodate up to three divers. All trips are made on a daily basis with the fishermen returning to market their catch by early afternoon. Most vessels are transported on trailers to launching sites that have the best access to the fishing grounds. Fishing occurs in territorial waters within 3 miles from shore. Eighty-percent of the fishermen use SCUBA gear to harvest conch and 20% use free-diving techniques. In addition to harvesting conch, some fishermen may harvest lobster and spear fish on the same trip. Conch are marketed by fishermen along the roadside or sold directly to hotels and restaurants. Conch are marketed cleaned and are sold along the roadside in 5-pound bags at \$4.00- \$5.00 lb^{-1}. Conch are not exported from the Virgin Islands, but only consumed locally.

Conch were historically found in very shallow waters along the coast and harvested by “feeling” for the conch with the feet. As the demand increased, fishermen used free-diving techniques to harvest conch in backreef waters less than 5 m in depth. With the use of scuba as the primary gear to harvest conch since the early 1970s, inshore resources quickly became depleted. At the present time, commercial fishing effort is concentrated in offshore waters from 15-30 m in depth. Recreational fishing effort continues to occur for conch in shallow seagrass backreef embayments. The majority of conch harvested from inshore areas are believed to be juveniles.

3.8.2 Conch Regulations

Management regulations for fisheries resources in the Virgin Islands are promulgated by the Commissioner of the Department of Planning and Natural Resources (DPNR) following recommendations from the local Fisheries Advisory Committees and the Division of Fish and Wildlife. Conch regulations were first established in 1984 for the island of St. Croix. The regulations consisted of a minimum harvest size of 9-inch shell length and a minimum meat weight of 2 animals per pound uncleaned and 3 animals per pound cleaned. A continued decline in landings for St. Thomas/St. John resulted in a 5-year moratorium on harvest from 15 February 1988 to 31 December 1992. The closure was continued for an additional two years to allow the stocks to recover. Heavy fishing pressure on stocks following the reopening of the fishery on 26 April 1994 resulted in the establishment of unified regulations for the Territory. Due to strong public reaction to specific provisions of the regulations restricting the sale of imports during the closure season and establishing a commercial harvest quota of 75 conch per fisherman, the regulations were amended on 12 July 1994 to include the following:

(i) Annual closed season from 1st July – 30th September.
(ii) All conch landed must be live and in the shell.
(iii) All conch landed must be at least 23 cm (9 inches) in length or at least 9.5 mm (3/8 inch) in lip thickness.
(iv) Commercial harvest limit of 150 conch per day per licensed fisherman.
(v) Recreational bag limit of 6 per person per day or 24 per boat.
(vi) Conch or conch shells not conforming to the size limit may not be sold.

After depletion of the conch stocks around St. Thomas/St. John in 1994, no further landings have been reported. On St. Croix, conch shell middens accumulated on the shoreline at landing sites following the first year of regulations. Fishermen objected to landing conch in the shell due to the lack of space in the small vessels to accommodate dive gear from several individuals in addition to their daily conch quota. Due to the lack of an enforcement presence at landing sites, most conch fishermen now no longer land conch alive and in the shell. Conch fishermen prefer to do one or more of the following to process meats: 1) remove the meat from the shell underwater, 2) take the conch to the boat where it is removed from the shell by the boat operator or 3) collect the days catch on the boat and motor back to shore, either removing the meat on the way or anchoring in a protected backreef embayment before removing the meat.

Conch densities were reported by Wood and Olsen (1983) to range from 2-10 conch ha^{-1} for St. Thomas/St. John and 2-10 conch ha^{-1} for St. Croix, based on habitat type. Friedlander *etal*. (1994) found conch densities around the island of St. John to be relatively low (38-75 conch ha^{-1} at Lamesur, Brown and Threadneedle Bays) despite a 7-year moratorium and new management regulations. Present management regulations in St. John National Park waters (2 conch per person per day) were believed to be inadequate to ensure stock recovery. Conch populations around St. Croix have not been resurveyed since 1983.

The objectives of the conch stock assessment workshop were (1) to attempt a U.S. Virgin islands conch stock assessment by utilizing available data in one or more stock assessment models which best fit that data, (2) to determine the success of present management regulations of the fishery based on stock assessment results, and (3) to make recommendations on data collection necessary to perform stock assessments and possible management regulations to improve existing conch stocks.

3.8.3 Description of Data

Catch Records – 1981 to present.

Commercial landings in the U.S. Virgin Islands are obtained from mandatory catch records submitted by commercial fishermen on a monthly basis to the Division of Fish and Wildlife. Commercial fishermen are not issued a new license unless all catch records have been submitted for the previous year. Prior to 1995, commercial landings data (pounds) was recorded per trip (day) by gear type (e.g. potfish, netfish, hookfish, conch, etc). To obtain better information on fishing effort and species in the fishery, a new catch record form was developed and implemented to include gear type, amount of gear used, area fished, effort (hours) and catch by family group. The new data collection instrument was introduced to the fishermen in the 1995-1996 commercial fishing year (1st July – 30th June) and became the required instrument to use in 1997-1998.

Landings data for the years 1993-1998 were used in a Schaefer catch-effort population model which compares observed and model catch per unit effort (CPUE) over time. The model uses three parameters (Appendix B), the population rate of increase (r), carrying capacity of the population (K) and the proportion of the population removed for each unit of effort (q).

Morphometric Measurements – 1986, 1994, 1995 1998

Conch morphometric measurements were obtained in 1986 from three samples of 100 conch harvested by a commercial fisherman from three commercial conch harvesting areas. Data collected included conch shell size, lip thickness, shell weight, sex and meat weight.

Harvesting regulations in 1994 requiring conch to be brought ashore live and in the shell resulted in conch shell middens accumulating on the shoreline at landing sites on St. Croix. Three sub-samples of 100 conch shell lengths were obtained from each of three landing sites in 1994 during the annual closed season. A sub-sample of 10% of the conch shell middens were obtained from six landing sites in 1995 during the annual closed season. All shells in the middens were counted before their removal from the shoreline. Data (shell length and lip thickness) were collected on 825 individuals. In 1998, shell length and lip thickness were recorded from 865 conch in middens at six sites on the shoreline.

Length-frequency, lip frequency and length vs lip thickness plots were used to follow harvesting trends in the fishery from 1986 to 1998.

Backreef Density Survey – 1998

Conch densities in a two-meter wide path on both sides of ten 50m transects are recorded monthly in each of three backreef embayments on the northeast coast of St. Croix during a reef fish survey. The backreef embayments are typical juvenile/adult conch habitat consisting of seagrass, sand, rubble and occasional patch reefs. Maximum depth in backreef waters is 6 m. Transect locations are randomly selected each month from cross points on a pre-established 20 m^2 grid for the embayment. Transect direction is also randomly selected from 360 compass points. Conch densities (conch ha^{-1}) were calculated for size categories of <10 cm, 10-20 cm and >20 cm.

St. Croix conch landings for the years 1993-1998 are shown in Tables 3.8.1 and 3.8.2. Until 1997 fishermen used old catch record forms to record landings. New catch record forms were introduced in 1995 and in 1997 became the standard form used. Landings show a declining trend from 1993-1996 (35 576 – 21 763 pounds); however, conch landings increased during 1997 (25 601 lbs) and 1998 (73 013 lbs). CPUE values exhibit a similar trend with a doubling of effort from 1996-1997 to 1997-1998 (558 trips and 1 261 trips, respectively).

Table 3.8.1 St. Croix conch landings. Data collected from old and new catch record forms.

Form	Year	Number of Trips	Total Catch (lbs)	CPUE (lbs trip^{-1})*
Old	1993-1994	659	35 576	53.98
	1994-1995	770	36 268	47.10
	1995-1996	603	19 557	32.43
	1996-1997	101	4 288	42.45
New	1995-1996	53	2 206	41.62
	1996-1997	457	21 313	46.64
	1997-1998	1 261	73 013	57.90

- trips are per day

Table 3.8.2 St. Croix conch landings, 1993-1998. Data combined for old and new catch record forms.

Year	Number of Trips	Total Catch (lbs)	CPUE (lbs trip^{-1})*
1993-1994	659	35 576	53.98
1994-1995	770	36 268	47.10
1995-1996	656	21 763	33.18
1996-1997	558	25 601	45.88
1997-1998	1 261	73 013	57.90

* trips are per day

3.8.4 Data Analysis

Due to the short time series and lack of contrast in the CPUE time series, the rate of increase could not be estimated and was fixed at the Caicos Bank value (0.53 year^{-1}). Also, the stock was already considered heavily exploited when the landings data begins (in 1993/94), so the initial stock size was assumed to be 60% of the unexploited biomass.

With the 5year time series used, both expected and observed CPUE values appear to have little variation, which can be explained by changes in catches (Fig. 3.8.1). Calculated maximum sustainable yield (MSY) was determined to be 35 000 lbs (Table 3.8.3), although given the limited data this result should be treated with caution. The implication is that the fishery is fully exploited. If this is the case, the much higher catch in 1997/98 (Table 3.8.2) should produce a decline in CPUE for 1998/99.

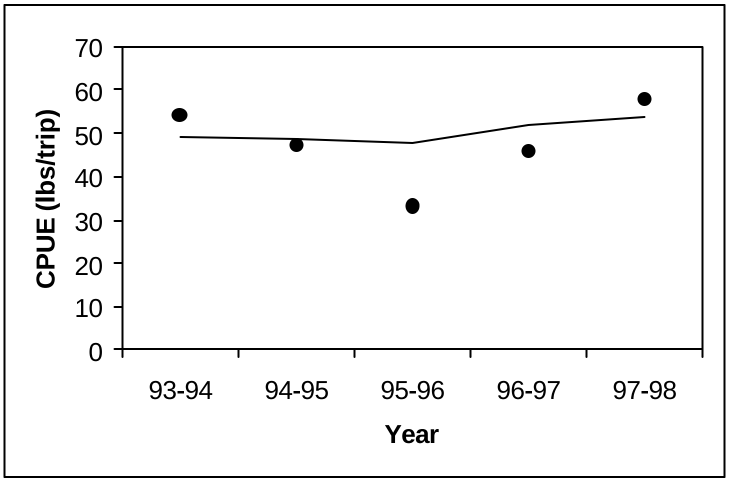

Figure 3.8.1 Observed (·) and expected (¾) CPUE from fitting the Schaefer model to the available five years catch and effort data. The rate of increase parameter (r) was fixed at 0.53 year^{-1}. Being unable to explain the observed change in CPUE, the model interprets most of these changes as random error and has adjusted the model so that, on average, the catches have equaled the biomass production.

Table 3.8.3 Parameter estimates and MSY limit reference points for the Schaefer model fitted to the 5 years of catch and effort data.

r (year^{-1})	B¥ (lbs)	q (trip^{-1})	Initial Biomass %	MSY (lbs)	Effort at MSY (trips)	F at MSY (year^{-1})
0.53	264919	$3.10\ 10^{-4}$	0.6	35 102	856	0.31

Stock assessment using the weight-based cohort model was not possible due to the unavailability of total landings data for the year during which the conch meat weights were obtained.

Length frequency plots for conch measured from shoreline middens in 1986, 1994, 1995 and 1998 are shown in Figure 3.8.2. Mean shell length decreased from 228.2 mm in 1986 to 214.2 mm in 1998. Length frequency plots show a shift towards harvesting smaller individuals.

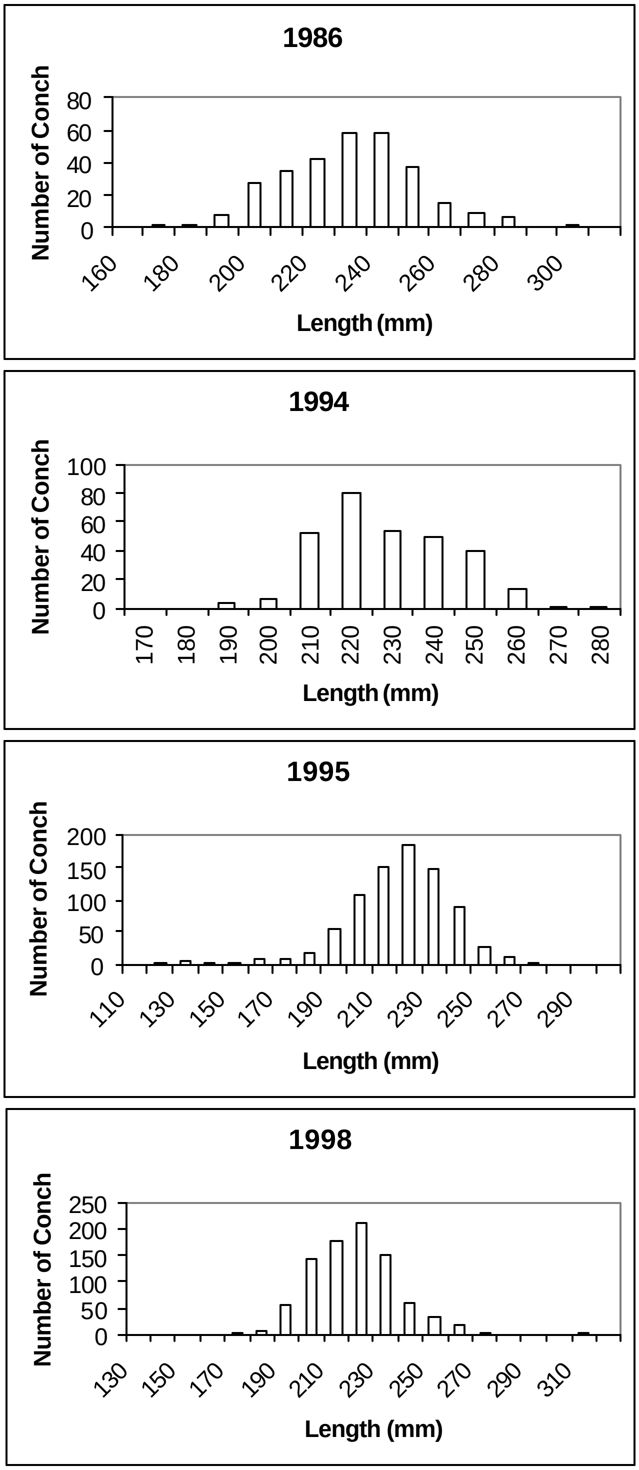

Figure 3.8.2 Shell length frequency from samples taken from middens (mounds of discarded shells) for the four sample years.

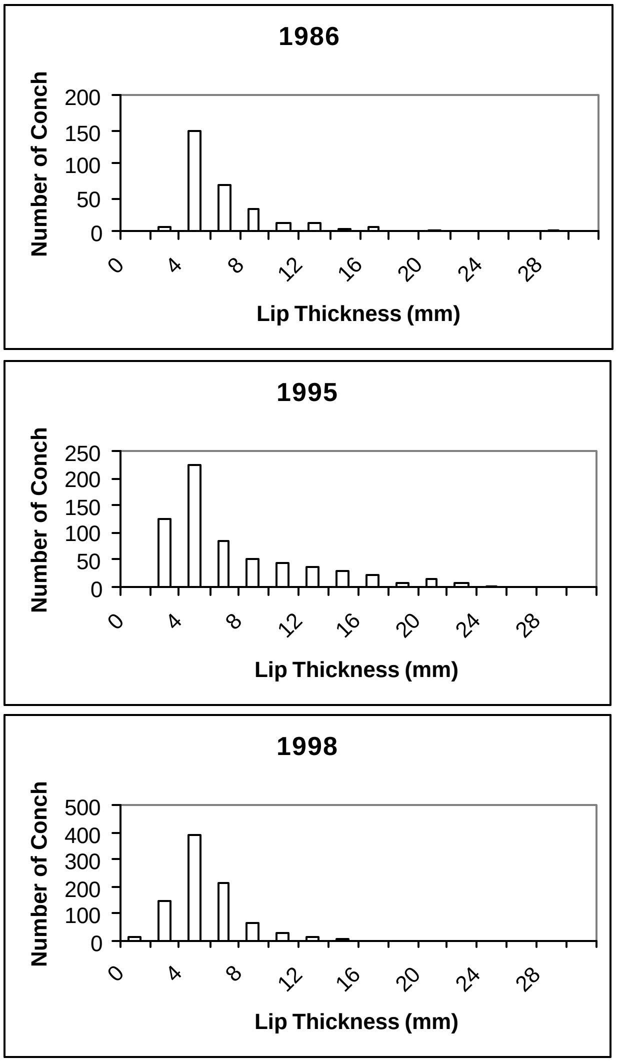

Figure 3.8.3 Lip thickness frequency plots for conch harvested in three seasons.

Lip frequency plots for conch harvested in 1986, 1995 and 1998 are shown in Figure 3.8.3. Mean lip thickness decreased from 5.2 mm in 1986 and 5.8 mm in 1995 to 3.7 mm in 1998. Measures of shell length against lip thickness for 1986, 1995 and 1998 verify the harvest of smaller individuals, although no relationship between the two size measures is discernable. Significant proportions of conch have been harvested in the years when sampling was conducted which are below the minimum size regulations (Table 3.8.4).

Table 3.8.4 Proportion of conch harvested that are below the U.S. Virgin Islands legal size limit.

%	1986	1994	1995	1998
Shell Length*	48.0	59.0	80.0	74.3
Lip Thickness**	89.3	-	78.8	94.0

* Minimum size = 228.6 mm
** Minimum size = 9.5 mm

Of the 121 visual conch surveys conducted in backreef embayments in 1998, a total of 60 individuals were found in the 10-20 cm size class and 29 individuals in the >20 cm size class. No individuals <10 cm were observed. Overall average conch density was 24.79 conch ha^{-1}.

3.8.5 Conclusion

Both total catch and CPUE values reflect an initial decrease and subsequent increase in conch landings from 1993-1998. The increase in landings is anticipated to be a direct result of a doubling of effort by fishermen (more commercial fishermen entering in the fishery) and an artifact created by the introduction of a new catch record form and monthly reporting requirement to increase landings accuracy. Landings data will have to be monitored closely to see if a decrease follows in subsequent years.

MSY calculated from using the Schaefer catch/effort model was 35 000 lbs of conch year^{-1} for St. Croix. Conch landings have exceeded this figure since 1993, with the exception of 1995-97. To increase the accuracy of using this model, a longer time series is required to show variation in observed against expected CPUE values.

Shell length and lip frequency values, supported by shell length and lip thickness measures, indicate that increasingly smaller conch are harvested each year in the fishery. Stocks of very old individuals are no longer abundant at the depth range that the resource is currently fished (15-30 m depth).

Compliance with existing harvest regulations for shell length by commercial fishermen is poor, lacking an enforcement presence. Conch densities in inshore embayments, believed to be nursery grounds for the commercial fisheries, are low. Although commercial harvest of conch no longer occurs in these inshore areas, recreational harvest continues. The recreational landings by recreational fishermen are presently unknown.

4 Data Collection

4.1 Introduction

The overall importance of data collection can not be overemphasized and is the first step in gaining knowledge about the stocks to be managed. The collection of both primary biological data on remote fishing grounds and commercial data at highly dispersed landing sites is often difficult. Given the limitations in the data collection abilities of many countries in the Caribbean region, it is of great importance that the data that is collected be used for specific purposes. The ultimate goal of any data collection program should be to provide information for the long-term sustainable management of the resources. To this aim the following section will provide a review of data collection systems used for queen conch, *Strombus gigas*, in the Caribbean region with particular emphasis on the participating countries at this workshop. This will include:

a) A brief review of the critical aspects of queen conch biology and life history that are important for assessment and management
b) Review of data types and collection methods applicable to queen conch
c) Data requirements for specific stock assessment approaches used during the workshop
d) Country by country review of the historical and existing conch fishery, presently available data and active collection systems, and suggested improvements and recommendations for future data collection

4.2 Important Biology and Life History Characteristics

The following section is intended as a short overview. General problems of tropical fisheries stock assessment may be found in Sparre *et al.* (1989). Details on all of the points specific to queen conch may be reviewed in Appeldoorn (1987b), Berg and Olsen (1989), Appeldoorn (1994b) and Tewfik (1997) as well as Chapter 2 of these proceedings.

a) Planktonic (veliger) larvae dispersal period (14 to 28 days, max of 35 days):

- Larvae spawned in one area may be retained locally or drift to other areas (within or between shelves or banks) through currents and gyres.
- High genetic similarity throughout the region (exception - Bermuda) supports the hypothesis of a single genetic stock, which requires a regional management program at this level.

b) Infaunal nature of 0+ cohorts (less than 12 months):

- Juvenile conch are generally not seen until their shell lengths exceed 60 mm.
- Early benthic life history is poorly understood.
- Critical early life history missing from assessment growth and mortality, as well as indices of future recruitment.

c) Overlapping cohorts:

- Extensive growth, breeding, and spawning periods spread egg, larval and juvenile recruitment over a large part of the year (Feb. – Nov.), making the identification of specific cohorts difficult (a common problem with tropical stock assessment).

d) Spatial and temporal variations in growth:

- Variations in depth, latitude, and growth season affect growth parameters.

e) Ontogenetic (development) changes in growth

- Various modes of growth through the life history (shell length, shell lip thickness, tissue)

f) Hard tissue growth (shell and operculum):

- Juvenile increases in shell length for ~ 3.5 - 4.5 years.
- Sub-adult overlap of shell length and shell lip thickness growth for ~ 0.5 – 1.0 years.

- Adult growth in lip thickness and original shell length complicated by problems of biofouling and bioerosion of the shell, both being highly variable with environmental conditions (particularly substrate).
- Operculum is also highly susceptible to variable erosion with respect to substrate types.

g) **Soft tissue growth (meat and viscera):**

- All tissue growth is highly variable over the life history.
- Increase in gonad growth relative to meat growth around maturity (~ 4.0-4.5+ years old).
- Decreased overall body weight due largely to decreasing volume of the shell with increasing age (shell is laid down by mantle tissue from the inside) beginning as early as 10 years of age.

h) **Ontogenetic (development) changes in natural mortality**

- Many early juvenile predators results in initial high natural mortality.
- Rates rapidly decrease with age largely due to increases in size and shell thickness.
- Natural mortality rates for adult conch are likely to be very low.
- Maximum longevity in unexploited populations may be over 20 years.

i) **Ontogenetic changes in habitat requirements and preferences**

- These relate to *shelter* (seagrass and shallow flats for predator avoidance), *food* (types of algae consumed) and *reproduction* (mating and spawning areas).

4.3 Data Types and Collection Methods

The types of data to be collected and the methods by which it is to be collected is dependent on many factors (see FAO 1999), including:

a) **Nature of the fishery**: This is often the first information that is required in setting up data collection systems. Several questions may be asked including determination of relative status (long-term exploitation vs. recent), location of primary fishing grounds, numbers of fishermen involved, number of landing sites, how the product is harvested and landed, and whether it is domestic or export driven.

b) **Analysis of the data**: The type of data that are collected dictates the stock assessment methods available for analysis. Broadly, methods may be divided into those that use sex, age and size structure in the population, and those that treat all animals the same. Biomass dynamic models are widely used where only a catch weight and effort times series is the available data. They treat the stock as a homogeneous biomass ignoring variations in growth and mortality within size/age classes. Other methods, which make use of variations in numbers in age, size and sex classes, require more detailed data. Cohort analysis, for example, makes use of the decreasing numbers of animals caught in sequential age classes to estimate mortality. Data may also be collected for a variety of other reasons, such as monitor the fishery performance, provide estimates of fishery value for Government decision-making, as well as monitor the enforcement of regulations.

c) **Objectives of management**: The objectives of management (Mahon 1990) should often be the most important driving force in determining the approaches to data collection (FAO 1999). Objectives should be set explicitly recognizing the risks inherent in fishery management, and under responsible management, are required to be precautionary (risk-averse). Objectives of management often include:

  - Maximizing sustainable yields
  - Maximizing sustainable yields for direct human consumption
  - Maximizing economic yields
  - Maintaining a minimum stock size or minimum spawning stock
  - Conserving marine habitats

d) **Funds, personnel and logistical support**: The allocation of resources to the management authority for the purpose of data collection, stock assessment and other management activities is directly linked to the importance government attributes to the fisheries sector.

4.3.1 Fishery Data

These types of data include basic catch and effort information, which can be used to fit biomass dynamics and other models for stock assessment. It is important to determine how conchs are landed in determining catch. For example, conch landed in the shell may require a conversion to meat weight. Similar determinations should be made for various grades of meat (levels of processing) that may exist within some fisheries. Wherever possible, it is important to separate catch and effort data for different gear types, in this case free-diving, SCUBA, and hookah.

The refinement of effort data is critical in reducing error within biomass dynamics models. For example, if fishermen 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. 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 to maintain catches. A final component in this category may include historical information on catch, areas fished that is invaluable and is largely free of cost to obtain.

4.3.2 Biological Data

An important use of biological data is to define the size/age structure of the population. Due to the complications of growth (see Chapter 2), the use of many standard measurements of conch, including shell length and shell lip thickness in adults, may be inappropriate for standard analytical models. The use of shell length and shell lip thickness within a population may however be important for the purposes of monitoring or refining regulations as well as determining sexual maturity. The subjective classification of adults by shell morphological differences, due to bioerosion, (young vs. old adults) may be important in some stocks (Tewfik 1996). It has been shown that shell length and total weight are important measures for juveniles. The use of meat weight may be a more appropriate parameter for adult conch for use with stock assessment models. Measurements of meat weights may also facilitate the collection of sex and maturity information based on the development of external sexual characteristics. The use of tagging data may be very important in determining growth and mortality rates as individual conch may be monitored over many years. Again the use of historical biological data is critical, especially when assessing long-term changes within populations.

4.3.3 Visual Abundance Survey Data

Use of visual abundance surveys in the assessment of conch resources is important to future data collection programs. Visual surveys give fishery-independent estimates of exploitable biomass, future recruitment, as well as habitat distribution, condition, and use by conch populations. The benthic nature of conch resources requires that divers, or possibly remote observation vehicles (ROVs) with on board video systems, survey the substrate over a measured area. This allows absolute determination of density and direct observation of individual conch on various substrate types. Such surveys within the region are reasonably inexpensive and short in duration given the limited shelf area of most countries. Large-scale surveys may only be needed every few years as long as other data collections continue in the interim periods. Visual assessments for conch have been done over the years on various spatial scales including: Berg *et al.* (1992a,b), Friedlander *et al.* (1994), Appeldoorn (1995b), Berg and Glazer (1995), Appeldoorn and Rolke (1996), Tewfik *et al*. (1998), Tewfik and Appeldoorn (1998), and Tewfik and Bene (1999). Visual surveys are particularly valuable when used with other data, such as catch and effort, and when a number of surveys have been completed.

4.4 Data requirements for Workshop

During the course of the workshop two specific assessment approaches were presented and used by participants. These are not the only methods available, but were useful based on the data available from many countries. (for the methods see Appendices 2-4).

4.4.1 Biomass Dynamic Model (Medley and Ninnes 1999)

a) A complete time series of total catch in meat weight
b) A catch and effort data time series, not necessarily continuous or covering all catches (a number of observations are required in the region of 10-15 years to obtain good results)

4.4.2 Meat Weight based Cohort Analysis (Ehrhardt 1999)

a) Total landings in meat weight
b) Individual meat weights and sample weight for landings by area and year
c) W_∞ for largest adult meat weights
d) Juvenile growth parameters for growth simulation (one time estimate)
e) Morphometric relationships (one time estimate)

4.5 Data and Collection Systems by Country

The following review is based on interviews with participants at the workshop, as well as information available in the literature (Appeldoorn 1994b; Tewfik 1997). Recommendations are provided for improvements to existing data collection activities as well as additional data that could be collected in future. It should be noted that annual harvest values are given in metric tonnes (t, 1000 kg) of clean meat.

4.5.1 Bahamas

A large shallow water fishery exists over the extensive area (150 000 km^2) of Little Bahamas and Great Bahamas Banks especially around Abaco, Andros, and the Berry Islands. The stocks are harvested from small boats using hooks in very shallow areas or free diving techniques. The product is landed as shelled meat. Present harvest levels include local consumption of 800 000 lbs (364 t) and a harvest for export that does not exceed 450 000 lbs (205 t) annually. Management regulations for conch include the prohibition of juvenile harvest and the use of closed areas.

Available data includes catch and effort information from 1990 to 1998 from five main landing sites (islands). Effort is calculated as man-days fishing. Biological data (1997-present) includes measures of shell length, shell lip thickness, shell weight, total tissue weight, and meat weight by sex and region (sample sizes in the 1000s). This will allow the revising of estimates of growth parameters over various fishing areas. Finally, visual surveys were preformed by Smith and Nierop (1984) and Higgs (1987).

Due to the extensive nature of the fishing grounds and relatively low catches from those areas fisheries officials are confident that present levels of harvest are sustainable. The levels of subsistence fishing are not well known due to lack of manpower. No studies outlining present stock status could be located, although research is presently underway.

4.5.2 Belize

A significant fishery for conch has existed for some time in Belize concentrating in the back reef areas and seagrass beds of the main barrier reef as well as lagoon areas of offshore atolls (Luckhurst and Auil-Marshalleck 1997). Harvest takes place in waters 3-18 m deep from small canoes using free diving techniques, which use sailing sloops as mother vessels. Landings are made as market cleaned meats and over the last five years are approximately 150 t annually. Management regulations for conch include a minimum shell length (178 mm), minimum meat weight (market clean 28g), closed season (July–Sept), and prohibition of SCUBA for harvest.

Data presently available includes landings from the late 1970s (through cooperatives), catch and effort data by fishing zones from 1996-present (effort recorded as landings day^{-1}), and biological data (shell length, shell lip thickness, total weight, and meat weight by sex and maturity) from a single fishing zone in 1996, 1997, and 1999. An assessment of the harvest sector and management of the fishery was conducted by Strasdine (1988) which includes some valuable growth parameter estimates. Finally an extensive visual survey was preformed in 1996 (Appeldoorn and Rolke 1996).

Several suggestions are made for additions and improvements. Since large amounts of market clean meats may be obtained at the cooperatives before production begins individual meat weight data can easily be collected on a large scale and can be linked with known fishing areas. Biological data should be collected for each zone during fisheries independent trips to establish morphometric relationships and growth parameters to define spatial differences. Further visual surveys should be continued on a regular basis in order to locate areas of adult biomass (spawning stocks) which are presently unknown. This is critical given the juvenile based harvest of the fishery. It should be noted that preliminary analysis of recent biological data reveals a decreasing shell length within both male and female adults over the last four years.

4.5.3 Cuba

The Cuban conch fishery has historically been known for large harvests peaking at 2353 t in 1977 (Munoz *et al.* 1987). This was followed by a four year closed season due to a depletion of the stock. The fishery re-opened in 1982 with a quota of 555 t raised to 780 t in 1984. A report by Grau and Alcolado (no date) indicated that populations were still decreasing at an alarming rate after the four year closure. Present harvest takes place from small boats using free diving techniques. The product is landed in the shell. During this workshop it was revealed that landings figures have always been recorded as total animal weight including the shell. Studies in Cuba indicate that meat weight is approximately 7-8% of total landed weight resulting in present harvest levels of approximately 100 t annually for human consumption (Formoso Garcia, per. comm.). No estimates exist for the exploitation of conch for the bait fishery. Although several regulations exist to manage conch (quotas, closed season, protection of juveniles, no recreational fishery) it is unclear whether these regulations are applied to the potentially large harvest for conch as bait.

At present only limited studies have been conducted on the conch fisheries of Cuba including Ferrer and Hernandez (1991). Biological studies include Alcolado (1976), which contains some estimates of growth parameters. No effort data or recent biological data is available.

The vast nature of the Cuban shelf area and potential harvest of conch for export requires immediate attention. Most importantly it was suggested that a reasonable estimate of conch exploitation for bait be established so as to understand the scope of harvest. This may be done using information on the numbers of traps and lines that may be involved in such baiting. Collection of available catch and effort data would be the next natural step, but may again be complicated by the bait fishery. Biological data collection and visual surveys need to be established in all fishing areas to examine the spatial differences within the stock.

4.5.4 Grenada

Grenada has traditionally been a supplier of conch to Trinidad, which continues to this day. The main fishing grounds occur on the north and northeastern shelf and harvest is done from small boats using free diving and SCUBA gear down to 50 m. Most recent estimates of harvest are about 25 t, which is thought to include a large portion of juveniles. The product is landed as meat. Management regulations follow the Organization of Eastern Caribbean States (OECS) harmonized rules (minimum shell length of 178 mm and 225 g meat weight).

Data presently available includes some landings data from 1997 and 1998. However the sales to local hotels and restaurants as well as some of the exports to Trinidad have not been recorded. Associated effort may be difficult to assess due to the multi-species nature of the landings. Biological data is available for adults from 1997 and 1998 including shell length, shell lip thickness, total weight, and meat weight by sex (N=600).

Several improvements are suggested for Grenada. Total landings data can easily be improved by gathering hotel and restaurant purchase information. An accounting of all exports to Trinidad, through required export licenses issued by the Fisheries Division and checked by Customs before export, should be incited. Effort figures may be improved by making calculations of average time spent fishing conch during a typical day (direct observations, question fishermen). A fisheries independent biological study needs to take place to establish juvenile growth parameters. Although meat weights have been gathered, an improvement in accuracy (+/- 1 g) of measurements would be desirable. Finally a visual survey may give a good indication of the exploitable biomass still available.

4.5.5 Jamaica

A rapid increase of the Jamaican conch fishery began in 1990 (Mahon *et al.* 1992), the majority of the harvest coming form Pedro Bank (95%) where high densities of old adult conch are found. A quota of 2000 t was set for the 1994-1995 fishing season with a plan for 100 t year^{-1} decreases thereafter. Present harvest is approximately 1500 t of landed meat of which 95% is exported. The conch resources are harvested by both artisanal fishermen making day trips from Pedro cays as well as larger industrial vessels (carrying Dominican and Honduran divers) making trips of approximately 14 days based in Kingston, Whitehouse and most recently Montego Bay. Divers utilize SCUBA and Hookah gear although some small level of free diving may still exist. Fishing depths average 20 m although it is known that harvest takes place down to 30 m.

Data presently available from Jamaica includes accurate landings for commercial producers from 1993-1998 with associated effort in hours fished and areas fished. Export data is available through CITES export permits sent to the Fisheries Division. Biological data is largely in the form of meat weights taken from 1995-1998 by sex and maturity level. Some estimates of growth parameters and morphometric relationships are available from Tewfik (1996) at specific sites on Pedro Bank. Finally two extensive visual surveys were performed on Pedro in 1994 (Appeldoorn 1995b) and 1997 (Tewfik and Appeldoorn 1998) as well as on Morant Bank in 1996 (Stephens 1997).

The main improvements for Jamaican data are focused on collection of landings and effort associated with the artisanal sector that has been allocated 20% of annual quota. Options for collection of these data include basing data collectors on the cays (perhaps Coast Guard personal) or collecting sales slips from packer boats landing in Kingston. Commercial landings in Montego Bay should also be investigated. It is further recommended that visual assessments be continued specifically for developing a recruitment index, monitor changes in population structure, and to make accurate exploitable biomass estimates. The visual assessment surveys should incorporate biological data collections specifically targeting the juvenile and very old adults.

4.5.6 Nevis

The conch resources of Nevis are a shared stock with St Kitts and exploited by a relatively small group of fishermen operating from small boats using SCUBA gear. A study by Wilkins *et al.* (1987) indicated that the conch resource was in serious danger of overexploitation at that time with harvests of 45 to 68 t annually. The most recent estimate of total harvest is about 55 t in exports plus an additional 5-10% local consumption annually. Management regulations include the landing of conch in the shell and the OECS harmonized rules (minimum shell length of 178 mm and 225 g meat weight).

Presently available data includes catch and effort from 1979-present, with effort measured in hours fishing through estimates of average number of days fishing, boats operating, and SCUBA cylinders used per trip. Biological data includes shell length, shell lip thickness and meat weights (1998, N=700). Information on growth parameters, morphometrics and reproductive potential can be found in Wilkins *et al.* (1987) and Buckland (1989)

Future data collection programs in Nevis should include samples of effort data from specific boat landings rather than estimation of mean values from interview. Review of growth parameters and morphometric studies could be done during a visual survey, which would be inexpensive given the limited shelf area. Continuation of biological data collection from landings (shell length and lip thickness) is also advised as a way to monitor changes in size and number of conch landed from various fishing grounds.

4.5.7 Puerto Rico

A long history of conch fishing exists in Puerto Rico. Primary fishing grounds include areas on the southwest and east coasts of the island. Steady declines in catches since the early 1980s have resulted in the most recent harvests of approximately 73 t that is used largely for local consumption. Fishermen operate from small boats using SCUBA gear down to 40 m. It has been observed that much of the harvest is juveniles (Appeldoorn 1991). At present there are no regulations for the harvest of conch.

Available information includes a long time series of catch and effort data (1980-1998) with effort measured in landings per trip by specific fishing ground. Biological data includes shell length, shell lip thickness, total weight and meat weights and have allowed morphometric relationships to be established as well as good estimates of growth (Appeldoorn 1988a, 1990) and mortality (Appeldoorn 1988a, 1988b). Finally several visual surveys have been conducted on specific fishing grounds (1985-1986, 1995-1996).

Puerto Rico's future plans include continuation of visual surveys as well as fishery censuses (collection of biological data from exploited individuals, density, abundance, areas fished, and CPUE information). It is suggested that the southern fishing grounds be included in such studies despite the logistical difficulties involved. Finally individual meat weight samples of landed conch should be collected.

4.5.8 St Lucia

The St Lucia conch fishery is another example of a small number of fishermen providing the needs of local demand. Harvest occurs in depths between 25 and 35 m, on both the north and south coasts, using SCUBA gear from approximately six small boats (18 fishermen total) (Nichols and Jennings-Clark 1994). The product must be landed in the shell with the most recent landings figures at approximately 13 t annually. Additional regulations follow OECS harmonized rules (minimum shell length of 178 mm) although minimum meat weight is increased to 280 g.

Available data includes landings obtained at the fishing complex (majority of landings) for both the north and south coast fishing grounds (late 1980s - 1998). Details on fishing effort are unclear although it is measured in boat days. Total exports (1993 - 1998), all to Martinique, are shipped as conch in the shell although recorded as meat weight (avg. 2.5 conch lb^{-1}). Biological data including shell length and shell lip thickness are available from 1996-1998 for over 4000 individuals. Total weight and meat weights by sex (N= 200) have also been collected. A study by Nichols and Jennings-Clark (1994) is said to have further unpublished data on a visual survey and estimates of growth parameters.

Total landings, including an estimate of local consumption, must be collected. Furthermore all available data collected during the Nichols and Jennings-Clark study should be retrieved and analyzed. This may include vital estimates of juvenile growth parameters from various areas as well as density and abundance estimates by fishing areas. Individual meat weights are available for measurement at the fishing complex despite the regulations requiring landing of conch in the shell.

4.5.9 Turks and Caicos Islands (TCI)

The TCI has a very long history of conch fishing with exports of conch to Haiti dating back to the late 1800s. (Doran 1958; Ninnes 1994). Fishing grounds extend over large areas of the Caicos Bank, however over the last few decades fishermen have had to travel to more distant areas to maintain harvest levels (Medley and Ninnes 1999). Fishermen operate from small boats and use free diving techniques to harvest conch from less than 15 m of water. Management regulations include minimum shell lengths of 178 mm, minimum clean meat weight of 227 g, and closed areas. Finally a national export quota of 600 000 lbs (272 t) is enforced. The quota was set using catch and effort data and a biomass dynamics model (Medley and Ninnes 1999).

Available data includes extensive landings figures (1901-present) as well as accurate catch and effort data from the mid-1970s to present, effort being measured in boat days. Biological data is available including shell length, shell lip thickness, total weight and limited meat weights. Hesse (1976) has made estimates of growth parameters. Finally some visual survey data is available for selected fishing areas.

It is suggested that individual meat weights be collected at the processing plants, which allows both sex and maturity to be identified. An expansion of visual surveys will allow a good estimate of exploitable biomass and recruitment levels to improve the stock assessment. Existing biological data from juveniles will allow new estimates of growth parameters to be made.

4.5.10 US Virgin Islands (St Croix)

Although a conch fishery has existed throughout the USVI at one time, the majority of commercial harvest is concentrated on the south and northeast coast of St Croix. Stocks around St. Thomas and St. John were considered seriously depleted by the late 1970s (Wood and Olsen 1983). Fishermen in St Croix operate from small boats and use SCUBA gear to harvest conch down to 27 m. Most recent harvest levels are approximately 15 t annually. Regulations for conch include landing the product in the shell, a minimum shell length of 230 mm (9 inches) and a limit on recreational catch of 6 conch day^{-1}.

Presently available data includes landings from 1986 (Tobias 1986), 1993-1998 with effort measured in hours fished. Catches must be reported for all harvested species. Biological data obtained from middens in 1986, 1994, 1995, and 1998 include shell length and shell lip thickness (N=1000s). Assessments of conch populations are also available from Salt River Canyon (Coulston *et al.* 1987). Meat weights are available for 1986 (N=300+). Wood and Olsen (1983) and Freidlander *et al.* (1994) have conducted visual surveys, and more recently some back reef areas have been survey during fish counts.

Planned future data collection activities in St Croix include a fishery census to gather morphometric data from harvested individuals, as well as abundance, areas fished, and CPUE information. It is suggested that an expansion of the fisheries independent visual survey be done to allow juvenile conch to be measured individually (estimates of growth parameters) and quantified in abundance (to be used as a possible recruitment index). Finally individual meat weights may be obtained at roadside stands where fishermen market product. Meat weights will need to be measured accurately (+/- 1 g).

4.6 Conclusions

Several recommendations are made here that pertain directly to data collection but also include general recommendations that could be implemented for any future conch stock assessment or other related workshops.

1) Data collection should be tailored to the individual situations (nature of the fishery), requirements (data applications, objectives of management) and limitations (funding, personal, logistical support) (FAO 1999).
2) Data may be used for stock assessment, formation of management strategies, monitoring, or refinement of management controls.
3) The sharing of technical information should be encouraged wherever possible, especially between islands and nations clearly sharing stocks, but also on a region-wide basis. A centrally located and shared facility could be established to assist regional members in the processing and analysis of all fisheries related data including those of queen conch.
4) Several specific types of data and analysis should be a focus for future data collection programs including the establishment of juvenile growth parameters throughout the region, comprehensive landings, specific effort by gear type, natural mortality of juveniles and adults, and visual abundance estimates.
5) A concerted effort should be made to develop and experiment with models that are designed to make use of large sets of easily obtained shell length and lip thickness data that exist throughout the region.
6) Pre-workshop preparation must be comprehensive for both participants and consultants. Although the general objectives of the workshop were well known ahead of time the specifics of the assessment approaches to be attempted were not. This included the lack of knowledge on the specific types of data required for each approach.
7) Improvements of available data will come with more advanced preparation as well as increased data collection that will be ongoing from this point.
8) It is essential that the participants at this workshop attend any subsequent workshops to allow a sense of continuity to build on experiences gained form earlier training.

5 Recommendations

5.1 General

Data collection needs to be reviewed and improved within all countries. Very few reliable stock assessments could be carried out, as the data were inadequate. In some cases, such as Jamaica, it is only a matter of time before new data are accumulated in the time series. In others, such as Cuba, a new data collection program needed to be developed and implemented. A detailed review of data collection is given in Chapter 4.

Regular workshops should be planned which enhance regional co-operation. This conch workshop provided a valuable opportunity for many participants to analyze and evaluate the data they possess. There was also an opportunity to share methods and data, such as a new method that had previously only been applied in the Bahamas, and parameter estimates and data from the Caicos Bank fishery, which proved useful for a number of assessments.

With a few exceptions, the analyses were not translated into management controls. As data sets and methods improve, greater emphasis should be placed in future on management advice. It should be emphasized that any management controls derived from conch stock assessments should be strictly precautionary. Conch stocks have a tendency to be overfished (see chapter 3), so care should be taken in setting quotas and other controls.

Although the workshop did not focus on standardized data collection, it is likely to become an important issue if data collection programs are expanded as recommended. Standard collection methods would be particularly useful in visual census surveys.

More detailed recommendations for improving stock assessment methodology, population models, and country-specific recommendations are set out below.

5.2 Stock Assessment Methods

With respect to methodology, several recommendations would enable scientists to make better use of the information they have or plan to collect.

- There is a clear need to develop stock assessment methods that can use shell length and lip thickness data. Many countries have been encouraged to collect shell length and lip thickness data to monitor changes in age and size composition, so data are already widely available.
- Methods need to be developed which allow the combined use of visual survey and catch-effort data. Methods based on the analysis of catch and effort data often suffer from a lack of fisheries independent information. Visual census data should make stock assessment much more robust if properly included in the assessment method. Although some use was made of visual census in the workshop, the methods were very crude and could be greatly improved.
- The development of Bayesian methods may particularly help countries with little data to make management decisions. A preliminary method was applied in this workshop using software currently under development. If this technique can be made more widely available, it could enhance data sharing and help rationalize the approach to risks in decision-making.

5.3 Biological Research

Natural mortality should be estimated directly through tagging studies. Many size and age based stock assessments depend on reasonable estimates of natural mortality. In the case of conch, the large change in mortality through its life history may make many stock assessment methods too unreliable to use. Large-scale tagging studies should be undertaken to estimate mean natural mortality as a function of age.

A new method should be developed to allow conch to be aged more accurately. Many stock assessment methods depend on ageing animals, either through their size or some other means, but no satisfactory method exists to age conch. It may well be possible to improve current methods. Research should be conducted on the measurable effects of conch ageing by obtaining information from tagging experiments and collecting alternative morphometric data.

5.4 Country Recommendations

5.4.1 Bahamas

Most problems with stock assessment in the Bahamas stem from data recording.

- The data collection program and assessments need to deal with the islands and banks separately. Clear differences in morphometric patterns give a strong indication that this is necessary.
- Effort data needs to be recorded in a way that allows CPUE to be proportional to species abundance. For many trips, effort directed at conch is not separated from that directed at other species caught, making much of the effort data unusable. Also the exploited stock may be only a small proportion of the total stock available, making CPUE indices a poor abundance index.

The results from the size-based assessment suggest that conch is not overexploited overall, but some areas may be locally overfished. Therefore, management controls to limit the fishing effort in particular areas may be warranted.

5.4.2 Belize

- In general, all data collection should be extended to all five fishing areas. Morphometric and biological data from all fishing areas must be collected to complete an assessment for this stock. The stock assessment carried out at this workshop could only be undertaken for one fishing area, since the morphometric data available was limited to that area only. We can not assume that the growth and mortality in this area is necessarily the same as that in the other five areas.
- Fisheries independent data on size composition should be obtained to assess the entire population. Except for 1998, the morphometric data have been fisheries dependent. As a result these data are taken from individuals greater than or equal to the legal size limit, and therefore does not include the population prior to recruitment.
- Periodic abundance surveys should be conducted, building on the baseline survey already completed. This might be used to develop a recruitment index for Belize and to locate the adult stock among other things.
- The fishing co-operatives should provide meat size frequency data. This is an inexpensive and efficient way to collect assessment data.
- All historical data should be obtained and compiled from the fishing co-operatives, to build as complete a catch-effort time series as possible. Analyses of these data should improve the fisheries co-operatives' data recording procedures.
- An estimate of the catch taken illegally should be made to correct recorded catches. This will lead to better estimates of stock size.
- Juvenile growth parameters should be estimated for Belize. The available published estimates have given some problems with their application, and it is not clear how reliable they are for this stock. A first step would be to re-estimate growth parameters from previous collected data (Strasdine 1988) using modern techniques.

5.4.3 Cuba

The aim in Cuba is to assess the conch stocks and to reopen the fishing operations for trading under CITES. To achieve this, the statistical data on the fishery must be improved in volume and accuracy for a better assessment and reference point estimates.

- Data collection must include the variables needed for stock assessment suggested at the workshop sessions.
- Other biological and ecological data are important and should be included in the research programs and surveys of this resource.
- A complete research project should be planned that includes assessment, population structure, management, monitoring, culture, stocking and protected areas for this species.
- The Ministry of Fisheries of Cuba should finance the investigations necessary to ensure responsible use of the resource and the conservation of the species.

5.4.4 Grenada

Basic data collection is required for Grenada before any reliable stock assessment is possible. Among other activities, it is necessary to:

- Put programs in place to collect accurate catch and effort data.
- Obtain historical catch data (from hotels, restaurants, exporters etc.).
- Conduct fishery independent surveys to obtain morphometric data on juvenile conch.
- Conduct an abundance survey to obtain a fishery independent stock size and an immediate assessment.

5.4.5 Jamaica

The following specific data collection activities are recommended:

- Collect morphometric data on Pedro Bank juvenile conch.
- Implement a data collection program (catch, effort and biological) for the offshore artisanal fishermen. Also consider biological data collection for the Morant Bank and the island shelf.
- Continue biological data collection and monitoring on the Pedro Bank.
- Test the assumption that meat weight of artisanal fishermen is the same as the industrial fishermen.
- Continue the abundance surveys using visual census.
- Estimate the level of poaching on the Pedro Bank, to obtain a better estimate of total landings.
- Develop GIS capabilities to monitor specific areas, and sites within certain areas.

5.4.6 St Kitts and Nevis

The key concern for the Nevis fishery assessment is the poor recording of effort data, which led to an unreliable stock assessment. Future assessments would be greatly enhanced with the following additional information:

- Improve the method of effort recording by direct sampling rather than relying on interviews
- A visual census on both Nevis and Caicos banks would allow better use of the Turks and Caicos Islands data set as a 'prior' in the Bayesian assessment.
- Morphometric data would allow better assessments of growth and reproduction in this stock, as well as the use of size-based assessment methods.

- Sample meat weights covering a wider age range of the stock (juveniles as well as adults) would allow better application of the weight-based cohort analysis.

5.4.7 St. Lucia

It was observed that many methods used are country specific and so specialist methods need to be adapted for St. Lucia which would allow better use to be made of data which are most easily collected. In addition, the following is recommended for data collection:

- St. Lucia will continue to collect data on lip thickness, shell length, landings and catch data. However data collection needs to be modified to get more morphometric data on juveniles and adults, and meat weights for adults in order to link meat weights to lip thickness and shell length. This will allow the application of a wider set of stock assessment methods.
- Visual surveys would also be most useful for St. Lucia in order to determine the status of the stock.
- A tagging study is needed to estimate **M**, **L_∞**, **k** and **t_o**.

5.4.8 Turks and Caicos Islands

The Caicos Bank has the longest catch effort time series, but other types of data are lacking. The time series data would be greatly enhanced with meat weight frequencies, data on local consumption (conch landings not being recorded), more morphometric data and visual census surveys. This would not only enhance the stock assessment for this fishery, but also benefit many others in the region that could make use of these data and stock assessment results. The TCI also possesses some shell morphometric data, which still requires analysis if a method became available.

The results of the stock assessment indicate the current export quota of 600 000 lbs is conserving the fishery and should remain. This quota should not be exceeded without more scientific information. Not only would exceeding the quota endanger the stock, but it would probably result in poorer economic returns for both the fishermen and the industry as a whole.

5.4.9 U.S. Virgin Islands

The following recommendations have been made to improve the management of conch resources in the U.S. Virgin islands:

- Assemble and review all available historical catch and effort data.
- Collect accurate catch and effort data on the present fishery.
- Continue the annual collection of morphometric measurements, which include shell length, lip thickness, meat weight and sex from juvenile as well as adult conch.
- Collect conch abundance data, both in nursery habitat inshore and at harvest sites offshore.
- Collect data on recreational conch fishery landings.
- Test stock assessment models with longer time series.
- Immediate measures should be taken by the U.S. Virgin Islands to enforce existing management measures and to establish closed areas inshore to protect nursery habitat.

6 References

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Appendices

A. The terms of reference

The working group will meet between 15-22 March 1999 in Belize City to carry out the following:

(1) Assess current data available to participating countries.
(2) Carry out analyses on available data to address:
    i) the status of stocks within the region
    ii) management advice to ensure sustainability of the fisheries
(3) Critically review future data requirements and methods addressing issues of regional harmonization.
(4) Make recommendations on data collection, management controls with reference to CITES and the FAO Code of Conduct requirements for responsible fisheries.

B. Catch-Effort Data Analysis

B.1 Introduction

Catch effort data analysis generally depends on two models. The first is the population model. Where catch is recorded as gross weight (catches are not broken down into size or age classes, for example) models are largely limited to the biomass dynamic form, such as the Schaefer model. These describe how the total biomass of the stock changes through time as the stock is exploited. The second model required links the stock abundance to some measurable variable, such as catch, effort or CPUE. It is often assumed that stock size is proportional to CPUE. This second model usually incorporates measurement error, which is used to explain all differences between the model and observations.

There are broadly two ways to interpret these models in relation to catch effort data. Firstly through maximum likelihood, which considers the relation between the data and model immediately around a particular set of point estimates. Maximum likelihood has the advantage that it is simple to do, but does not use all information available to the best advantage and cannot be used in decision analysis. Alternatively, Bayesian statistics considers the entire probability distribution for all parameter combinations. Although much harder to do, it makes much better use of available information and can be used in decision analysis. An example from each of these methods is explained in the next sections.

B.2 Maximum Likelihood

Models

The population model used was the Schaefer model, which describes biomass growth and depletion. In the difference equation form, the model is written as an equation, describing how the population changes through discrete time:

$$B_{t+1} = B_t + rB_t\left(1 + \frac{B_t}{B_\infty}\right) - C_t \qquad (1)$$

where B_t is the stock biomass at time t, and C_t is all catches combined in the fishery. The model requires two parameters: r = the rate of population growth and B_∞ = unexploited stock size, and may require an initial population size (usually parameterized as a proportion of B_∞) if catches have not been recorded from the start of the fishery.

In terms of data, the model requires a stream of observed total catches. It is important these catches include all removals from the population, not just measured catches. For example, illegal fishing might be known to occur, but the quantity of illegal catches would be unknown. Ignoring illegal catch assumes it is zero, which is known not to be the case. Therefore, it is better to guess some illegal catch than ignore it. Where unknown catches are a high proportion of the total catch, the model will probably not work well and provide poor results.

The population model is linked to an observed catch and effort time series by assuming the mean CPUE is proportional to the stock size, or equivalently that the expected catch is proportional to effort multiplied by the stock size:

$$m_t = qf_tB_t \qquad (2)$$

where q = a catchability parameter and f_t the observed effort which produced the observed catch. The mean catch can now be used as a parameter in a probability model to link the expected to observed catches. Often a least-squares approach is used. Least-squares is equivalent to maximizing the Normal distribution log-likelihood. In the general case, the data and expected values can be transformed to stabilize the variance:

$$Min \quad L(q, r, B_\infty) = \sum_t \left(c_t^a - m_t^a\right)^2 \qquad (3)$$

where c_t = the observed catch, a = the power transform variable and for the normal least-squares estimate a=1. As a gets smaller the distribution approaches the log-normal, which should be used instead (i.e. ln(c_t) and ln(μ_t)). There are good theoretical reasons why the mean should be proportional to the variance even in the best possible case, so putting a<=½ is probably always justified. However, sometimes no pretence is made that the parameters are maximum likelihood, but are simply the least-squares estimates. Although in this context there may be little theoretical support for least-squares estimates, they are often close to the ML estimates, are clearly defined and are objective.

There are several advantages to separating the population and observation models:

1. While a complete time series of total catches are required for the population model (1), the observation model does not require a complete time series of catch and effort data. Periods missing effort data do not present a problem. However, the usual results of statistics apply. The more catch and effort observations exist the better the estimates, and ML estimates generally can not be obtained where there are less data than parameters needing to be estimated. For r, B_∞ and q, at the very least 4 years data are needed and reasonable estimates probably require 12 or more years catch-effort data.
2. The catch for the observation model does not have to be the total catch. As long as we have some catch data and its associated effort the model can be fitted. For example, we might have two fleets, but only the second one supplies good effort information. For the population model we simply add the catches together to produce a series of total catches. The observation model would only use the catch and effort data of the second fleet to fit the model. This would obtain estimates of all parameters except catchability for the first fleet.
3. With multiple fleets fishing the same stock, we can fit several observation models simultaneously to obtain common fitted population model parameters, but separate q parameters for each fleet. An advantage of multiple fleets is that we can have multiple repeat observations on the stock, which will improve estimates of population parameters.
4. The population and observation models (equations 1-3) are examples and can be altered separately to cater for different situations. For example, it might be suspected that gear interference is significant, so effort is not proportional to catch. This effect can easily be modeled by introducing a transform of f_t in equation 2 (e.g. $\mu_t = q\sqrt{f_t}\,B_t$). Also other likelihood models besides least squares, such as the Poisson or Gamma probability distributions, can be used.
5. In the least-squares case, the q parameters can be calculated directly without using numerical fitting methods. So, for any series of population sizes given by the population parameters, the ML estimate of q can be derived. This can make the fitting process faster, of particular interest where there are a large number of fleets, as the numerical algorithm only has to fit the population parameters r and B_∞. For the general transformed least-squares case, the estimate of q is given as:

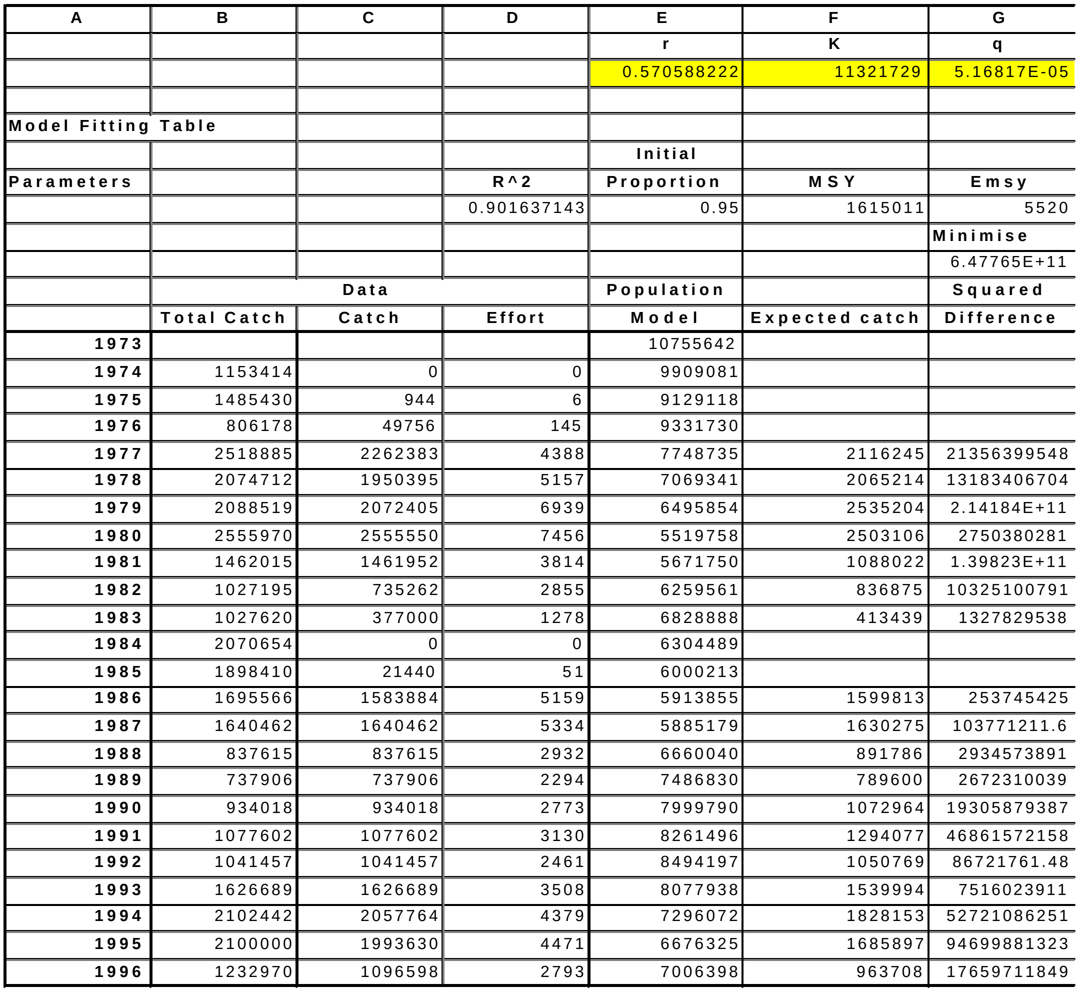
$$\hat{q} = \sqrt[a]{\sum_t \left(f_t B_t c_t\right)^a \Big/ \sum_t \left(f_t B_t\right)^{2a}}$$

and in the log-normal case (where n is the number of observations) : (4)

$$\hat{q} = \sqrt[n]{\prod_t c_t \Big/ \prod_t f_t B_t}$$

The models were used to define the limit reference points, MSY = $rB_\infty/4$ and effort at MSY = r/2q. These two quantities are the values of interest and can be used to advise management by suggesting precautionary limits to fishing capacity, where the aim is not to exceed these values.

Given a good length data set and data of good quality, it should be possible to obtain a reasonable result from the ML procedure if there is adequate contrast in the data. Even if the model is not a good description of the fishery dynamics, as long as the fishery has been through depletion and recovery periods, it still provides some simplified measure of the level of exploitation the stock can sustain. The real problem with the method is the requirement of contrast in the data, so that estimates of both the overall stock size (B_∞) and the rate of biomass growth after depletion (r) can be estimated. If CPUE has not changed over the observation period, then the method will either not work, or worse, provide very poor estimates. If the estimates are very poor, they should not be used. The only recourse is to fix some of the parameters as though they are known, which can also lead to false optimism over results and make the use the analysis dangerous.



A	B	C	D	E	F	G
				r	K	q
				0.570588222	11321729	5.16817E-05
Model Fitting Table						
				Initial		
Parameters			R^2	Proportion	MSY	Emsy
			0.901637143	0.95	1615011	5520
						Minimise
						6.47765E+11
		Data		Population		Squared
	Total Catch	Catch	Effort	Model	Expected catch	Difference
1973				10755642		
1974	1153414	0	0	9909081		
1975	1485430	944	6	9129118		
1976	806178	49756	145	9331730		
1977	2518885	2262383	4388	7748735	2116245	21356399548
1978	2074712	1950395	5157	7069341	2065214	13183406704
1979	2088519	2072405	6939	6495854	2535204	2.14184E+11
1980	2555970	2555550	7456	5519758	2503106	2750380281
1981	1462015	1461952	3814	5671750	1088022	1.39823E+11
1982	1027195	735262	2855	6259561	836875	10325100791
1983	1027620	377000	1278	6828888	413439	1327829538
1984	2070654	0	0	6304489		
1985	1898410	21440	51	6000213		
1986	1695566	1583884	5159	5913855	1599813	253745425
1987	1640462	1640462	5334	5885179	1630275	103771211.6
1988	837615	837615	2932	6660040	891786	2934573891
1989	737906	737906	2294	7486830	789600	2672310039
1990	934018	934018	2773	7999790	1072964	19305879387
1991	1077602	1077602	3130	8261496	1294077	46861572158
1992	1041457	1041457	2461	8494197	1050769	86721761.48
1993	1626689	1626689	3508	8077938	1539994	7516023911
1994	2102442	2057764	4379	7296072	1828153	52721086251
1995	2100000	1993630	4471	6676325	1685897	94699881323
1996	1232970	1096598	2793	7006398	963708	17659711849

Figure B.1 Illustration of a typical model set up in a spreadsheet. The data displayed comes from the Turks and Caicos Islands conch fishery. Column B is the total catch, and columns D and C are the available effort data and its associated catch data, respectively. The catch data can be equal to or less than the total catch data, as in this case. Catch and effort series need not be complete, but total catches need to be known. The population model in this case (Column E) is the Schaefer difference model, which defines how the population changes over time. It uses the fitted parameters r and K (i.e. B_∞), and the specified parameter, the 'Initial Proportion', which defines the start population size as a proportion of B_∞. The expected catch is the population size times effort times the estimated catchability parameter. The squared difference (Column G) is the measure of difference used in this model between the observed and expected catches. The optimizer ('Solver' in the case of MS Excel) is asked to minimize the sum of these squared differences by manipulating the three parameters, r, K and q. The user does not need to understand how the minimum is found. However, Optimizers are not always successful and the resulting parameters should be carefully checked to ensure they make sense.

Fitting Method

The models are most easily fitted in a spreadsheet (Fig. B.1) with capabilities for minimizing functions (an optimizer). MS Excel was used for this purpose, although most other spreadsheets offer this capability. Familiarity with spreadsheets is assumed.

In general the following steps should be taken if fitting models in spreadsheets.

1. The data would usually be annual. Months may be used, but the user should be wary of seasonal effects. The total catch data, and catch and effort data should be placed in columns.
2. The population, expected catch model formulas and the measure of difference between the observed and expected catches for each year should be placed in parallel columns. The sum of the measure of difference should be defined in one cell. Parameters should be place in contiguous cells for clarity. Additional fixed parameters should be placed on the spreadsheet, but separate to ensure they are not changed by the optimizer.
3. The optimizer is run from the menu (Tools!Solver… in MS Excel; if Solver is not present, reinstall Excel making sure the Solver option is selected). The target cell is the cell containing the sum of the measure of differences. The optimizer should be instructed to minimize the target cell by changing the parameter cells containing the values for r, K and q. Also, you should always tick the 'Use Automatic Scaling' in the Options dialog.
4. The optimizer may not work. It can produce invalid results during the fitting, causing the process to stall, or produce estimates, which are clearly incorrect. There are a number of remedies for this that can be tried:
    - Try different start points for the parameters. The closer the initial parameter values to the minimum, the greater the chance that the optimizer will be able to find the minimum. It is wise to restart the minimization process from a number of points to check whether the minimum applies over all the parameter space.
    - Calculate any q's using the formula (Equation 4) rather than getting the optimizer to fit them. This is often necessary if several q's are being estimated.
    - Use the IF() function in the measure of difference formula to check the result of the model in each year, and give a very high value if model is invalid. This encourages the optimizer away from parameter space, which is invalid and works well as long as the model starts with valid parameters. For example, the IF() function can be used to check whether the population has gone negative and return an 'impossible' value such as 9.9E+99 if it has. Alternatively, use the constraints in the optimizer to constrain parameters within known bounds.
    - Alter the optimizer options. MS Excel Solver should always be instructed to use automatic scaling. Changing other options may also help (see the Solver 'Help').
5. On completing the fit procedure, it should be checked how well the model fits the data. A number of plots are available. In general, the most important plot is the observed and expected CPUE time series. The expected CPUE should pass through the center of the observed CPUE points following any trends. The observed CPUE should form a random scatter around the expected CPUE with no obvious remaining patterns in the data. Other plots of residuals should similarly show no patterns, as any patterns indicate inadequacy of the model. Although some problems may be seen through these plots, they do not automatically mean the model is of no use. The ultimate test for any model is its ability to forecast future catch rates. If the model forecasts CPUE which then turns out to be consistently higher than that observed, the model should probably be discarded as it is clearly giving incorrect advice.

Empirical Bootstraps

Bootstrapping uses errors from the fitting process to create simulated data sets. Each of the simulated data sets are used to estimate parameters. By re-estimating the parameters a large number of times a frequency distribution of the parameter estimates is created. This can be used for a variety of purposes, but usually is most valuable in estimating confidence intervals for the ML estimates.

In the simplest bootstrapping case, the difference between the observed and expected CPUE (residuals) are used as a sample from the underlying error probability distribution. A residual is randomly selected (with replacement) and added to a expected CPUE to create a simulated CPUE, and this is repeated for all expected CPUE. These simulated CPUE data are multiplied by the effort to obtain a simulated catch. Note that the actual total catch used in the population model remains the same. The model is then fitted to the simulated catch series and the resulting parameter estimates stored. The whole procedure is repeated again as many times as possible generating a large number (at least 1000) of parameter estimates. These parameter estimates can be used to generate the MSY confidence interval, the lower 95% limit of which could be used to set a quota, for example. Bootstraps were only attempted in the TCI case where the data set was large enough for the method to have some validity.

B.3 Bayesian Assessment

Introduction

The new method presented here combines information from the Turks and Caicos Islands, which has a relatively good catch effort time series, with Nevis, which has a very poor catch effort time series, to provide some stock assessment information for Nevis.

The stock assessment model is based on the Schaefer model. Although the model takes little account of ecology, it is relatively robust and should provide guidance on fishing levels in the form of overall quotas. However, the approach carries with it several potential pitfalls, which need careful consideration.

The parameter probabilities are interdependent, so it is necessary to model the prior and posterior as a joint probability distribution for the three parameters (r, B_∞ and q). This increases the complexity of the analysis, but does allow correlations between parameters to be correctly taken into account and therefore yield robust estimates of the reference points of interest.

The general approach is set out very briefly below. Details of the method are set out in Press (1989), Gelman *et al.* (1995) and McAllister and Kirkwood (1998a).

Method

The posterior was generated as an unnormalized function of the parameters:

$$h(r, B_\infty, q) = p(r, B_\infty)\, L(r, B_\infty, q)$$

The prior, based on the TCI data, is used to supply information on the stock population dynamics only, r and B_∞. The catchability parameter (q) is assumed to be fishery dependent and estimated from the St. Kitts and Nevis data.

For robustness, the prior probability was derived based on bootstrap estimates from the Turks and Caicos Islands stock assessment presented elsewhere in this report. Individual bootstrap sample points were used to create a smoothed prior probability density function (pdf) as described in Press (1989). The unexploited population size was simply scaled by the area, so bootstrap estimates of B_∞ were multiplied by 845/6110, being the relative areas of the Nevis and Caicos Banks. The likelihood for the Nevis catch-effort time series used the standard Schaefer model with Normal likelihood.

While the function can be calculated at individual points, it is not practical to integrate it using standard numerical techniques. Instead two Monte Carlo methods were used. Rejection sampling was to draw random parameter sets from the posterior, and importance resampling was used to provide estimates of expected values (see Gelman *et al.* 1995). Both methods work well with a good approximation to the underlying function. A trapezoidal approximation was calculated over a grid of points. The grid was adjusted as much as possible so that vertices lie on modes. Even so, it was difficult to obtain a good approximation and the grid therefore consisted of a large number of points, which slowed the analysis.

In all cases, parameters were constrained to be positive. In addition, the parameter r was limited to a maximum value of 2. Values greater than 2 begin to produce specific deterministic behavior, which is an artifact of the model rather than a possible population behavior. Otherwise, for practical purposes, limits on parameters were chosen which covered all but an insignificant proportion of the posterior probability.

Results

The posterior PDF indicates two hypotheses with respect to parameter values, represented by two modes. The modes are a result of the TCI prior, and essentially represent the problem observed with the model fit. The early part of the time series, with a rapid decline and recovery is consistent with a high-r low-K model. However, more recent CPUE series suggest r is lower and K higher than this, so either the data time series varies or it is possible that r and K are themselves functions and may need to be modeled on the age structure of the population, moving away from this biomass dynamics approach.

The St. Kitts and Nevis data adds its weight to the higher K as there is no observable decrease in CPUE (Fig. B.2). However, this lack of decline may be as much due to the poor effort measurement as a lack of depletion. The posterior PDF can be used in a number of ways, to obtain expected catches (or utility) from controls, to develop marginal posterior distributions of values of interest, such as MSY. Both methods are used to provide advice for St. Kitts and Nevis fisheries (see the St. Kitts and Nevis stock assessment section).

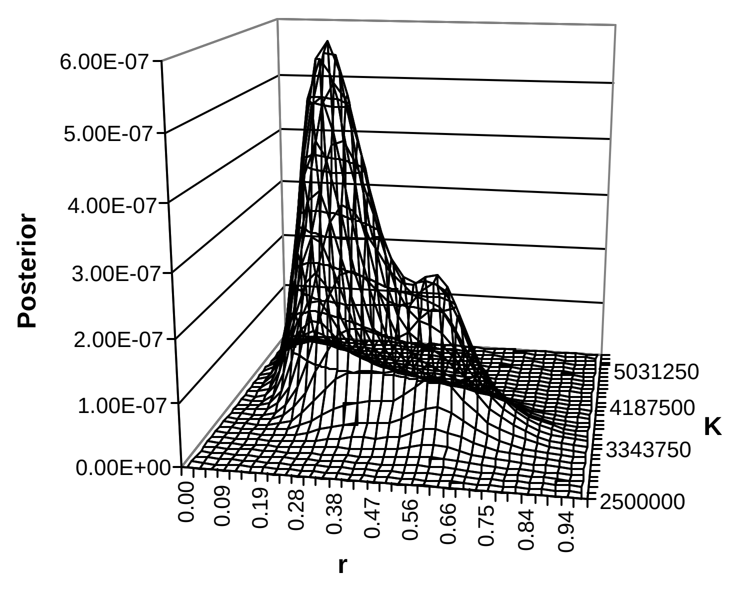


Figure B.2 An example 'slice' of the unnormalized posterior probability function for fixed q (5.0 10^{-6}) illustrating two modes for high and low r. The Nevis catch effort data likelihood more strongly supported the high K (measured in lbs), illustrated by the much higher peak in the posterior for values of r 0.2-0.3. However, the prior clearly remains very influential and essentially set up the two modes (hypotheses) in parameter estimates (see text).

C. Weight-Based Stock Assessment Technique Applicable to Species for Which Weight Frequency Statistics in the Landings Are Available: Queen Conch as a Case Study

C.1 Introduction

Stock assessments of queen conch are significantly more difficult than finfish or even crustacean stock assessments due to several biological and population dynamic features that characterize the species. In general, queen conch has shells that do not show temporal depositions of calcareous material, which may follow temporal changes in their metabolism. For this reason, these conchs are lacking hard parts that can be used to age the animals according to chronological events related to growth. Another peculiar characteristic of queen conch is that they grow in siphonal length (shell length) until the onset of maturity, after which, growth is predominantly in the formation of a shell lip and thickening of the shell. Thus, shell lip thickness is representative of the growth in these animals after maturity. Consequently, the change in the axis of growth implies a change in the character of growth after maturity that prevents the use of common methods developed to study growth in fishes that use size modal progressions to express the change in size with time. Moreover, queen conch is caught by divers and a large fraction of the conch landed are shelled at sea or onshore on arrival. Thus only edible parts are delivered to processing plants or to local markets. Therefore, queen conch landings are mostly expressed by the weight of the edible parts (conch foot), which are not easily measurable to be readily incorporated in statistical databases with which to perform stock assessments. Queen conch, on the other hand, varies in size at first maturity according to zones or ecological substrates - a fact that further complicates the study of their growth.

In the absence of appropriate statistical measurements that may be used in stock assessment techniques, and in the absence of adequate functions to express their growth in length, most queen conch stock assessments have historically being performed either by direct censuses carried out by divers or through use of models that use landings in weight per unit of fishing effort. In this way, there are no estimates of the fishing mortality at age or estimates of their abundance by size or age – two very important pieces of information to manage these fisheries.

Appeldoorn (1988a) developed a growth-in-weight algorithm to estimate an approximate weight-at-age of queen conch in the fishery of Puerto Rico. A similar approach was adopted in an ongoing conch research program in the Bahamas. In what follows weight-based stock assessment techniques are presented that may be useful to estimate abundance and fishing mortality of queen conch or other species that show similar characteristics in their landed products. These techniques were developed for applications at the Queen Conch International Stock Assessment Workshop.

C.2 Methods

A simple model to express growth in weight.

Growth functions are an essential element in most stock assessment work. In the case of queen conch, growth cannot be easily modeled as the species experiences notorious changes in their axis of growth, especially as they approach maturity. In the absence of hard parts to determine the age of the individuals, development of simple growth equations for the adults of these species is rather difficult or impossible. Appeldoorn (1988a) developed a growth algorithm to express growth of queen conch, which couples juvenile and adult growth in weight via a juvenile von Bertalanffy-type growth function of siphonal length converted to weight through a length-weight relationship for juvenile conch. Then, added weight in the adult ages is modeled as a function of lip-thickness at age and a lip-thickness-weight relationship for the adult conch. The resulting growth at age data is subsequently modeled by fitting a Gompertz-type growth function in weight to the estimated growth data. The Gompertz growth in weight at age function used by Appeldoorn (op cit) is expressed as

$$W_t = A1 * \exp(A2 * (1 - \exp(-A3 * t))$$

where W_t is weight at age, t is age and A1, A2, and A3 are parameters.

The Appeldoorn growth algorithm is data intensive, therefore an attempt has been made here to simplify the above algorithm such that a more readily available technique is available for stock assessment purposes. The simplification is possible when average weight of the older (mature) animals is available, and a fairly good description of the juvenile growth is also available. This appears to be the case of the queen conch throughout the Caribbean region since there is an extensive literature available on the growth of juvenile conch (see for example Appeldoorn and Rodriguez 1994). On the other hand, extensive information on edible meat weight for the larger mature conch has been collected in most fisheries of the Caribbean region. In the particular case of the Gompertz equation, when age (t) is large, say equal to infinity, we have that

$$W_\infty = A1 * e^{A2}$$

Thus, the growth equation can now be expressed as

$$W_t = \frac{w_\infty}{w_\infty^{\,EXP(-A3*t)}}$$

Since these animals do not appear to grow in meat weight after maturity, then the asymptotic meat weight, W_∞, can be estimated as the average of the weight over a range of large mature animals. Then the parameter A3 in the above equation is the only missing piece of information, which can be estimated by least squares procedures from a truncated growth in weight data series for juvenile stages and the average asymptotic weight assigned to larger, thus older ages. This may be easily accomplished with the MS Excel Solver tool.

The merit of the above equation is that real data on meat weight of old animals and fairly well estimated growth in weight curves for juveniles are integrated to generate a growth curve that covers the whole life span of the species. This is done without the need of estimating growth in length or lip thickness, and dubious lip thickness-meat weight relationships (usually with zero slope and very low correlation) corresponding to sizes when the animal experience near zero meat growth are not required by the simple model.

Total mortality estimation from weight converted catch curves

A catch curve is defined as the frequency of animals in each age in a population. Catch curve analysis refers to the estimation of the total instantaneous mortality rate (Z) by the slope of a regression line fitted to the natural log of the abundance or catch in numbers of a given age t, on the age t. That is

Since conch cannot be easily aged, or given that the length statistics cannot be appropriately used in stock assessments, then C_t in the catch equation can be replaced by the number of animals in a given weight class. Thus, in the case when only weight frequency statistics are available, this is achieved by dividing C in the weight class by the time needed to grow through the weight class. This elapsed time is defined by the growth equation adopted for the species.

$$\ln C_t = a + Zt$$

The simple growth equation developed above, can be rearranged to give age as a function of weight as follows:

$$t = \frac{-\ln\left[\dfrac{\ln\left(W_\infty / W_t\right)}{\ln\left(W_\infty\right)}\right]}{A3}$$

Thus, if W_j and W_{j+1} are the lower and upper edible meat weight limits, respectively, of edible meat weight interval j, then the time required to grow through size interval j can be expressed as

$$\Delta_{t_j} = t_{j+1} - t_j = \frac{1}{A3}\ln\left[\frac{\ln\left(W_\infty / W_j\right)}{\ln\left(W_\infty / W_{j+1}\right)}\right]$$

Thus, an edible meat weight catch curve for queen conch is given by

$$\ln\left(\frac{C_t}{\Delta t_j}\right) = a + Zt'$$

where t' is the relative age of the conch at the mid-weight of the edible weight class interval j. This median age t' is computed from the formulation derived the simple growth in weight function given previously.

Once Z is estimated from the above procedure, the fishing mortality rate is estimated as the difference between the total mortality rate Z and the natural mortality rate M.

Tuned Weight-Based Cohort Analysis

Age-based cohort analysis was introduced by Pope (1972) as a computationally simpler approximation to virtual population analysis. The catch is assumed to be caught instantly at the midpoint of the time period so that the exponential decline of the population throughout the time period is replaced by a step function with only natural mortality occurring throughout the period. Thus the number of animals in a cohort of age t (N_t) can be computed directly from the numbers at age t+1 given the catch at age (C_t) and an estimate of the natural mortality (M) are available and using the following equation:

$$N_t = (N_{t+1}\, e^{M/2} + C_t)\, e^{M/2}$$

If the number of animals in the oldest age (t +1) is estimated, the number of animals in each younger age (t) is computed by successive backward applications of the above equation. The number of animals in the oldest age class can be estimated by

$$N_A = \frac{C_A}{(F/Z)_A}$$

where A is the oldest age and $(F/Z)_A$ is the ratio of fishing to total mortality for the oldest age, which must be supplied from outside sources. The total mortality rate for age a (Z_t) is estimated by

$$Z_t = \mathrm{Ln}\left(\frac{N_{t+1}}{N_t}\right)$$

and the corresponding fishing mortality rate at age (F_t) found by $F_t = Z_t - M$. Thus population size and fishing mortality rates can be estimated from catch data if the natural mortality rate and F/Z for the oldest age group are given.

Landings data in numbers by weight classes instead of age can be used in cohort analysis under equilibrium conditions if a growth function is available to determine the amount of time spent in each size class. Jones (1984) developed a similar approach for the case when landings in numbers at length data are available. The basic cohort analysis equation using weights is

$$N_j = (N_{j+1}\, e^{M\Delta t_j/2} + C_j)\, e^{M\Delta t_j/2}$$

where j=1,n are weight intervals, N is population size in numbers, C is catch in numbers, M is natural mortality, and Δt_j refers to the time an individual requires to grow through weight interval j. The Δt_j can be estimated from any growth equation appropriate for the conch – such as the simple growth equation given previously.

A common computational simplification in weight-based cohort analysis will be to compute $X_j = \exp(M\Delta t_j/2)$ and replacing Δt_j by its function such that it can be computed as

$$X_j = \left[\frac{\ln\left(W_\infty / W_j \right)}{\ln\left(W_\infty / W_{j+1} \right)} \right]^{\frac{M}{2*A3}}$$

for each meat weight size interval. Thus, the cohort analysis equation becomes

$$N_j = (N_{j+1} X_j + C_j)\, X_j .$$

Thus, once the number in the largest, and therefore oldest, weight interval is known, the numbers in each successively smaller size interval can be estimated through application of the weight cohort analysis equation. As in the age-based cohort analysis, if the largest size interval is assumed to be a plus group, the number in the largest size interval (n) can be estimated by

$$N_n = \frac{C_n}{(F/Z)_n};$$

where again $(F/Z)_n$ is the ratio of fishing to total mortality for the largest, and therefore oldest, size group. If the approach used in age-based cohort analysis to estimate total mortality rates (Z_j) is followed in weight-based cohort analysis, an estimate of $Z_j\Delta t_j$ will result due to the different growth rates at size. Instead, the total mortality rate for each size interval (Z_j) can be estimated by

$$Z_j = \frac{M}{1 - (F/Z)_j}$$

where $(F/Z)_j$ is estimated from the number of animals caught divided by the number dying for each size interval, that is,

$$(F/Z)_j = \frac{C_j}{N_j - N_{j+1}}.$$

The fishing mortality rates per size interval (F_j) are then estimated as $F_j = Z_j - M$.

The population numbers in each size interval (N_j) computed refer to the number of animals attaining the size during the time period of the catch. However, an animal may attain the weight at the start, middle or end of the time period. To estimate the standing stock, the average numbers in the sea per size interval ($\underline{N}_j$) can be computed under the assumption of steady state as

$$\overline{N}_j = \frac{N_j - N_{j+1}}{Z_j}.$$

Use of the above equations can be used to convert the number of animals caught in weight intervals into population estimates and fishing mortality rates given a growth curve, natural mortality, and F/Z estimate for the largest animals. According to Ehrhardt and Legault (1996) these population and fishing mortality estimates are highly sensitive to the $(F/Z)_n$ value entered for the largest animals. If outside information is available, $(F/Z)_n$ can be chosen such that the estimated population size or fishing mortality rates most closely agree with this externally estimated index.

Outside information, such as the overall fishing mortality rate for the time period, may be used to tune the weight-based cohort analysis. The overall fishing mortality rate needed for tuning (F_{tune}) can be estimated from a total mortality rate estimated by weight-catch-curves (as given above) and an estimate of M. In the tuning of the weight-based cohort analysis procedure, the overall fishing mortality rate derived in these manner should be compared to a weighted average of the fishing mortality rates from the weight-based cohort analysis. According to Ehrhardt and Legault (op cit), the tuning process thus consists of changing the F/Z value for the largest animals until the weighted F estimate from the size intervals is equal to the overall F from a weigh-converted catch curve analysis, that is,

$$\frac{\sum N_j F_j}{\sum N_j} = F_{tune}$$

Tuning the length-based cohort analysis using either an overall fishing mortality rate or a biomass estimate will produce more consistent population size and fishing mortality rates in successive time periods relative to an analysis that does not use tuning. This is because time periods are treated totally separately in untuned weight-based cohort analysis, while the index estimation procedure creates a linkage between time periods in the tuned analysis. The high sensitivity of weight-based cohort analysis to the initial F/Z value entered for the largest animals requires additional information to prevent bias from propagating through the successive applications of the weight cohort analysis equation. A calibration index provides a means to choose a more appropriate F/Z value for the largest size interval. The results of the tuned weight-based cohort analysis are only point estimates though, and should have levels of uncertainty associated with them to reflect the uncertainty inherit in the data collection and analysis.

C.3 Applications

Use of simulated growth equation

Average growth parameter estimates for juvenile conchs from an ongoing research project in the Bahamas are used for demonstration purposes in this application. These parameters correspond to juvenile conch tagged in the Berry Islands in the early 1980s and estimated by several methods including Ford-Walford plots, Gulland's growth rates approach, Fabens least squares procedure and modal progression (ELEFAN). The average parameters used are: L-inf = 222.3 mm siphonal length, and K=0.64. The parameters for a siphonal length-meat weight relationship for juvenile conchs are given as a=0.00388 and b=1.9594. The average upper limit of a meat weight of adult conch in the Grand Bahama fishery resulted in 143 grams. With these data a parameter A3 equal to 1.08896 was estimated in an MS Excel template using the Solver tool. This spreadsheet was made available at the Workshop.

Use of weight frequencies in weight-converted-catch-curves

Plots of the log-converted catch in numbers per weight class interval on median age obtained with the data generated in an ongoing research project for the conch fishery in Grand Bahama are presented in figure C.1. The regression range is for the points in the descending right limb of the distributions shown in the figure, and the slope of the estimated lines is an estimate of the total instantaneous mortality rate (Z=1.59 in the example). Sreadsheets were developed in MS Excel to perform the above analyses, and was made available at the Workshop.

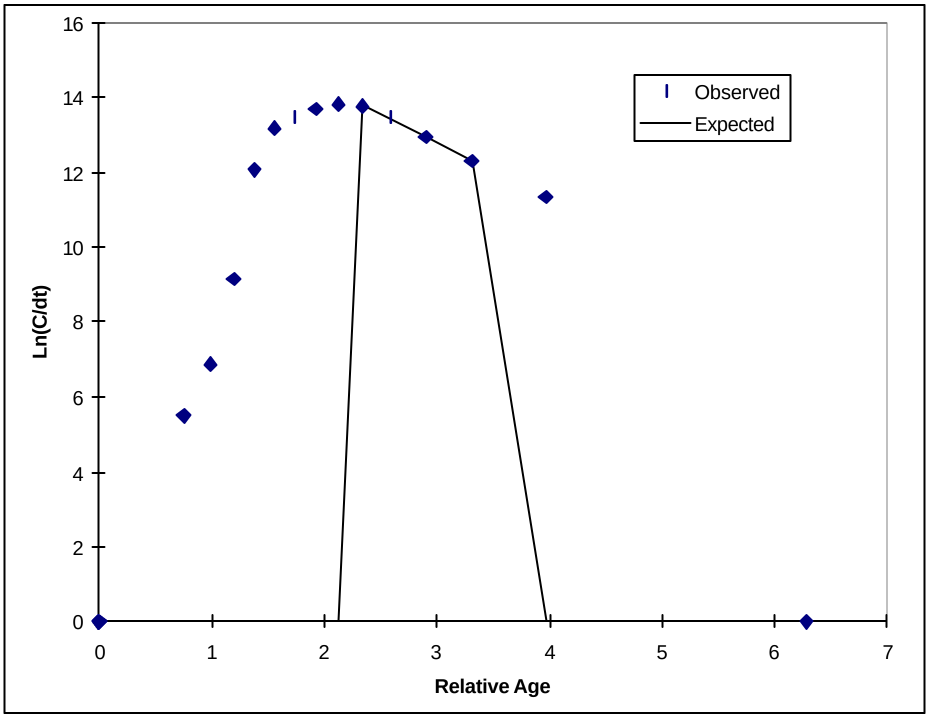


Figure C.1 Plots of the log-converted catch in numbers per weight class interval on median age obtained with the data generated for the conch in the Grand Bahama fishery in 1997.

Tuned Weight Cohort Analysis (TWCA)

The tuned weight cohort analysis approach suggested here is demonstrated with the same conch data for the Grand Bahama fishery used above and using the fishing mortality rate of F=0.3686 obtained in the weight converted catch curve analysis as a tuning index for weight classes 90 to 130 grams. An average of published natural mortality rates for conch of 1.19 was used in the demonstration analysis. In a MS Excel spreadsheet, tuning is simplified by use of the Solver tool. For this purpose it is necessary to make average F-values from cohort analysis converge to the external F-value provided for the tuning. Results of applying this technique to the weight frequencies of total landings in the Grand Bahama fishery are shown figures 2 and 3. In figure 4.1.1 (Bahamas stock assessment section), the fishing mortality rate in 1997 is shown by mid-class weight, while in figure 4.1.2 the total stock abundance as well as the catch in numbers corresponding to each mid-class weight is given. The analysis indicates that an overall fishing mortality rate of F=0.1953 is affecting the stock between 45 and 140 grams meat weight, however, the fishing mortality rates for meat weight classes between 80 and 120 grams (or 166.8 and 120 mm siphonal length) are the greatest (close to 0.5). These fishing mortalities correspond to animals just prior to reaching first maturity.

Total abundance in numbers resulted in 16 million for the meat weight range between 10 and 140 grams with a corresponding biomass of 691 t.

The set of methods and programs developed for this workshop, demonstrate the potential of their use in conch stock assessment work. It is imperative, however, that appropriate statistics should be used for the above work, since the availability of uncorrelated data between weight samples and landings may prompt the improper use of the techniques.

D. Analysis Of Covariance (Ancova) To Test Differences Among Linear Regressions

D.1 Introduction

Frequently in biology and in population analysis it happens that the unit observations to be analyzed can be classified into two or more groups. For example, a set of fish lengths and weights might be grouped according to seasons, or morphometric relationships may be grouped according to areas. This raises the question of whether separate equations (linear regressions) should be used for each season or area, or could some or all of the groups be represented by a single equation? Analysis of covariance provides a means of answering this question.

In the case of simple linear equations, group regressions may differ either because they have different slopes or, if the slopes are the same, because they differ in level (intercept). Under the assumption that the groups have similar variances, the standard covariance analysis (ANCOVA) first tests the hypothesis of no difference in slopes. Then, if there is no evidence of a difference in slopes, since the lines may be parallel the hypothesis of no difference in levels is tested. If no significant difference is found in either the slopes or levels, then a single regression may be fitted ignoring the groups.

Based on the arguments above, this technique has ample application in fisheries research, especially when, due to insufficiencies in the database, there are critical decisions to be made regarding the pooling of data sources. Pooling data sources may make false assumptions regarding the fundamental biological or dynamic processes, invalidating the conclusions of the analysis. Therefore, testing the hypothesis that functional groupings are not significantly different before the pooling of the data is useful. In what follows we summarized a well-known technique of analysis of covariance for testing the equality of linear regressions and we introduce an ANCOVA algorithm in a macro written in MS Excel with re-sampling capabilities (bootstrapping).

D.2 The ANCOVA Technique.

The following data set will be used to illustrate the analysis of covariance.

	Group A		Group B		Group C	
	y	x	y	x	y	x
	5.9	0.8	5.2	1.6	7.8	0.6
	10.7	3.1	13.4	5.8	12.4	3.4
	11.4	4.4	10.0	3.6	10.9	1.5
	9.6	1.6	7.5	2.0	9.9	0.7
	12.6	4.6	10.1	4.3	16.8	4.5
	8.0	2.6	11.9	5.8	13.9	4.1
	12.8	5.5	10.7	4.8	11.4	2.3
	7.5	1.1	6.8	3.3	8.9	1.3
	12.5	3.9	9.0	2.6	13.7	3.1
	14.2	4.9			16.0	4.6
	8.4	1.4				
sums	113.6	33.9	84.6	33.8	121.7	26.1
means	10.33	3.08	9.4	3.76	12.17	2.61
n	11		9		10	

	Group A	Group B	Group C
ΣY^2	1242.72	848.20	1559.73
ΣX^2	132.73	145.98	89.47
ΣXY	390.91	346.69	356.57
$\Sigma\, d_y^2$	69.54	52.96	78.64
$\Sigma\, d_x^2$	28.26	19.04	21.35
$\Sigma\, d_{xy}$	40.82	28.97	38.93

Pooled values (ignoring groups)

$n = 30$ $\Sigma y = 319.9$ $\Sigma x = 93.8$

$\Sigma y^2 = 3650.65$ $\Sigma x^2 = 368.18$ $\Sigma xy = 1094.17$

$\Sigma d_x^2 = 74.90$ $\Sigma d_y^2 = 239.45$ $\Sigma d_{xy} = 93.95$

where: $\Sigma d_x^2 = \Sigma\ (x-\overline{x})^2$ $\Sigma\ d_y^2 = \Sigma\ (y-\overline{y})^2$ $\Sigma d_{xy} = \Sigma\ (x-\overline{x})(y-\overline{y})$

The slopes of the lines are defined as, $\hat{s}_1 = \Sigma d_{xy} / \Sigma\ d_x^2$

If a separate regression were fitted for each group, we would have:

Group A

$\hat{s}_1 = 40.82/28.26 = 1.4445$

with sum of squares due to regression and residuals defined as

$SS_{regression} = \hat{s}_1 \Sigma d_{xy} = (1.4445)(40.82) = 58.96$, with 1 d.f.

$SS_{residuals} = \Sigma d_y^2 - SS_{regression} = 69.54 - 58.96 = 10.58$ with 10 d.f.

Group B

$\hat{s}_1 = 28.97/19.04 = 1.5215$

with sum of squares due to regression and residuals defined as

$SS_{regression} = \hat{s}_1 \Sigma d_{xy} = (1.5215)(28.97) = 44.08$, with 1 d.f.

$SS_{residuals} = \Sigma d_y^2 - SS_{regression} = 52.96 - 44.08 = 8.88$ with 7 d.f.

Group C

$\hat{s}_1 = 38.93/21.35 = 1.8234$

with sum of squares due to regression and residuals defined as

$SS_{regression} = \hat{s}_1 \Sigma d_{xy} = (1.8234)(38.93) = 70.99$, with 1 d.f.

$SS_{residuals} = \Sigma d_y^2 - SS_{regression} = 78.64 - 70.99 = 7.65$ with 9 d.f.

Groups A, B and C

If a single regression were fitted (ignoring groups) we would have:

$\hat{s}_1 = 93.95/74.90 = 1.2543$

with sum of squares due to regression and residuals defined as

$SS_{regression} = \hat{s}_1 \Sigma d_{xy} = (1.2534)(93.95) = 117.85$, with 1 d.f.

$SS_{residuals} = \Sigma d_y^2 - SS_{regression} = 239.45 - 117.85 = 121.60$ with 28 d.f.

The steps in ANCOVA are summarized in the following table:

Line	Group	d.f.	Σd_x^2	Σd_{xy}	Σd_y^2	d.f.	SS	MS
1	A(residuals)	10	69.54	40.82	28.26	9	10.58	
2	B(residuals)	8	52.96	28.97	19.04	7	8.88	
3	C(residuals)	9	78.64	38.93	21.35	8	7.65	
4 Total						24	27.11	1.13
5 = (line 6-line 4)		Difference for testing slopes				2	1.85	0.93
6 = (lines 1+2+3)		27	201.14	108.72	68.65	26	28.96	1.11
7 = (line 8-line 6)		Difference for testing levels				2	92.64	46.32
8 = (Pooled values)		29	239.45	93.95	74.90	28	121.60	

1) For test of difference in slopes

$F_{(2,24)} = 0.93/1.13 = 0.82$, not significant at 0.05 level

2) For test of levels (assuming common slopes)

$F_{(2,26)} = 46.32/1.11 = 41.73$, significant at 0.05 level

Analyzing the ANCOVA table we see that the first three lines summarize the results of fitting separate linear regressions for each group. In line 4, the residuals about the separate regressions and the associated degrees of freedom are pooled. This pooled term can be thought of as the sum of squared residuals about the maximum model; it represents the smallest sum of squares that can be obtained by fitting straight lines to these observations.

Skipping to line 6, the first four columns are the pooled degrees of freedom and sum of squares and products for the groups. The last three columns summarize the result of using the pooled sum of squares and products to fit a straight line. The normal equation and solution for this fitting should be:

$$68.65\,\hat{s}_1 = 108.72$$

$$\hat{s}_1 = 1.5837$$

Thus the $SS_{regression} = 1.5837(108.72) = 172.18$,

and $SS_{residuals} = \Sigma d_y^2 - SS_{regression} = 201.14 - 172.18$

$SS_{residuals} = 28.96$, with 26 d.f.

This represents the residual that we would get by forcing the regressions for all groups to have the same slope even though they were at different levels. Since this is a more restrictive model, the residuals sum of squares will be larger than that obtained by letting each group regression have its own slope. The mean square difference in these residuals (line 5) can be used to test the hypothesis of common slopes. The error term for this test is the mean square of the pooled residuals for separate regressions (line 4). The F test gives no indication that the hypothesis of common slopes should be rejected. If the hypothesis of common slopes is rejected we would usually go no further in the analysis.

Having shown no significant difference in slopes, the next question would be whether the regressions differ in level. Under the hypothesis of no difference in levels, we would in effect ignore the groups and use all of the data to fit a single regression. The results are summarized in line 8. Because of the added restriction (common levels) that has been imposed on this regression, the residuals will be larger than those obtained where we let the group regressions assume separate levels, but force them to have a common slope (line 6). The mean square difference (line 7) provides a test of the hypothesis of common levels. The error for this test is the residual mean square for the model assuming common slopes (line 6).

The significant value of F suggest that the group regressions are different.

E. An Overview of the Conch Fisheries of Mexico

E.1 Brief History

In Mexico, and particularly in the Yucatan Peninsula, queen conch has had cultural, economic and social value since pre-hispanic times. Nowadays the species still has dietary value and represents an important source of income for fishermen and artisans in the area.

The commercial exploitation of queen conchs began in the 1950's in the states of Yucatan and Quintana Roo, when Cozumel and Isla Mujeres were opened to tourism. In the 1970s exports began to the United States, which led to a considerable expansion of the fishery.

Official statistics regarding the conch resource in Mexico encompass at least 20 species of gastropods, among which *Strombus gigas, S. Costatus, S. Pugilis, Xancus angulatus, and Pleuroploca gigantea* constitute most of the landings in the Gulf of Mexico and Caribbean areas.

Landing records became available in 1973 for the state of Quintana Roo and in 1979 for Yucatan, and they indicate that maximum annual production levels were attained in 1975 (with 345 t of clean meat) and 1979 (306 t), respectively. Soon after, rapid declines in the landings and other signs of overexploitation started to appear in both fisheries. In the 1980s some management measures were implemented to halt this sharp decline in production, but since signs of overfishing were still evident, by 1990 both fisheries had been closed indefinitely.

E.2 Fishing Areas

In Mexico conch resources of the genus *Strombus* have traditionally been fished in the Yucatan Peninsula, from Ciudad del Carmen, Campeche to Chetumal, Quintana Roo. The fishery of the species *Strombus gigas* has concentrated in the states of Yucatan and Quintana Roo.

Yucatan

Celestún, Dzilám de Bravo and San Felipe were important fishing areas, which in 1981 contributed to a 93 % of the state's total production. However, the largest queen conch stocks were located 65 nautical miles off Puerto Progreso, in the waters surrounding the Alacranes Reef. By 1985, a 70% of the catch was being obtained from this area.

Quintana Roo

The coast of the state of Quintana Roo was divided into three main fishing areas according to the volume of conch landings: North, Central, and South Zones. The most productive areas were the North and South Zones. In the North Zone, queen conch was mostly collected off Isla Mujeres; in the Central Zone, off Puerto Morelos, and Bahías de la Ascención and Espíritu Santo; and in the South Zone, Chinchorro Bank stood out as the most productive area throughout the Yucatan Peninsula.

E.3 Fishing Methods

Extraction of conch resources in the Yucatan Peninsula has traditionally been carried out by small dingy boats, ranging in size from 18-25 ft and equipped with 24-45 HP outboard engines. An average of 3 fishermen participate in 4-6 hour fishing trips, and generally conchs are shucked and cleaned on board the vessel and most of the shells are discarded at sea. According to the depth, free, scuba, and/or compressor (hooka) diving have been used as fishing methods. Similar to other countries in the Caribbean, intense exploitation in shallow areas resulted, over time, in fishermen going further afield and into deeper waters to collect conchs. In the South Zone of Quintana Roo, conchs were usually found in depths ranging from 1.5 to 2.5 m (in Chinchorro Bank) and therefore free diving was the only method used. On the other hand, depths in the North and Central Zones averaged 20-30 m, so scuba and hooka prevailed. In Yucatan, conchs were found in depths ranging between 3 and 18 m and all three methods were used. Nowadays, conchs are generally found over 30 m deep in most areas, except for Chinchorro Bank, where some shallow water stocks remain.

E.4 Trends in the Fishery and Management Measures

Yucatan

The high productivity attained in 1979 was followed by a rapid decline in the landings, such that, by 1985, only 54 t were landed in Puerto Progreso, Yucatan (Fig. E.1). This situation forced the local authorities to suspend the renewal of fishing licences for the exploitation of conch resources. Despite this measure, fishing practices continued, and by 1987 conch landings in Yucatan had declined to the lowest levels ever, 10 t, so since 1988 a permanent closure of the fishery was implemented. This regulation protects five main species of marine gastropods: *Strombus gigas, S. costatus, Pleuroploca gigantea, Turbinella (Xancus) angulata,* and *Busycon* sp.

Quintana Roo

A declining trend in the landings was also clear in this state after 1975 (Fig. E.1). The lowest production levels were recorded for 1982 (80 t) and 1990 (51 t). The establishment of catch quotas per region, along with a seasonal closure (July 15 to September 30) were attempted as management measures between 1980 and 1986. A 30% increase in the landings with respect to the maximum production levels (1975) was observed. However, a side effect of these regulations was a three-fold increase in fishing effort, so signs of overexploitation reappeared soon after. In 1990, the temporal closure was expanded to a six-month period, spanning from May to October. The co-operatives that had access to the resource followed these regulations, but poaching then became a major problem, and stocks continued to decline. In 1991, an indefinite closure of the fishery was enacted in the state of Quintana Roo, which will prevail until the resource shows signs of recovery.

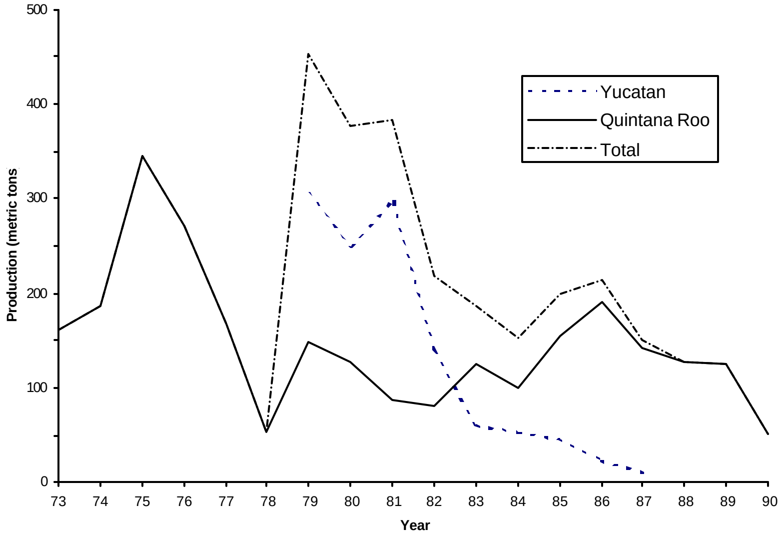


Figure E.1. Annual conch production in the States of Yucatan and Quintana Roo (SEPESCA, 1974-1990).

Status of the Resource

It is evident that the uncontrolled expansion of the fishery and the use of compressors and scuba gear promoted the rapid decline of conch stocks in the states of Yucatan and Quintana Roo. Despite the implementation of management regulations, the regenerative capability of the stocks has been undermined by the continued removal of juveniles and by illegal fishing activities. There is a limited amount of information regarding the status of the resource after 1994. Nonetheless, until that year the queen conch stocks in the Yucatan Peninsula still presented severe signs of overfishing and no clear signs of recovery.

Population and Stock Assessment Studies

Five main institutions have been involved in conch research in Mexico since the 1980s: CINVESTAV, IPN, (Merida); Instituto de Ciencias del Mar y Limnología, UNAM (Puerto Morelos); CRIP (Campeche) and CRIP (Puerto Morelos), INP, SEPESCA; and CIQRO (Chetumal), Q. Roo Government. These institutions have conducted studies on basic biology, population and community ecology, behavior, demography, aquaculture, population dynamics, and fisheries of the species in the Yucatan Peninsula. With this knowledge base, some population surveys and stock assessments have been conducted to determine the status of the resource in the main areas of exploitation. The following studies stand out:

Quijano (1986) applied Schaefer's model to estimate MSY and optimum effort for each of the three fishing zones in Quintana Roo. He used historical data from 1972-1986 and obtained MSYs of 20.5, 14.5, and 127 t year^{-1} for the North, Central, and South Fishing Zones, respectively. Optimum effort estimates (in number of fishermen) were 255, 75 and 146, respectively. The author also indicates that CPUE decreased by 90% during the 1975-1986 period.

Chávez (1990) conducted an age-structured assessment of the resource in Chinchorro Bank by transforming catch data (expressed in weight) into numbers based on length-frequency samples. Once he reconstructed the likely age-structure of the population for a thirteen year period, he conducted a stepwise simulation and was able to estimate population sizes and exploitation rates for each year of catch data available. He reported abundances of 0.95-1.05 ind m^{-2} and estimated a natural mortality value, M=0.185, a fishing mortality, F=1.42, and an exploited adult stock of 558 000 conchs.

This study was further utilized by Chávez and Arreguín (1994) to construct a model for conch fisheries management in the Mexican Caribbean. They carried out 20-year simulations of an age-structured population of *Strombus gigas* and examined three scenarios and five management strategies. Biomass yields, exploitation rates, employment levels and economic benefit/cost ratios were assessed. The authors concluded that the best approach to management would be a combination of MSY and constant quota strategies, whereby fishing levels could revised each year and a minimum number of fishermen could have access to the resource.

Domínguez Viveros *et al.* (in review) reported population densities for four areas of Chinchorro Bank: 0.25 conch m^{-2} in Cayo Norte and Cayo Centro, 0.04 conch m^{-2} in Isla Che and 0.02 ind/m^{2} in Cayo Lobos. Their analysis also indicates that the population is composed of individuals of ages 1-4, but that ages 1-2 are predominant. Their natural and total mortality estimates are M= 0.585, and Z= 1.509.

All these studies have contributed significantly to estimate the real magnitude of the problem in Quintana Roo. The management strategies some of these authors proposed were, for the first time, based upon quantitative assessments of the conch populations.

E.5 Data Collection

Official statistics regarding conch resources in Mexico are collected by the Ministry of the Environment, Natural Resources and Fisheries (SEMARNAP). Regional offices in each state collect monthly data of landings in weight per fishing area. Information on the type, size and number of vessels involved in conch fisheries is also available at local (county and state) levels.

Biological information on queen conch is collected by the institutions conducting research on the species (see above section). Official biological and fisheries studies have been carried out basically by the two Regional Centers for Fisheries Research (CRIP Puerto Morelos, and

CRIP Campeche) in the area, which are subunits of the National Fisheries Institute (INP, SEMARNAP); and by the Quintana Roo Research Center (CIQRO).

E.6 Conclusions and Recommendations

The indefinite closure of conch fisheries in Yucatan and Quintana Roo was a necessary measure to prevent the total collapse of those stocks. However, after such a long history of overexploitation, and given that illegal fishing still occurs, it is unlikely that conch stocks can recuperate in such a short time. It is important that the institutions involved in conch research conduct an interdisciplinary and inter-institutional program to monitor the populations periodically. Biological and ecological studies, along with assessments of the status of the stocks would be necessary in order to re-evaluate and re-design management options as the conch populations evolve.

It is well known that the problems Mexico has experienced with conch fisheries are very similar to other countries' in the Caribbean region. Hence, it is strongly recommended that Mexican authorities and scientists participate in international workshops and conferences, whose main objective is an international co-operation to better understand, assess, and manage this important fishery resource.