Preliminary Calculations of Sustainable Yield for Queen Conch (*Strombus Gigas*) in Puerto Rico and the U.S. Virgin Islands

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The queen conch resource of Puerto Rico and the U.S. Virgin Islands has been reported as overfished and in decline. As an aid to management, and to illustrate the problems of interpreting limited data, estimates of Maximum Sustainable Yield (MSY) were made for the Puerto Rican and U.S. Virgin Island conch resource. Calculations were based on a Gulland-Fox stock-production model of the Puerto Rico west coast fishery using data from the 1970's, from yield-per-recruit analyses applied to the U.S. Virgin Islands, and from examination of landing trends. The stock production model gave a yield estimate of 0.571 kg (1.26 lb)/ha. Analysis of yield per recruit gave higher estimates, but based on assumptions used these may likely be overestimations; in any case their reliability is certainly more in question. Using a conservative approach, overall estimates of MSY were 227 mt (500,000 lb) for Puerto Rico, 19 mt (42,000 lb.) for St. Croix, and 91 mt (200,000 lb) for St. Thomas - St. Johns. Variability of the estimates obtained in these analyses is as great as for those reported elsewhere. Thus, they should not be used blindly, but as guidelines for management decisions.

INTRODUCTION

Specific indications are as follows:

1. recent large decreases in catch, noting particularly that these shortly followed a period of landings well above historical levels.
2. the low density of conchs observed in surveys relative to other areas, and this has led to
3. a change in attitude among fishermen that the resource is noticeably declining, and
4. high levels of fishing mortality (F) measured in comparison to natural mortality (M), indicating that the harvested yield is exceeding productivity. The above indications should be considered against the background of known collapses of conch fisheries in other areas (e.g. Florida, Cuba, Bermuda) due to overfishing, and the generally large reduction in conch populations throughout the Caribbean.

Although overfishing is clearly indicated, and the need for management apparent from lessons learned elsewhere, no quantitative evaluation of the entire Puerto Rican-USVI resource has been made. Thus, the degree of overfishing has not been determined, nor has there been a determination of where the resource should be, i.e. determination of maximum sustainable yield (MSY) and associated parameters. The purpose of this report is to review available data, provide a quantitative framework for stock assessment, and attempt to estimate MSY and associated parameters for the conch fishery of the Puerto Rican-USVI shelf.

APPROACH

The approach to be used here is as follows. An analysis is made of catch and effort data for Puerto Rico's west coast using a stock-production model. Results are compared to historical landings to evaluate consistency. They are also compared to results from other studies. The Virgin Islands data of Wood and Olsen (1983) are re-analyzed, and using their approach, survey and mortality results are used to estimate recruitment and, by multiplying it by yield-per-recruit (YPR), estimate MSY. Results for Puerto Rico and USVI are then compared to each other and to estimates from other areas. Attempts are made to reconcile any differences and estimate potential yield on a per area basis. This is then expanded for the shelf areas of Puerto Rico and the USVI to obtain estimates of overall MSY. Estimates of shelf area were taken from Wood and Olsen (1983) for the USVI and from Weiler and Saurez-Caabro (1980) for Puerto Rico. Area estimates used for Puerto Rico's north and east coasts were reduced by one half and one third, respectively, because much of the shelf is greater than 45 m, and therefore inaccessible to divers. Throughout, it should be noted that all calculations have an unknown and presumably high degree of variance associated with them. Also, a number of extrapolations are made. It is not intended that calculations, then, be taken at face value. In attempting to reconcile differences between studies, sources of possible error are considered. The strength of the results relies not on one or two analyses, but on the potential agreement between many fully or partially independent analyses.

ANALYSIS OF THE PUERTO RICAN WEST COAST CONCH FISHERY

Estimation of Maximum Sustainable Yield

An analysis was made of Puerto Rico's west coast conch landings data. This subset of data was chosen because it represents the vast majority of Puerto Rico's conch landings, the data are thought to be the most reliable, they are most comparable to studies done at La Parguera (an area primarily fished by west coast fishermen), and by using a subset of data some variability could be eliminated. Data are taken from Appeldoorn (1991) and are given in Table 1. A detailed review of these data were presented by Appeldoorn (1991), and this should be consulted in conjunction with the analysis presented below. In particular, it should be noted that effort is measured as number of full-time west coast fishermen, which assumes that the ratio of conch fishermen to others has remained fairly constant. This is probably not the case (Valdez-Pizzini, 1987), particularly during the late 1970's and 1980's when landings rose substantially. Greater effort was probably spurred by the greater demand for conch, yielding a higher price, and the presence of the dominant 1980 year class, which could temporarily support increased effort. The effort data also do not account for possible increases in effort due to fishing longer hours, more days, further afield, or in deeper waters.

The Gulland-Fox stock-production model was applied to the whole data and to data just for the 1970's. The reason for the latter was to remove those years in which effort data were thought to be most suspect. The Gulland-Fox model assumes an exponential relationship between catch-

TABLE 1. Catch, effort (number of full-time west coast fishermen) and catch/effort (U) used in analyses of the queen conch fishery of the west coast of Puerto Rico.

Year	Catch (lbs)	Effort	U
1971	130,000	165	788
1972	140,000	171	819
1973	130,000	275	473
1974	136,000	338	402
1977	153,000	398	384
1978	138,000	452	305
1980	298,845	258	1158
1982	402,360	316	127
1983	466,123	185	2519
1986	170,725	172	993

TABLE 2. Results of production model analyses of Puerto Rico's west coast conch fishery. MSY = maximum sustainable yield, Es = effort to achieve MSY, Us = catch/effort at MSY, Umax = catch/effort at maximum biomass, Y = yield.

	All Data	1970's Data
MSY (lbs)	190,102	151,900
Es	200	312
Us	950	486
Umax	2,584	1,322
Y/ha (lbs)	1.529	1.264

per-unit effort (U) and effort, and results in an asymmetric parabolic relationship between yield and effort with maximum yield being shifted to the left. This model is felt to be more appropriate when effort in previous years is thought to affect current yield and when yield is expressed in biomass (Ricker, 1975). The model was fit using predictive regression of Ln(U) on effort. Results of the analyses are given in Table 2 and shown in Figure 1.

The west coast landings data can be divided into two phases; one in which landings were fairly constant at about 65,772 kg, and another, starting in 1979, where landings increased dramatically to over 204,120 kg before collapsing in following years. The implication here, at least, is that during the period prior to 1979 the fishery was able to maintain its rate of harvest, although vagaries in the effort data prevent one from knowing if this was indeed the case. Nevertheless, it is assumed here that the results of any analysis, to be accepted, must be consistent with a sustained fishery during the 1970's. The analysis using all the data show an MSY (86,230.3) substantially below peak landings, but it is also substantially above landings for the 1970's. More critical to its acceptance are predictions for effort at MSY (Es) and catch-per-unit-effort at MSY (Us). At MSY, Us is predicted to be twice the values observed during the 1970's, with effort being only half that employed during that time.

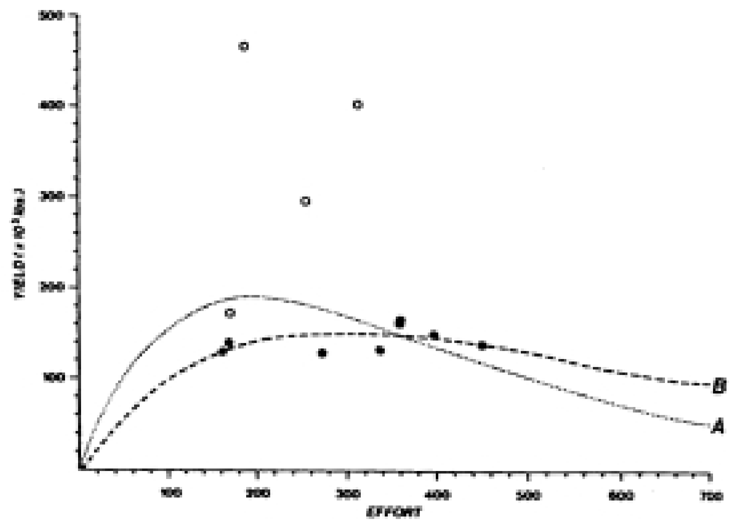

FIGURE 1. Prediction of yield versus effort for the Puerto Rican west coast conch fishery from two Gulland-Fox stock production models. Data points represent observed values. Closed points are from the 1970's. A: all data, B: 1970's data.

The analysis restricted to the 1970's data has a substantially better statistical fit, as would be expected. MSY (68,901.8) is slightly above average values for the 1970's, which is consistent with the data, especially the decline in U in 1977 and 1978. Predictions of Es and Us are also very consistent with these data.

Although the second analysis is consistent with the data, a caveat needs to be raised. Again this is because true effort is not known. Model predictions only apply to the state of the fishery during the 1970's. If the fishery at this time was limited to shallower depths or areas closer to port, implying that much of the increased landings in the 1980's came from exploiting previously unfished areas, then model predictions would apply only to the areas being fished at that time, and MSY values for the entire shelf would be higher. Unfortunately there is no way to determine if this indeed happened and to what degree. Caution would advise that, at least, true MSY levels would not be higher than those predicted and most probably would be less than that.

Estimation of Biomass and Catchability (q)

A population survey of the La Parguera shelf in 1985-1986 found an average density of 8.11 individuals/ha, with 32.33% adults and 67.67% juveniles (Torres, 1987). From sampling in August-September 1985 it was found that average adult meat-weight was 252.88 g; average juvenile weight was 78.38 g (Appledoorn and Ballantine, 1985). This gives a biomass estimate (meat weight) of 1.090 kg/ha. If exploitable biomass is somewhat arbitrarily defined as only individuals > 19 cm in shell length then the estimate is .9271 kg/ha. The catch by area for the west coast in 1985 was 1.070 kg/ha. This results in estimates of instantaneous mortality (F) of 0.98 based on total biomass and 1.154 based on exploitable biomass. These are similar to that previously estimated by Appeldoorn (1987) from tagging data (F = 1.14). No effort level is available for 1985, but the data show little change between 1983 and 1986. To calculate catchability (q) a value of E of 180 is used. This yields estimates of q of 0.00545 and 0.00641, respectively, using the two estimates of F.

As a check, the above q values can be used to calculate population biomass for an unexploited population (Bmax) and one at a level yielding MSY (Bs). Using, for example, q for the total population predicted Bmax and Bs values are about 108,864 kg and 40,370 kg. respectively. Respective Bs values are 72, 576 kg and 39,917 kg. However, expanding the population estimate for the La Parguera shelf yields a biomass estimate in 1986 of 635,040 kg. i.e. several times that for a virgin population. This is clearly impossible. The obvious conclusion is that the estimate of effort (180) is way below true effort. Thus, the estimate of q calculated is way too large, but the degree cannot be ascertained. As such, biomass estimates for MSY and virgin stock cannot be reliably calculated for the whole shelf. This further supports the assumption that the measure of effort has changed and therefore validates the dropping of the 1980's data from the stock-production analysis.

ANALYSIS OF U.S. VIRGIN ISLANDS CONCH POPULATIONS

Estimation of Maximum Sustainable Yield (A re-analysis using Wood and Olsen's (1983) approach and data)

Wood and Olsen's 1981 survey calculated abundances of adult conch on St. Croix and St. Thomas-St. John of 260,680 and 1,580,372 individuals, respectively. A recalculation of their lip-thickness frequency distribution (Appeldoorn, 1988a) showed 3 year classes (ages 4.25, 5.25, 6.25 yr) representing 75.42%, 19.74% and 4.84% of the population, respectively. These percentages were multiplied by abundance to get the respective numbers of individuals per year class. The re-analysis also gave a total mortality estimate (Z) of 1.34 between ages 4.25 and 5.25 yr. This level was used to back calculate numbers of individuals at recruitment (3.1 years of age, as used by Wood and Olsen). [Note: in their analysis, Wood and Olsen pooled all adults into one year class (effectively tripling its size) before back calculation, and used only natural mortality (a value also found to be way too low), not total mortality to back calculate.] Recruitment was roughly 900,000 for St. Croix (= 26 individuals/ha) and 5,500,000 for St. Thomas-St. John (= 33.8 individuals/ha).

Wood and Olsen's YPR analysis predicted that 80 g/recruit could be achieved. This would result in MSY values of 71,850.2 (2.09 kg/ha) for St. Croix and 439,085 kg (2.69 kg/ha) for St. Thomas-St. John. However, their value of M used (from analysis of juvenile length-frequencies) was much too low. A recalculation (Appeldoorn, 1988b) yielded M = 0.85. This level was used in a YPR analysis presented by Appeldoorn (1991). Using this as a close approximation to the situation in the Virgin Islands one would expect values of 30 g/recruit for reasonable values of F and age-at-recruitment. This would result in MSY values of roughly 27,216 kg (.785 kg/ha) for St. Croix and 164,656 kg (1.01 kg/ha) for St. Thomas-St. John.

However, Appeldoorn (1988b) has shown that natural mortality is not constant, but steadily decreases over time. A further YPR analysis incorporating variable mortality (Appeldoorn, 1991) showed that yields could be substantially reduced, down to 1/3 to 1/6 of previous estimates. If this is so, then predicted MSY values would have to be correspondingly reduced.

Estimation of Biomass and Catchability (q)

In 1981 commercial landings for St. Croix were estimated at 20,412 kg, and effort was 500 trips. In a survey of St. Croix populations, Tobias (1986) reported an average meat weight of 320 g/adult. Given the estimate of 260,680 adults, this yields an adult biomass of 83,243.8 kg. This results in F = 0.245 and a value of q = 0.000490 for the commercial fishery. In St. Thomas mortality rates from size-frequency analysis yielded an F value of 0.49 from F = Z-M (see values above). Note that the area sampled was supposed to be lightly fished as it was accessible only by scuba diving.

Yield-per-recruit analysis does not allow the biomass estimates Bs and Bmax to be made.

COMPARISON OF YIELDS AND ADJUSTMENTS TO MSY ESTIMATES

Estimation of yield for the Puerto Rican west coast was .571 kg/ha from models using 1970's data. Data for the other coasts indicate that during the period 1978-1984 constant yields were harvested from the south and east coasts, averaging about 40.824 kg each. Corresponding areal yields are, respectively, 0.33 kg/ha and 0.23 kg/ha. Both figures are lower than that for the west coast indicating either significant under reporting, lower productivity, or that yields during this time were not near MSY. For the east coast, catch increased in 1985 to 90,720 kg. Fishermen indicate that this level or more is currently being harvested, and that under reporting is widespread. This corresponds to a current yield of at least 0.503 kg/ha.

Estimates of MSY for the Virgin Islands are more difficult to give, as they vary greatly depending upon the assumptions of the YPR analysis. Estimates of .785 kg/ha for St. Croix give a total of 27,216 kg. This level was harvested in 1979; landings have decreased steadily and in 1985 were 15,422 kg. Either effort is way above that for MSY, the MSY figure is too high, or both. Without historical records of landings and effort it is impossible to tell which is the case. Given this, it is safer to assume the latter, i.e. MSY is too high. This is also consistent with YPR analyses.

St. Croix and St. Thomas-St. John have a similar distribution of bottom habitats (Wood and Olsen, 1983). Differences in predicted yield between the two arise directly from the lower density of conchs on St. Croix. This could be a true effect, or could be explained by differences in mortality between areas or simply by inherent variation in the density estimates. For purposes here the two areas will be considered equal in potential yield. Since good estimates are not available but should be lower than calculated, the estimates obtained for Puerto Rico's west coast (0.553 kg/ha) are assumed to equally apply to the Virgin Islands.

Smith and van Nierop (ms) reported on a survey of Great and Little Bahama Banks and calculated potential yields using Cadima's formula (see Garcia *et al*., 1987). Their estimates of MSY, based on M = 0.8, were .5388 kg/ha and 1.517 kg/ha respectively. Exploitation was only slight; under these conditions Cadima's formula is roughly equivalent to that of Gulland (1971) although a positive bias should exist. However, Caddy and Csirke (1983) and Beddington and Cooke (1983) have reviewed Gulland's formula and found it ineffective in many situations. In particular, for tropical species it was more likely to substantially overestimate MSY. The degree of bias is unknown, but for the sake of argument it is estimated that true MSY is one third less. This yields estimates of .3593 kg/ha and 1.011 kg/ha.

Olsen (in Berg and Olsen, in press) ran a surplus production model on catch and effort for Caicos Bank. Resulting MSY was 1.16 kg/ha, close to the estimate for Little Bahama Bank.

These variations in estimates of MSY between areas are substantial, and, thus, no specific generalizations can be made.

Variations in yield/ha among areas (if significantly different) could arise from one of two main factors: differences in levels of recruitment and differences in the percentage of productive habitats (e.g. algal plains, grass beds). Nothing is known of recruitment for any population. Higher yields in the Bahamas and in Turks and Caicos would be expected based on their much greater percentage of favorable habitat (Smith and van Nierop, MS) compared to the Virgin Islands (Wood and Olsen, 1983) or La Parguera (Torres, 1987; Appeldoorn, 1991).

Total MSY values can be calculated by multiplying the above figures by shelf areas. Using a value of 0.553 kg/ha for Puerto Rico yields an MSY 263,088 kg. This assumes all areas will be harvested equally, which no doubt will not be the case. For example, the prediction for Puerto Rico's north coast, 18144 kg, has never been approached, probably due to a reduced resource (due to unfavorable environment), poor weather and poor access for fishing. Similarly, the prediction for the south coast, 68,040 kg, is substantially greater than the average historical catch. In fact, estimated landings dropped markedly following catches in 1984-85 that approached this level. True areal productivity for the south coast may be less than elsewhere due to its narrow shelf. Taking a conservative approach, the predicted yields for the north and south coasts are reduced by one half and one third respectively. This would give a realistically achievable MSY of 226,800 kg for Puerto Rico.

For the USVI a value of 0.571 kg/ha yields 19,504 kg for St. Croix and 92,988 kg for St. Thomas-St. John.

DISCUSSION

The usefulness of these calculations is limited by their imprecision. Variability in these, as well as other estimates of productivity are high. This is particularly the case for any calculations based on yield per recruit. As a consequence, these estimates cannot be applied too rigorously to management, although they may serve as general guidelines. However, it is important to keep in mind their explicit and implicit assumptions and limitations. For example, to achieve the predicted MSY it is assumed that fishing effort will be distributed fairly uniformly over the insular shelf. Intense fishing in localised areas to achieve MSY will most likely result in overfishing, and possible population collapse in those areas. Another problem is that the amount of fishing needed to achieve MSY, either in terms of fishing effort or fishing mortality, is unknown. Calculations made from the analysis of Puerto Rico's west coast fishery during the 1970's are no longer valid for the present fishery, nor can they be applied elsewhere. Yet, eventually, it will be only through the regulation of fishing effort that long-term management will succeed. MSY calculations based on analysis of yield per recruit imply that recruitment will be unaffected by reductions in spawning stock. It is, at least, possible that this will be the case (Appeldoorn, 1989). As yet, too little is known about the dynamics of conch populations, especially aspects of larval recruitment, early juvenile mortality and their respective spatial and temporal variabilities. Another factor to be considered is the possibility that the system has been substantially altered, either by habitat modification or overfishing, and that predicted levels of MSY based on past data may not be achievable in the present. Many shallow seagrass beds, once productive nursery areas for juveniles, are no longer productive. Is this because recruitment is limited with spawning stock reduced, because no conchs remain in these beds to attract new recruits, or because the beds themselves have been altered, principally by increased siltation? Given these uncertainties, any decisions based on the above calculations should be made with caution. Resulting landings and population levels should be monitored to assess the success and validity of such management measures.

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