History and Recent Status of the Puerto Rican Conch Fishery

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ABSTRACT

The queen conch, *Strombus gigas* has been fished in Puerto Rico since pre-Columbian times for both its meat and shell. However, a significant fishery did not develop until recently. Currently, most fishing is by scuba diving, and is conducted at depths down to 50 m or more. The vast majority of conch are landed on the west coast. Total estimated landings peaked in 1983 at roughly 325 mt, but have since declined steadily, with less than half that landed in 1986. At a present price of $3.45 (US)/kg, conch is still one of Puerto Rico's most important commercial species. However, the fishery cannot meet demand, and much conch meat is imported.

Research on conch has been conducted around Puerto Rico, with particular emphasis on the population offshore of La Parguera in the southwest part of the island. Peak landings from the west coast follow closely the recruitment of the dominant 1980 year class to the fishery. Low densities, markedly reduced landings, and high fishing mortality (F-1.14) relative to natural mortality (M-1.05) clearly indicate overfishing. Of particular concern is an observed relationship between adult stock-size and reproductive output. Yield-per-recruit analyses indicate a maximum-harvest age prior to maturity, and juveniles constitute a large portion of the catch. Thus, recruitment overfishing must be considered.

The queen conch, *Strombus gigas*, is one of the most important commercial species in the shelf fishery of Puerto Rico. As in other Caribbean countries, fishing pressure has increased steadily, and concerns about the continued health of the resource have been raised. In response to these concerns, the University of Puerto Rico initiated a series of investigations on the biology, ecology, fishery, and mariculture potential of the queen conch. The purpose of this review is to document the development of the fishery and its present characteristics, and to report and summarize ongoing analyses on the current status of the population and the fishery it supports. Lastly, a few comments are made on suggested management strategies as they apply to Puerto Rico.

TRENDS IN THE FISHERY

Throughout the Caribbean and adjacent islands, the queen conch represented an important resource to pre-Columbian inhabitants. The use of its meat for food, and its shell for fashioning religious artifacts and tools (*e.g.* scrapers, fish hooks) has been well documented (Olsen, 1974). In Puerto Rico, however, the use of conch, particularly of its shell, seems to have been to a lesser degree. This difference is attributed to the ready availability of other materials, which is a consequence of Puerto Rico's much greater size in comparison to the Lesser Antillian Islands (Olsen, 1974).

This situation does not seem to have changed during the period of Spanish colonization; however, records kept by the local government were lost upon the change in government in 1898, so information for this period is scant. Wilcox (1900, 1903) made surveys of the fishery and fish trade for the United States government. His reports do not include any mention of conch, but local oyster populations were commented upon where abundant. This lack of attention again indicates that conch were not a significant fishery resource.

The first mention of the conch fishery comes from Jarvis (1932). At this time conch were used for human consumption, the majority was used for bait. Harvesting was done by "naked divers in shallow waters" (Jarvis, 1932).

Estimates of total fishery catch do not vary much over the first half of the 1900's (Wilcox, 1903; Jarvis, 1932; Inigo, 1963). It can probably be safely assumed that the harvesting of conch paralleled the entire fishery during this period. During the 1950's and 1960's considerable effort was spent developing local fisheries (Inigo, 1963). No specific information on the conch fishery was recorded, but in consort with the rest of the fishery it can be assumed that catch and effort increased during this time.

A program to collect detailed statistics on catch, effort and other characteristics of the Puerto Rican fishery was started in 1967 (Suarez-Caabro, 1979). Major emphasis has been specifically to document total landings. This program has provided statistics on a continuing basis since that time. However, the program has been plagued by periodic lapses and a significant amount of under and/or misreporting. As a consequence the data are, at best, approximations and should be accepted with suitable caution. Nevertheless, the long time-series accumulated still represents one of the best records of conch harvest in the Caribbean, and useful analyses can be made.

Figures 1 and 2 show the estimated total landings and landings by coast, respectively, since 1970. Simple inspection of these data can reveal some interesting trends. In the first half of the 1970's the fishery was fairly stable, yielding roughly 70-75 mt/yr. Starting in 1975 landings began to increase, first on the east and south coasts, then on the west coast. This increase follows closely the increase in value of conch meat. The lag in production on the west coast may be explained by the generally lower price obtained for the meat further away from the metropolitan areas of the northeast. The latter 1970's through 1981 were marked by a dramatic increase in landings, primarily from the west coast. From interviews with fishermen it was apparent that increases in production were obtained through increasing the number of fishermen, increasing the use of scuba diving for harvesting, which had been used by some fishermen since the early 1960's, and searching further afield, in deeper waters, to fish previously unexploited areas. However, like the early 1970's, this

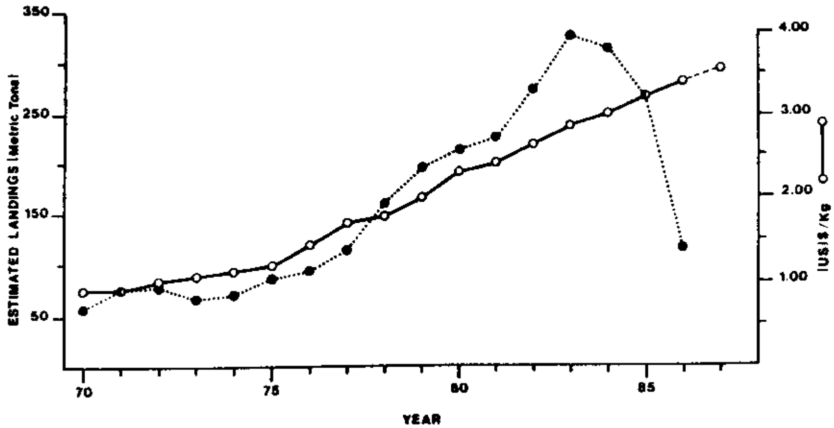

Figure 1. Estimated total commercial landings and average price/kg of queen conch in Puerto Rico. Dashed line represents anticipated price. Sources: Juhl & Suárez-Caabro (1971, 1972), Suárez-Caabro (1973), Suárez-Caabro & Rolón (1974), Rolón (1975), Weiler & Suárez-Caabro (1980), Collazo & Calderon (1987), Garcia-Moliner *et al.* (1987), Garcia-Moliner & Kimmel (Pers. Comm.).

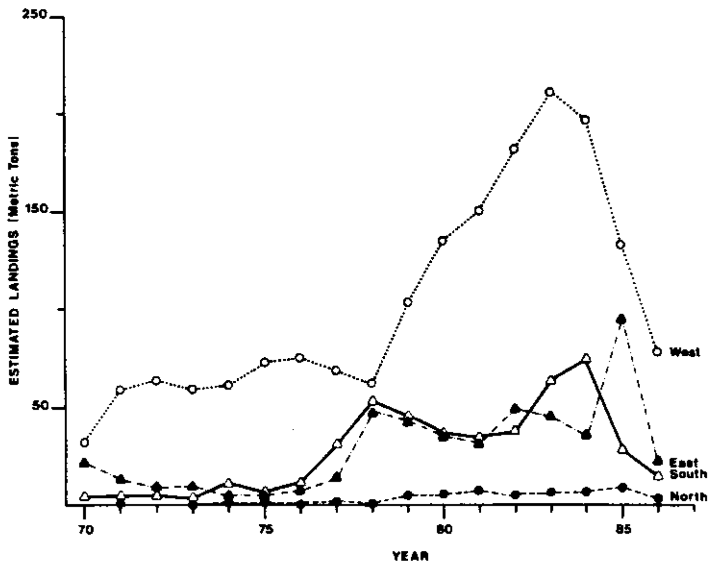

Figure 2. Estimated commercial landings of queen conch in Puerto Rico by coast. Sources: same as Figure 1.

increase was in parallel with increases in the price per kilogram. This would imply that the driving force behind the increased production was economics, *i.e.*, the better price received by fishermen for conch meat.

The period 1982-1985 shows that landings increased at a substantially greater rate than did price, and then began to decline. The reasons for this relative acceleration in catch are unknown and probably multifaceted. However, this period was marked by the presence of a dominant year class, spawned in 1980, in the population off La Parguera (Appeldoorn, 1987a; see also below). If the dominance of this year class was a general phenomenon, as seems probably (Appledoorn, 1987a; Section 2), then the higher landings could reflect a temporary increase in abundance, upon the recruitment of this year class into the fishery in 1982, resulting in greater catch per effort.

From interviews conducted in late 1984, it was apparent that fishermen at this time were not concerned about decreasing densities, absence of large individuals, or overfishing in general, although some admitted that they needed to range over a greater area than previously.

The above observations are reflected in a plot of catch-per-effort versus effort (Figure 3), where effort is measured by number of full-time fishermen for

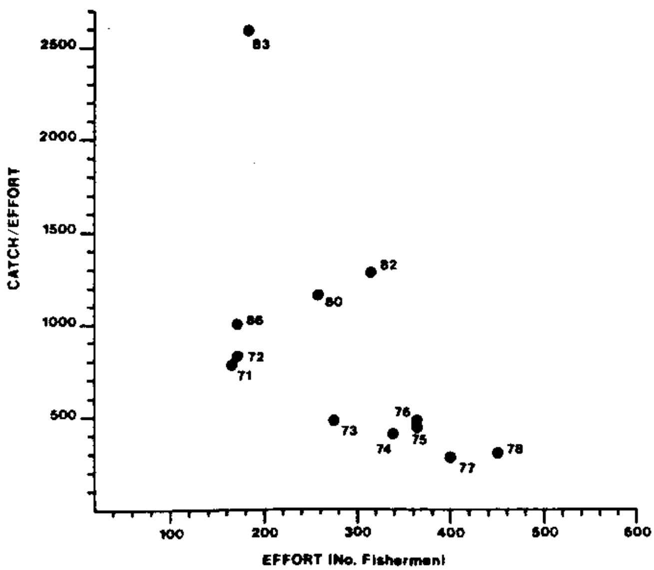

Figure 3. Catch per effort (kg/person) versus effort for the queen conch fishery on the west coast of Puerto Rico. Effort is total number of fulltime fishermen (regardless of species fished) on the west coast. Sources: same as Figure 1.

all commercial species (the assumption is that the ratio of conch fishermen to all fishermen has not significantly changed). The spread of points indicates a general linear trend, with two years showing a large and significant departure: 1982 and 1983. The latter occurred at the time of full recruitment and growth in size of the 1980 year class just prior to maturity. By 1986, the next year of available effort data, the year class had been completely fished out (unpublished data), and catch-per-effort is comparable to other years.

The rapid decline in landings in the last few years parallels the decline in the 1980 year class, and indicates the relatively lower levels of subsequent recruitment (Appledoorn, 1987a: Section 4: See also below). In more recent interviews, conducted in 1986, fishermen admitted that conch were now more scarce than before, and the lower densities encountered have necessitated a change in fishing methods (see below).

That price per kilogram has not increased dramatically with the current reduction in landings probably reflects the increased importation of conch meat to meet demand. The amount of conch imported is now significant, but exact figures are not available, as conch meat statistics are lumped with all other shellfish, including lobsters (U.S. Dept. Commerce, personal communication).

CHARACTERISTICS OF THE FISHERY

Major areas for conch fishing in Puerto Rico are on the southwest coast, the south coast, and the east coast, including the island of Vieques. Conch from the southwest corner of the island, including the western offshore-banks are fished primarily by fishermen from El Combate, the southern-most fishing village on the west coast. Landings of conch are low on the north coast due to its narrow shelf and generally rougher seas, which limit the number of days available for fishing. Depths fished range from 7 m to over 50 m; most fishing is done at depths requiring the use of scuba equipment.

The fishery is pursued by both full-time and part-time fishermen. The latter vary seasonally, dropping particularly during sugar-cane harvesting. Fishermen use mostly small boats equipped with outboard engines, in which they make daily excursions. Usually they work in teams, with one person remaining in the boat and one or more divers in the water at any one time. On average one to two scuba tanks per person are used per trip, although some use as many as three. When fishing, an area is generally searched by either towing free divers or by free divers making shallow test dives to locate conch aggregations. When density is high, divers will load conchs into a basket, which is then raised to the boat, emptied, and lowered back down. Conch are thus shucked in the boat while fishing is in progress and/or while returning to port. With densities decreasing in recent years, many fishermen have started to remove the meat from the shell while on the bottom, using variously a rock hammer, hammer and chisel, or hatchet to cut a hole in the shell. This allows the diver to cover a greater area per dive in search of scattered individuals. When densities are high, fishermen will selectively harvest larger individuals, gradually taking smaller ones as harvesting in an area continues. Interviews and personal observation indicate the smallest individuals taken are about 15 cm in length; this size corresponds to an approximate age of 1.75 yr for the population off La Parguera (see below).

Given current fishing practices, diving safety is a particular problem. Most of the diving accidents recorded in Puerto Rico can be attributed to the conch fishery. Often fishermen recovering from the bends will continue to do surface work (boat operation, conch shucking). Repeated diving accidents often result in retirement from the fishery.

RESEARCH RESULTS AND CURRENT STATUS

Detailed studies on the distribution, population biology and fisheries of queen conch in the La Parguera area (southwest Puerto Rico) have been in progress since the early 1980's. Most of the work has been concentrated in an offshore area located in 17 m of water. While it is known that conch populations around Puerto Rico differ in age structure, average adult size, and other characteristics (Appeldoorn, 1986), the La Parguera area and the specific site studied can be considered as representative of commercially important areas with respect to habitat and fishing activities.

A two-year mark-recapture study was conducted from August 1983 to August 1985. This study provided information on recruitment, age structure, growth, and mortality. Mortality rates were estimated using the Jolly-Seber method (Seber, 1982). Since fishing did not occur between all sampling periods it was possible to obtain estimates for both fishing (F) and natural (M) mortality. Resulting values were $F = 1.14$ and $M = 1.05$ (Appeldoorn, 1987b). To obtain the latter value, an assumption had to be made on the rate of emigration from the study area. Thus, it should be accepted with some caution. These estimates are for the entire population, which consisted of both juveniles and adults. A separate estimate of total mortality for adult conch was obtained by analysis of lip-thickness-frequency distributions using the method of van Sickle (1977). A value of $M = 0.52$ was obtained by subtracting from total mortality the value of F obtained above (Appeldoorn, in prep.). The difference between the two values of M is due to the higher rate of mortality on juveniles included in the higher estimate (Appeldoorn, 1988).

The high value of F relative to those of M indicates that the La Parguera conch population is intensely exploited. Presumably, especially in lieu of trends in landings, this condition holds true for other areas as well. Gulland's (1971) calculation that F approximates M at the point of maximum sustainable yield (MSY) would indicate that conch were being fished at or above FMSY at the time of the study. However, Francis (1974) demonstrated that this relationship does not always hold, and Caddy and Csirke (1983) stated tropical species, which are characterized by high levels of M, would more likely be overfished according to this formula. Thus, overfishing seems to be clearly implicated on the basis of these data.

Length-frequency distribution were tabulated for each sampling event during the mark-recapture study. These are shown in Figure 4. Clearly indicated

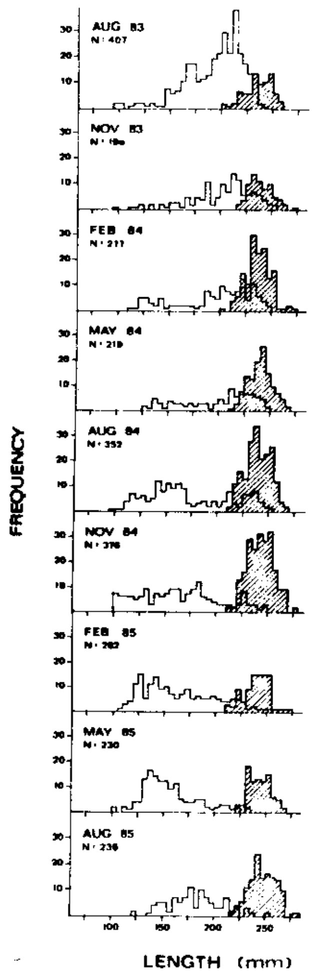

Figure 4. Length-frequency distributions of juvenile (open) and adult (shaded) queen conch taken offshore of La Parquera, Puerto Rico. N = sample size.

in the first sample is the large 1980 year class (centered around 21 cm). As can be seen in subsequent distributions, this year class is gradually recruited into the adult population. Note that year classes of comparable strength are not evident, either before or after. Lip-thickness frequency distributions yield similar conclusions (Appeldoorn, in prep.). That year-class strength is variable has a significant impact on the fishery and on the population, particularly with respect to reproduction (Hennemuth, 1979). A single large year class can support a fishery for a number of years and give a false impression of well-being. Thus the initially high density observed upon recruitment tends to promote overfishing. The true density observed upon recruitment tends to promote overfishing, and the true status of the population may not be seen. Even in the absence of a distinct stock-recruitment relationship, indications are that the probability of good recruitment is higher if stock size is also high (Gulland, 1983). Thus, if a dominant year class is fished heavily such that its reproductive life is shortened, the probability of its replacing itself is also reduced, and poor recruitment may follow for a number of years.

A population survey of both queen and milk conch, *S. costatus*, was conducted in the La Parguera area from May 1985 to April 1986. Data were collected by divers, who ran 10-k wide strip transects at randomly chosen stations. Details of the methodology and density estimates were reported by Torres (1987). Abundance and density estimates are summarized in Table 1.

Table 1. Observed densities of queen conch, *Strombus gigas*, and milk conch, *S. costatus*, on the insular shelf off La Parguera, Puerto Rico as determined from transects run at 81 stations between May 1985 and April 1986.* Juv = juveniles, Adl = adults, Tot = total.

Bottom Type	Area Sampled (ha)	Queen Conch Abundance Juv	Adl	Tot	Queen Conch Density (No./ha)	Milk Conch Abundance Juv	Adl	Tot	Milk Conch Density (No./ha)
Patch Reef	5.546	1	0	1	0.18	1	0	1	0.18
Hard Bottom	4.282	8	4	12	2.80	2	36	38	8.87
Rubble	2.238	105	32	137	61.49	0	90	90	40.39
Coarse Sand	4.088	50	12	62	15.16	4	128	132	32.29
Sand	10.433	30	14	71	6.80	0	201	201	19.25
Grass Bed	9.826	29	18	47	4.78	3	76	79	8.04
Mud	4.397	1	0	1	0.23	0	6	6	1.36
Total	40.810	224	107	331	8.11	9	538	547	13.40

*Source: Torres (1987)

From the table it can be seen that milk conch are more abundant than queen conch, which is to be expected since the former are not fished to a significant degree. Distributions are marked by the considerable overlap in habitat preference between species, although queen conch seem to be associated more with coarser sediment-types (Torres, 1987). It is possible that differential allocation of fishing pressure among bottom types affects the observed distribution of queen conch.

Densities of queen conch are low, although distributions are patchy and local density within a patch is much higher. Population estimates of queen conch obtained from the Jolly-Seber analysis of tag-recapture data indicated an average of 1200 individuals in the 40 ha study site, yielding an average density of about 30 conch/ha. The bottom in this area is roughly equally divided among rubble, coarse-sand and sand habitats. Based on these observations, the predicted density from the survey data would be 27.8 conch/ha. Thus, agreement between the two methods is good and supports their general validity.

The pooled mean density of 8.11 queen conch/ha in the La Parguera area is similar to values reported for St. Thomas (9.7) and St. Croix (7.6) in 1981 by Wood and Olsen (1983). They used different bottom-type classifications, so more direct comparisons cannot be made except for sand bottoms. Here density off La Parguera was again between values for St. Thomas (9.31) and St. Croix (5.76). However, differences in methodologies would predict that the Virgin Islands study would undersample small conch, so their densities may be higher on a comparable basis. Wood and Olsen (1983) felt the St. Croix population was being overfished.

These densities are substantially lower than those reported from other areas. In the Bahamas (1983-1984) densities on Little and Great Bahama Banks were 28.5 and 20.8 conch/ha, respectively (Smith and van Nierop, MS), or roughly three times that off La Parguera. These areas are generally shallower, where conch are typically more abundant, but they are also open to fishing.

Weil and Laughlin (1984) measured densities in fished and protected areas of Los Roques Archipelago, Ven. Density declined with depth. However, at depths of 12-18 m (comparable to La Parguera), average density ranged from 300 to 600 conch/ha in protected areas. Only reports for shallow depths were available for comparing fished and unfished areas. Here, densities in fished areas were reduced to 1/2 to 1/5 those of unfished areas. However, the lowest average densities recorded in fished areas (100 conch/ha) were still substantially higher than found off La Parguera.

The survey data also show that two-thirds of the queen conch found were juveniles. This proportion can be expected to have increased. At the time of the survey, the population was still dominated by the very large 1980 year class, which by this time had completely matured. These adults are no longer present, and with the lack of any large, recently recruited year classes their numbers in the adult population could not be proportionally replaced.

Thus, the survey data, on the basis of age structure and density, give the same indication as did the analysis of mortality: a high rate of exploitation, and in comparison to other areas, probably overexploitation of queen conch in Puerto Rico.

Mark-recapture data from the La Parguera population was used to construct growth curves for both juveniles and adults. Juvenile growth was based on shell length; adult growth was based on shell lip-thickness. Data were analyzed according to Fabens (1965) to yield estimates of the von Bertalanffy growth parameters:

$$l_t = L_\infty (1 - e)^{-k(t-t_0)}$$

where l_t is length or lip-thickness at age t, L_∞ is asymptotic size, and k is the growth coefficient. The parameter t_0 is a location parameter and is defined as the hypothetical age when l_t = O. This cannot be estimated from the analysis of tagging data, but it is necessary if estimates of length-at-age are to be made. In order to obtain t_0, at least one estimate of length-at-age is necessary. For the La Parguera population 8 estimates of length-at-age were obtained from the analysis of length-frequency distributions (Figure 4) using the method of Akamine (1985), and the growth curve was fitted to these to estimate t_0 for juvenile growth. Resulting growth models are as follows:

Shell length (mm)

-0.250 (t - 0.173)

$$l_t = 460 (1 - e)^{-.250 (t - 0.173)})$$

Shell Lip-thickness (mm)

-0.371 (t)

$$l_t = 54.9 (1 - e^{-0.371 (t)})$$

For adult growth it is not necessary to estimate t because the start of adult growth is relative, occurring at the time of maturation. Thus time is not measured in absolute age, but in adult age. The average length of adults in the La Parguera population is 24 cm. This size is reached at age 3.2 yr. Adding adult age to this allows one to approximate total age of adults.

Appeldoorn (in prep.) has modelled adult growth in weight using the above lip-thickness growth equation and lip-thickness - weight relationships after accounting for differences in size at maturity. Estimates of adult weight-at-age can be added to those for juveniles to yield a single weight-growth curve. The best fitting model is the logistic, where meat weight (g) can be predicted as follows:

$$w_t = W_\infty (1 + A e^{-kt})^{-1}$$

Where $A = (W_\infty - W_o)W_\infty$. For the La Parguera population $W_\infty = 252.9$ g, $W_o = 0.985$, $k = 2.115$.

This equation can be used to assess the fishery by incorporating it into Ricker's (1975) yield-per-recruit (YPR) function. Presented in Figure 5, are the results of two analyses. The analysis shown in the bottom graph is based on an assumption of constant natural mortality, with M = 0.85. This rate, for a population consisting of both juveniles and adults, was chosen somewhat arbitrarily, but it is consistent with estimates made for the La Parguera population (Appledoorn, 1987b; in prep.; see above) and estimates made by others, accounting for decreasing mortality with age and including a re-analysis of Wood and Olsen's (1983) data (Appeldoorn, 1988). The analysis shown in

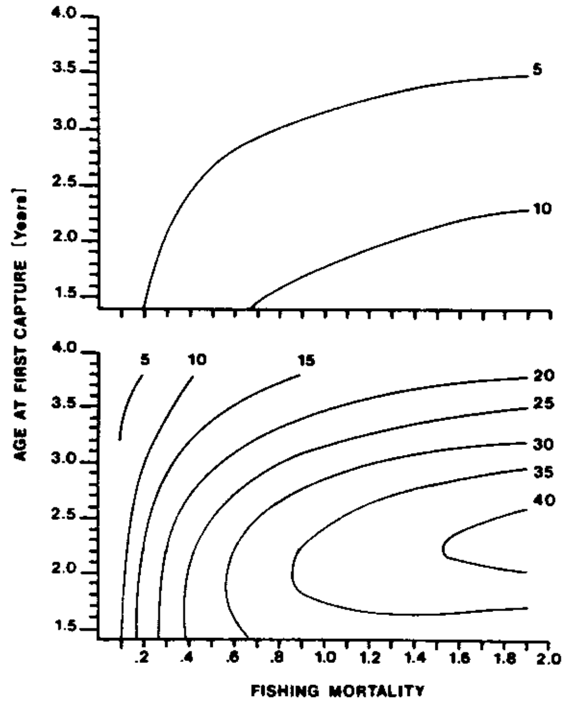

Figure 5. Results of yield-per-recruit analyses under assumptions of constant (M = 0.85) (bottom) and variable ($M = 4.189\, t^{-1.2}$) (top) mortality. Isopleths are in g/recruit. For both figures growth in meat weight (g) is modelled by the logistic equation:

$$W_t = 252.9\ (1 + 255.75\ e^{-2.115\, t^{-1}}).$$

See text for discussion or mortality assumptions.

the top graph explicitly models the decline in natural mortality rate with age, using a modification of the model developed in Appeldoorn (1988):

$$M = 4.189\ t^{-1.2}$$

What is important when comparing the two graphs is not the differences in absolute YPR. These are mostly dependent upon the absolute magnitudes of M, which are still not precisely known. The above equation generally predicts values of M greater than 0.85, so yield will consequently be less. Of more importance here is the effect of the assumptions of constant versus variable mortality on the optimum age at entry into the fishery. Under the assumption of constant mortality YPR increases with age, reaching a maximum at 2.3 yr. With declining mortality YPR consistently decreases from time of recruitment. These analyses thus illustrate the need for determining more precisely the age-dependent mortality structure of queen conch populations.

Both analyses indicate that YPR is optimized significantly before the age of maturation (3.2 yr). This data is disturbing because YPR analyses do not account for reproduction and recruitment. In these two cases, simple application of YPR results would promote recruitment overfishing, *i.e.*, yield would decline when the spawning stock is significantly reduced by intensive fishing of juveniles. This condition raises the question of the nature of the stock and spawning-recruitment relationship in queen conch. During the early 1980's, when work was concentrated on hatchery research (Ballantine and Appeldoorn, 1983), queen conch egg masses could generally be found at the La Parguera study site. In subsequent years this was not the case. In 1983 only one egg mass was found; none were found in 1984. It was not until the 1980 year class had fully recruited to the spawning stock (1985) that egg masses became more abundant. With the passing of this year class egg masses have again become rare.

The few studies made on spawning frequency (Davis and Hesse, 1983; Davis *et al.*, 1984; Weil and Laughlin, 1984) suggest that egg production is related to copulation rate, and copulation rate may be related to density. Thus, because of their slow rate of movement, there could conceivably be a threshold density below which conch cannot re-aggregate rapidly enough in response to intensive fishing to successfully reproduce. While the stock structure and source of recruits for conch in the eastern Caribbean are unknown (Appeldoorn *et al.*, 1987), it is obviously unwise in the face of uncertainty to reduce a population below its replacement level. Optimistic examples where conch populations have rebounded rapidly after closure of the fishery (*e.g.*, Cuba) are countered by examples where they have not (*e.g.*, Florida; Bermuda).

MANAGEMENT CONSIDERATIONS

Trends in landings and detailed research both indicate a decline in the Puerto Rican conch fishery. These problems have been recognized by local authorities, and a review of management options have been implemented in anticipation of developing a management plan. Obviously, any management plan will represent a compromise between the biology of queen conch and the socio-economic characteristics of the fishery, and it must be enforceable. Because limited resources are available for enforcement, it is difficult to achieve, particularly if it requires monitoring the fishery in the field. Most conch fishing is done out of a limited number of villages, so it would be easier to monitor the fishery at the dock.

Two management options have been repeatedly mentioned, and these will be specifically addressed: implementing size limits, and banning the use of scuba gear for harvesting. In Puerto Rico, banning the use of scuba gear for harvesting would all but shut down the fishery in the short term. If stocks increased, production through harvest by free divers could be increased and the fishery maintained at a low level.. This policy would conserve the stock, but probably also result in significant underfishing because many productive areas are at depths of 25 m or more.

Size limits are usually mentioned with respect to shell length. Although conceptually simple, there are many practical constraints to their use. Populations in different areas are of different average length at maturity, when final size is achieved. For example, for areas reported by Appeldoorn (1986), adults in the La Parguera population averaged 24.7 cm in length, those off Caja de Muertos on the south coast averaged 21.9 cm, while adults from other areas averaged somewhere between the two. Thus, overfishing could occur in some areas, and underfishing in others depending upon what size limit was chosen. Also, females, on average, are larger than males, so they would be subject to greater fishing pressure (Appeldoorn, 1987a). Enforcement is also a problem. Most fishermen do not land their catch still in the shell, thus sizes cannot be checked; an increasing number of fishermen are now shucking conch on the bottom, leaving the shells behind. The use of a weight limit, corresponding to a desired length, has also been suggested. This idea suffers from all the above problems and is an even more variable parameter than length.

If concern for the health of the spawning stock is paramount, then it might be desirable to let all individuals reach maturity before harvest. Egan (1985) found no ripe gonads in conch with a shell-lip thickness of 4 mm or less. This thickness could be employed as a "size" limit, allowing fishermen to easily ascertain the status of any individual. The advantage of this approach is that it should be enforceable. Mature individuals can be identified, without the shell, by the presence of fully developed reproductive structures: the male verge and female genital groove (Appeldoorn, in prep.). Thus, inspection of the catch could be done at the dock.

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