Practical Considerations in the Assessment of Queen Conch Fisheries and Population Dynamics

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ABSTRACT

Proper management requires reliable information on the biology, exploitation and stock status of exploited species. With queen conchs, data collection and analysis are often complicated by the particular biological and life-history characteristics of the species (e.g., cessation of growth in length at maturation, partial recruitment, variations in mortality, growth and recruitment) and the nature of its fishery. The problems of sampling and assessment are reviewed with emphasis on the estimation of growth and mortality. Special attention is given to the use of length-frequency techniques. Specific examples are included based on original research and literature reports.

While problems do occur, useful information can be obtained if appropriate precautions are taken. It is strongly recommended that, if possible, results be corroborated by additional sampling and/or by employing a variety of techniques. In instances where decisions must be made with incomplete assessments, it is imperative to consider the variability of results and possible consequences of errors when developing management strategies.

INTRODUCTION

Management policies should be designed to achieve desired socio-economic benefits through the intelligent utilization of fisheries resources. Regardless of management goals, rational decision-making requires basic, reliable information. In fisheries, information on the biology and exploitation of target species is prerequisite to the management process. Of particular importance are stock size and rate of production. The latter is dependent upon the basic biological processes of growth, natural mortality, reproduction and recruitment, and upon mortality due to fishing activities.

Literature reports have demonstrated or advocated the application of assessment methodologies to populations of queen conch, Strombus gigas, with most recent attention being given to length-frequency analysis, e.g., Wood and Olsen, 1983; DuBois, 1985. Much can be gained from the analysis of length-frequency data (see Munro, 1983), as well as data from other sources. However, as with any analysis, data must meet the assumptions of, or otherwise fit, the assessment techniques used. Queen conchs have unique life-history characteristics that complicate

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stock assessment and can lead to serious errors if assessment methodologies are uncritically applied.

The purpose of this paper is to analyze some of the difficulties that can arise in assessment when techniques cannot be uniformly applied, sampling is biased, or data are otherwise affected by the biology of the queen conch or the nature of its fishery. Emphasis is placed on the estimation of growth and mortality, with special attention given to the use of length-frequency techniques. The analysis will first review some assessment techniques in general, then examine aspects of conch biology and fisheries that confound their use. Illustrative examples are given based on research conducted in Puerto Rico and on literature reports.

REVIEW OF METHODOLOGIES

Length-Frequency Analysis

Population dynamics can be studied, using a variety of techniques, through the analysis of size-frequency distributions. Although any measure of size, e.g., linear dimension, weight, volume, can be used, length is most typical. In its most restricted sense, length-frequency analysis is concerned about age structure, with respect to length, and subsequent age-based descriptions of growth and mortality. Although age-independent length-frequency techniques exist (Jones, 1981), emphasis here will be on typical age-dependent techniques. General reviews of length-frequency analysis are given by Brothers (1980), FAO (1981), and Jearld (1983).

Length-frequency analysis seeks to divide the length-frequency distribution of a population into component distributions representing individual cohorts. It assumes that each component frequency-distribution is approximately normal (Fig. 1). (To simplify discussion here, each cohort will be considered a separate year-class). Mean length of each year-class corresponds to the mean of its distribution; abundance is equal to the area under the curve, and can be obtained from information on the height and variance of the distribution.

There are a number of graphical procedures (Harding, 1949; Cassie, 1954; Bhattacharya, 1967; Tanaka, 1962, Appeldoorn, 1981) or computer programs (Yong and Skillman, 1975; Macdonald and Pitcher, 1979; Pauly and David, 1980) for analyzing length-frequency distributions. The graphical methods are considered to be more subjective, but most computer programs require information on the number of year-classes represented or changes in variance with age: decisions that often entail subjectivity. The objectivity of computer based methods does not guarantee meaningful results. Critical examination of results is therefore necessary, and validation through sampling or other techniques is advisable, when possible.

The analysis itself yields no information on absolute age; these must be assigned to individual year-classes based on other information. Mean growth is obtained from differences in the location (mean length) of successive year-classes. Mortality

estimation is based on differences in abundance.

The primary assumption of length-frequency analysis is that sampling is unbiased and representative. This means that all age groups in the population must be fully sampled and in proportion to their true abundance. Age groups for which this assumption cannot be met, or otherwise accounted for, should be dropped from the analysis. Although there is no set rule on sample size, reliable results require samples large enough to provide adequate statistical descriptions of each underlying distribution; mean length is the easiest parameter to estimate. Relatively larger samples are needed if year-classes are numerous or their distributions overlap extensively, or if more detailed descriptions are required, e.g., variance, abundance.

Mark-Recapture Methods

The use of mark and recapture methods to determine age, growth and other parameters is reviewed by Brothers (1980), FAO (1981), and Jearld (1983). Detailed reviews specific to the estimation of abundance and mortality are given by Ricker (1975) and Seber (1982). These methods assume that tagging in no way affects behavior, in terms of growth, mortality, or sampling, and that sampling is unbiased.

The analysis of growth is straightforward, growth rate being simply the growth increment between captures divided by the time. As with length-frequency analysis, tagging gives no direction information on absolute age. Parameters of the von Bertalanffy growth function:

$$1_t = L_\infty \ (1 - e^{-k(t-t_o)})$$

where 1_t is length at time t, L_∞ is the theoretical asymptotic length, k is the growth rate coefficient, and t_o is time when $1_t = 0$, are usually estimated using the techniques of Abramson (1971) or Fabens (1965). It is important to note that growth observed from tagging studies is usually quite variable. This is because individual growth is in itself variable, and because usually the number of recaptures is small. Consequently, the precision of parameter estimates will also be variable. Also, individual variability in k and L_∞ can often result in overestimation of L_∞ and length-at-age, and underestimation of k; this problem is particularly prevalent in mollusks (Sainsbury, 1980).

The estimation of mortality requires additional assumptions. There must be no tag loss. Any tag loss unaccounted for will be treated as mortality. Some techniques additionally require complete capture and reporting of tags, particularly those involving a single episode of mark and release. Lastly, any permanent migration out of the sampling area will also, unless otherwise accounted for, be counted as mortality.
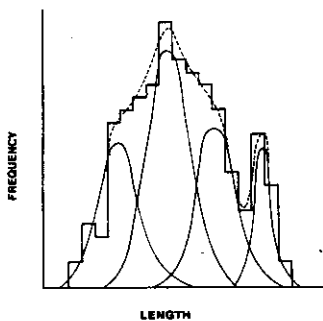
Figure 1. Resolution of a hypothetical length-frequency histogram into component, normal distributions (solid curves). The dashed line represents the sum of these component distributions.
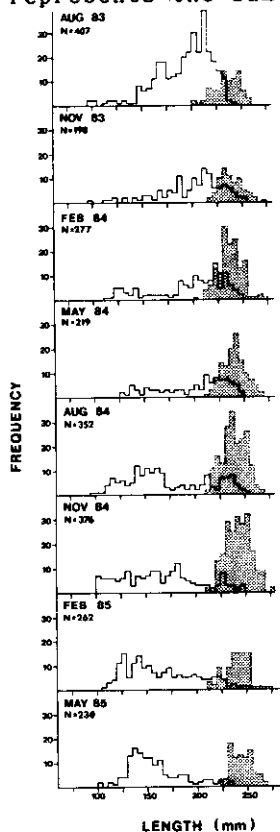

Figure 2. Length-frequency histograms for queen conchs sampled quarterly off La Parguera, Puerto Rico. The open portions represent juveniles, the shaded portions represent adults. N = sample size.

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STROMBID BIOLOGY AND FISHERY INFLUENCES ON ASSESSMENT

Maturation and Growth

The most unique aspect of queen conch biology that leads to difficulties in life-history studies and stock assessment is cessation of shell-length growth at sexual maturity. This occurs approximately midway through the life of a conch, thereby creating two life-history stages, juveniles and adults, that must be analyzed separately. Since conchs recruit to the fishery as juveniles, it is essential that both stages be analyzed. This leads to problems in sampling and analysis, particularly when size-frequency techniques are employed as the measurement of length yields little information on adults. Wefer and Killingley (1980) clearly showed that thickness of the flared shell-lip, characteristic of adult conchs, could be used to obtain growth and age information. Wood and Olsen (1983) attempted to use lip-thickness-frequency analysis to assess growth and mortality in adults, and conventional length-frequency analysis to study juveniles. However, application of these techniques is not straightforward.

The reasons problems arise, especially with size frequency techniques, are illustrated in Figure 2. In the first sample, the frequency mode of a large year-class is centered at 21 cm. In successive samples this mode shifts to the right as growth continues, and then stops, with abundance progressively decreasing as conchs mature and become adults. Note the correlated increase in the relative number of adults. The transition of conchs from juveniles to adults affects both the location of the mode on the length-frequency histogram, and its size, in both height and width (=variance). Changes in the shape and size of the frequency modes, as well as the transition between length frequency and lip-thickness frequency have profound effects on the estimation of growth and mortality.

(i)   The estimation of mean linear growth (for juveniles) may be adversely affected. Note that the length-distribution of the largest year-class never fully approaches that of the adults (Fig. 2). While maturation is occurring within the year-class, the observed mean size will always be less than 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 (see Partial Recruitment to Population).

(ii) 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. The effect of this is as yet unpredictable. The observed variance of the mode will decrease, which should tend to increase the precision of parameter estimates above their "true" values, but the frequency abundance will also decrease, and this may have the opposite effect.

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(iii) The reverse of items (i) and (ii) occur when looking at adult growth using lip-thickness. The problems here are similar to those due to partial recruitment to the population (here to the adult stage), which will be covered under Partial Recruitment to Population. The only difference is that here the conchs have already entered the fishery.

(iv) Although linear growth stops at maturation, growth in weight does not. This is an important consideration as management plans are often based around the goal of optimizing biomass production. A preliminary aim of any growth study should be the development of a weight-age relationship that can be used for assessment purposes. For simplicity, length-frequency analysis or other methods of determining linear growth are often used as proxy, with linear growth subsequently converted to weight using a conventional length-weight relationship. With conchs, this process is complicated since the linear measure used is different for juveniles and adults. While length is a good estimator of juvenile weight, lip-thickness is not a good estimator of adult weight (see the size-weight relationships of Wood and Olsen, 1983: p. 116). Adult weight depends on both size-at-maturity (final juvenile weight) and adult weight-gain, the latter a function of lip-thickness. Thus, there is no simple way to develop a size-based relationship that can be used to predict adult biomass for assessment purposes.
Wood and Olsen (1983) attempted to solve this problem with the implicit assumption that meat weight versus age can be modeled using the von Bertalanffy formula, and that, given a high correlation between length and weight during juvenile years, adult weight can be estimated through conversion of extrapolated lengths calculated using adult ages. Thus, their W_∞ is obtained through a straight length-weight conversion of L_∞. This assumption, if wrong, could produce serious errors in yield-per-recruit analyses.

(v) Any process that affects frequency mode shape will affect the estimate of year-class abundance, and hence mortality. Thus, the shift from juvenile growth to adult growth has serious consequences. For example, as conchs mature, the size of the year-class length-frequency mode for juveniles decreases. Length-frequency analysis cannot distinguish between this loss and mortality. 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) or if the number of newly matured adults is added to the number of juveniles in the maturing year-class.

Partial Recruitment to the Population

Small juvenile conchs are typically buried beneath the substrate. Thus, they are hidden and rarely sampled. As they grow larger, conchs are found progressively more frequently. For an individual the transition from an infaunal existence to an epibenthic one is gradual, for a year-class it is even more so. The result is that small juveniles will be selectively undersampled, with the effect that average size of the year-class will be overestimated and its abundance underestimated. In a partially recruited year-class, a false frequency mode will appear, as observed abundance of smaller individuals declines. This is not because there are no small individuals, but because they are buried and not available for sampling. The following examples illustrate the possible ramifications.

In Puerto Rico, even with extensive sampling, individuals less than 10 cm are rarely found (Figs. 2 and 3); the year-class is not fully recruited until some larger average size is reached (13 cm?). In his analysis of a single length-frequency distribution (Fig. 3), Berg (1976) estimated the length of year-old conchs to be 8.8 cm based on only a couple of individuals. It is highly likely that most year-old conchs were too small to be sampled (i.e., buried); the true average length should have been smaller. Note that the growth increment between 1 and 2 years (3.8 cm) was less than that between 2 and 3 years (5.4 cm): an unlikely situation, and one that prevents further calculation of von Bertalanffy parameters.

Alcolado (1976) recognized the problems of partial recruitment in the estimation of mortality, and was careful to conduct his analyses only on fully recruited year-classes. The possible effects of partial recruitment on mortality estimation are shown by comparing Figure 2 with the data of Wood and Olsen (1983) in Figure 4. Wood and Olsen found a frequency mode at 9.0 cm. Based on sampling experience in Puerto Rico, the decrease in abundance on the lefthand side of the mode (<9.0 cm) would be due, to some extent, to selective sampling of larger individuals. Without a subsequent sample to verify this, it is difficult to assess the effect of partial recruitment, but there are other observations which indicate that it was significant. Wood and Olsen (1983) used the abundance of the recruiting year-class in their estimation of natural mortality. In an analysis of natural mortality (Section 7) this estimate was found to be exceedingly low: an expected result if the abundance of their recruiting year-class was underestimated due to partial recruitment. Also, note that Wood and Olsen's recruiting year-class is the same one that in Puerto Rico was found to be dominant (Fig. 2; Section 4). Based on the proximity of Puerto Rico and the Virgin Islands, one might expect the abundance of Wood and Olsen's recruiting year-class to be dominant as well (this may explain why conchs less than 10 cm were found in the abundance they were), and not just slightly greater than the two older year-classes, as calculated.

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Similar problems will occur (using lip-thickness frequency) in the analysis of adults. While a year-class is undergoing maturation, only a portion of its true abundance will be available for sampling in the adult population.

Using mark-recapture techniques, partial recruitment may have two effects. First, since large individuals will be more frequently observed, it is possible that the sample of small conchs will be biased toward fast growers. This would obviously affect the estimation of growth parameters, probably by increasing k and decreasing L_∞. Second, since small conchs will be periodically buried, it is possible that some previously tagged small conchs will be missed during recapture. Some techniques consider this equal to death, thereby overestimating true mortality.

Spatial Variability in Recruitment and Distribution

Little is known about the settlement dynamics of conchs. However, since small juveniles spend much of their time buried, they might be expected to be found predominately in softer sediments, which would facilitate movement. The observations recording small juveniles in sea-grass beds, though few (e.g., Brownell, 1977), would support this. Juveniles have limited ranges (Hesse, 1979; Appeldoorn and Ballantine, 1983; Appeldoorn, 1985); therefore, when they emerge and recruit to the population, their distribution should reflect the distribution of suitable juvenile habitats. In Puerto Rico observations indicate that newly recruited juveniles (9-13 cm) are predominately found in certain areas, which are characterized by soft sediments. These areas are patchily distributed on a scale of up to 1 km. On the other hand, larger juveniles and adults are much more mobile and are found in a variety of habitats.

It is likely, unless precautions are taken, that sampling will be biased, either for or against small juveniles, depending on the habitat sampled. The sampling program should cover an area adequate to encompass a variety of habitats to minimize the effect of patchy distributions. An extreme example is provided by Wood and Olsen (1983), who sampled one area primarily for juveniles, and another for adults. In this instance it is important that sampling effort in different locations be uniform, or results otherwise adjusted to account for effect differences, if an unbiased frequency distribution is desired.

Temporal Variability in Recruitment

One of the major assumptions invoked when comparing different year-class abundances for the estimation of mortality is that recruitment is constant from year to year. This assumption can be relaxed somewhat for techniques that look at trends over a series of years (e.g., catch curve analysis; Ricker, 1975), but these require the additional assumption that the total mortality rate is constant. The analysis of conch mortality given in Section 7 indicates that even in unfished populations this

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assumption cannot be met until late in life. Thus, the assumption of constant recruitment becomes paramount. This assumption cannot be supported by observations made on the offshore conch population studies in Puerto Rico. Successive sampling (Fig. 2) clearly has shown the year-class of 3 year-old conchs, centered at 21 cm in sample 1, to be a dominant year-class. Dive records document the first appearance of this year-class in late 1981. Subsequent year-classes are considerably smaller, particularly the one recruited in late 1983, which is less abundant than both the 1982 recruited year-class and the year-class recruited in late 1984-early 1985 (Fig. 2). Alcolado (1976) also documents recruitment variability. In one instance (Institution Cover) the apparent complete failure of a year-class to recruit was observed (see Alcolado's Figure 3).

The estimation of mortality based on a single length-frequency distribution is tenuous at best. Additional samples would at least identify the presence of exceptionally good or bad year-classes that would adversely affect results. Annual sampling would allow abundance within year-classes to be compared year to year if sampling effort differences were properly accounted for. Age-specific mortality could then be estimated independent of recruitment variability.

Growth and Environmental Variability

It is well established that the growth and shell morphology of mollusks are highly variable and dependent upon habitat characteristics (e.g., Holme, 1961; Newell and Hidu, 1982). Alcolado's (1976) work showed this to be true for queen conchs. Habitat characteristics such as depth, substrate and food supply were cited to be of particular importance. Hence, growth parameters may differ among populations or areas. For example, juveniles up to 25 cm have been observed offshore of La Parguera, Puerto Rico (Fig. 2). This is 10% greater than the largest juvenile found by Berg (1976) off Puerto Rico's west coast (Fig. 3) and over 5 cm greater than that reported by Wood and Olsen (1983) in the Virgin Islands (Fig. 4). Randall (1964) found the average length of adults to be about 20.5 cm in the Virgin Islands. Off La Parguera the average is about 24 cm. Alcolado (1976) found average adult length to vary between 17 cm and 23 cm among populations in Cuba.

More information is needed on the relationships between shell length, shell weight and meat weight throughout the life history of the conch, and the relationships between growth rate, final size, and age of maturation. Until then, growth parameters developed in one area should not be applied to others without some corroboration (e.g., via comparison to a length-frequency histogram) or other justification (e.g., similarity between habitats). It is realized that in the absence of information on the variability of growth within an assessment area, a single estimate may be all that is available. While some useful information can be obtained by uniformly applying an uncorroborated growth estimate, managers are cautioned to
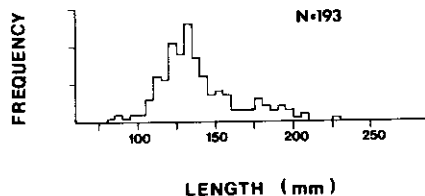
N=193

FREQUENCY

100   150   200   250

LENGTH (mm)

Figure 3. Length-frequency histogram for juvenile queen sampled
4 July 1973 by Berg off Cabo Rojo, Puerto Rico. N = sample size.
The ordinate axis is marked at intervals of ten.

N=332

50

40

30
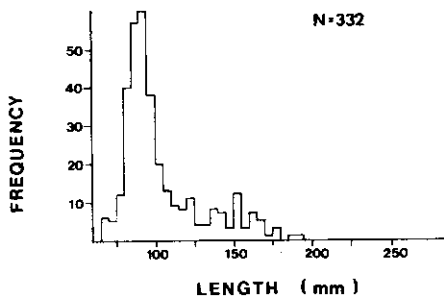
FREQUENCY

20

10

100   150   200   250

LENGTH (mm)

Figure 4. Length-frequency histogram for juvenile queen conchs
sampled September 1981 off St. James Islands, St. Thomas,
U.S.V.I. N = sample size. (Adopted from Wood and Olsen, 1983;
Figure 2).

15

FREQUENCY

10

5
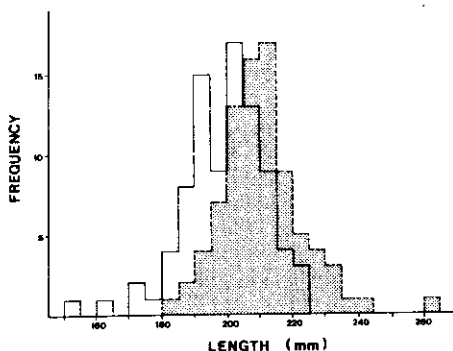
160   180   200   220   240   280

LENGTH (mm)

Figure 5. Length-frequency histograms for adult male (open) and
female (shaded) queen conchs from Salt Pond Bay, St. Johns,
U.S.V.I. as reported by Randall (1964).

consider the possibility of variation and errors when deciding on strategies. For instance, without specific information on the variability of growth between areas, it would be tenuous to restrict fishing effort based on minimum size limits.

Sexual Dimorphism

Randall (1964), Alcolado (1976) and Percharde (1968) found female queen conchs to be larger than males. The possible consequences of this for assessment and subsequent management depend on the magnitude of the difference relative to the degree of overlap. Randall (1964) presented length data for 84 females and 87 males, which are plotted in Figure 5. The mean difference between sexes is 1.14 cm; females are roughly 5% larger. (If differences in shell size reflect differences in tissue weight, using Wood and Olsen's (1983) regression equations, suggests that female conchs weigh 21% more than males in marketable weight). About 65% of the frequency distribution of either sex overlaps with that of the other. The degree of overlap relative to differences in mean length is great enough to give the combined frequency distribution a unimodal appearance. Alcolado (1976), however, observed differences in mean shell length between sexes of up to 1.9 cm, a large enough difference to produce bimodality in a frequency distribution. Note also Figure 2, sample 1; the large year-class shows a bimodal peak that may be due to sexual differences. Uncritical application of length-frequency analysis, especially using "objective" computer methodologies, could misidentify sex-dependent frequency distributions as separate year-classes.

An interesting possible consequence of sexual dimorphism relates to the use of minimum size limits for management. Because of dimorphism, any size-based regulation will automatically result in differential selection between sexes. A limit on minimum shell-length could be used to protect a portion of the population for spawning or to maximize yield-per-recruit. Using Randall's data as an example, suppose a minimum limit was set equal to the average adult length of 20.4 cm. This would protect half the adults. However, roughly two-thirds of these would be male, i.e., the law would favor selective harvesting of females, obviously reducing the reproductive potential of the population. Using minimum weight limits would have a similar effect. Size-limits are an important potential tool for conch managers, but they must be applied with full understanding of their effects relative to management goals.

Variation in Natural Mortality

Mortality is usually modeled with the Beverton and Holt equation, which describes a decreasing exponential decline in abundance over time. The formula is

$$N_t = N_o \, e^{-Zt}$$

where N_o is initial abundance, N_t is abundance after time t (usually expressed in years), and Z is the coefficient of the instantaneous rate of total mortality. Usually, Z is the sum of coefficients for natural mortality (M) and fishing mortality (F). Here we are concerned only with natural mortality, so Z = M. In most fisheries model M is considered to be constant over the exploited phase.

Figure 6 shows a plot of estimates of natural mortality versus age that were reported in the literature, calculated from data reported in the literature, or from original work. The ages reported are from the midpoint of the time period over which mortality was estimated. The data, excluding the outlying values of Wood and Olsen (1983) were modeled using a Weibull function via functional regression of ln(Z) against ln(age. The resulting equation, also shown in Figure 6, was $Z = dt^{c-1}$ ($r^2 = .90$; p<.01) where t = age and d and c are constants (in this preliminary analysis c = .085, d = 4.00). The validity of the predicted relationship between age and mortality is supported by three other observations. Appeldoorn (1984) found Z to decrease by 40-50% as size increased from 30 mm to 40 mm. This corresponds to ages of 0.27 and 0.45 years. The decline in Z between these ages, as predicted by the Weibull function, was 42%. Jory and Iversen (1983) stated that a marked decline in predation should occur after a length of 10-15 cm, corresponding to an age of 1.5 yr (range: 1-2 yr), is reached. This is also reflected in the shape of the predicted curve. Lastly, Hoenig (1984) presented empirical equations where Z can be estimated from oldest observed age. Taking the life span of queen conchs to be 7 yr (Wefer and Killingley, 1980; Berg, 1976), the equation predicts Z = .716, which is characteristic of Z predicted by the Weibull function for mid-age adults.

The above results lead to some pertinent conclusions.

(i) The rate of natural mortality in the queen conch is variable over a large portion of its life span. The assumption of constant mortalilty is only roughly approximated for adults (> 3.5 yrs). However, conchs generally start recruiting to the fishery at approximately 15 cm in length - roughly 1.5-2 years of age (pers. obs.; Menzel, 1971). Thus, for assessment purposes the assumption of constant mortality over the exploited phase cannot be made.

(ii) The rates of mortality used by Wood and Olsen (1983) differ markedly from those predicted in Figure 6. In view of previously mentioned sampling problems, this casts doubt on the validity of their yield-per-recruit analysis.

(iii) The observations of high mortality in small, hatchery-reared conchs released offshore (Appeldoorn, 1984; 1986) do not appear anomalous. Thus, the release of small juveniles, unprotected, does not seem to be a viable method for population restoration or mariculture
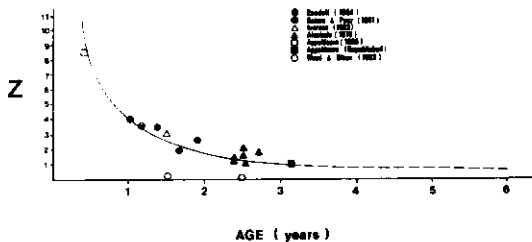
Figure 6. Plot of instantaneous mortality versus age for queen conchs. Data were obtained from the literature as indicated. The relationship is approximated by a Weibull function (solid line) fit to the data, excluding the values of Wood and Olsen (1983). The dashed line is an extrapolation of the model.
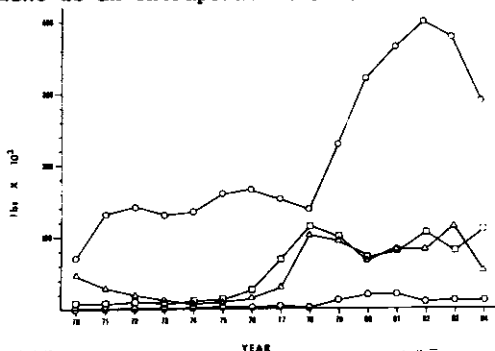

Figure 7. Estimated landings (meat weight) of queen conchs in Puerto Rico by coast: circles = west; triangles = east; squares = south; hexagons = north.
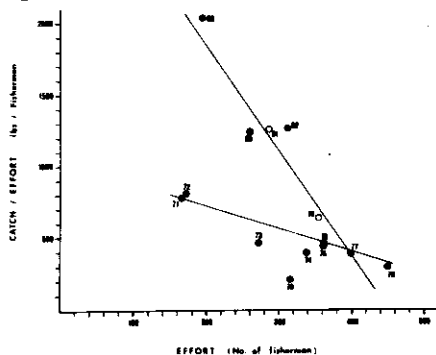

Figure 8. Approximation of the relationship between catch per unit effort for queen conchs landed on Puerto Rico's west coast. Numbers represent year. Effort data for open circles were obtained by averaging values from adjacent years. Lines represent functional regressions of the data from 1971 - 1978 and 1978 - 1983, and are significantly different at p = 0.05.

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growout; a lesson previously learned for other commercially important mollusks (see Jory et al., 1984 for review). While seasonal variations in the mortality observed in small juveniles might suggest an opportune time of release (Appeldoorn, 1986), Figure 6 clearly indicates that long-term survival will require either some form of protection (e.g., cages), a larger size at release, or both.

Status of the Resource

Declining stocks, harvesting of juveniles, and increasing effort (going further afield or into deeper waters) are frequently cited as evidence for overfishing. While in the extreme these are often good indicators, quite often they can be misleading. How this can occur is illustrated by examining the conch fishery of Puerto Rico.

In 1976, it was stated "many island fisheries are already severely threatened, e.g., Puerto Rico, Bahamas and Grenadines (Adams, 1970)" (Brownell, et al. 1977). Adams (1970) referred only to the Grenadines. This assessment of Puerto Rico has since been repeated in the literature (Brownell and Stevely, 1981; DuBois, 1985). Figure 7 shows the commercial conch catch, by coast, for Puerto Rico. The fishery is dominated by the west coast landings. (Note: the increase in landings on the west coast from 1970 to 1971 may be more reflective of better data collection rather than real differences in catch (Suarez-Caabro, 1973). From the early to mid-1970's conch landings from all areas were stable. Those from the west coast vacillated around 150,000 lb. Based on landings alone, the stability of the fishery at this time would argue against an estimation of severe overfishing (but see below). Toward the mid to late 1970's landings increased, first on the east and south coasts, then on the west, with the latter landings almost tripling between 1978 and 1982. While not being indicative of the current state of the fishery, these trends clearly show that by the inclusion of Puerto Rico's fishery (Brownell et al., 1977) among the "severely threatened" was premature.

Figure 8 gives an approximation of the relationship between catch and effort for Puerto Rico's west coast; the trends are the same for the other coasts. (Note: effort does not account for increases in distance traveled, depth, or search time). The relationship is marked by two phases, before and after 1978, which clearly indicates a change in the nature of the fishery. Conversations with fisheries personnel and conch fishermen suggest that during the mid-1970's the conch fishery switched from being centered primarily inshore to offshore, mostly through the adoption of scuba for harvesting.

Officially, by the mid-1970's the fishery was indeed considered to be on the decline, but this was based solely on the performance of the fishery. The resource as a whole, however, was healthy; the assessment, being based on the fishery, could not account for areas outside those fished. The first point here, then, is that the limits of the fishery versus

the potential distribution of the resource must be considered when assessments are made.

Second, the important point in stock assessment is productivity, not abundance or standing biomass. Abundance, and its proxy measure - catch per effort, will decline as long as effort is increasing, regardless of the level of effort. Without reference to some standard, measures of abundance will not be indicative of stock status except in extreme conditions. At present, not enough is known about the productivity of queen conchs, especially with respect to reproduction and recruitment, to offer suggestions on appropriate levels of abundance.

A confounding problem here is that on a broad scale, conchs are a relatively stationary resource, and local populations are, therefore, susceptible to depletion. This may give the appearance of overfishing when the resource as a whole is healthy. Indeed, this was the case in Puerto Rico; by the mid-1970's the inshore populations had been markedly reduced (Ballantine and Appeldoorn, 1983). Thus, with respect to the area being fished, the resource was overexploited, but for the entire population, it was not.

The use of indicators that are reliable only under extreme conditions would not allow the resource to be exploited optimally. Management would be called for only after the resource had been severely depleted, and often this is too late to avoid collapse of the fishery and/or acute socio-economic disruptions. However, that populations can be affected on a local scale suggests that the fishery could be subdivided and managed on an areal basis. Although still subject to the limits of knowledge mentioned above, at least here when severe stock depletion occurs, the immediate area can be closed or otherwise managed, without regard to the resource as whole. Thus, management actions can be invoked before the resource as a whole is threatened, and stability of the fishery can be enhanced.

CONCLUSIONS

Ideally, judgments on the status of any fishery resource are made through comparison of observed levels of yield, effort, mortality, stock size, etc., to corresponding values predicted to maximize or optimize the potential benefits of the resource. These predictions would be based on reliable information on growth, mortality, etc., and obtained through critical application of appropriate methodologies, e.g., yield-per-recruit or surplus-production models.

In reality, the necessary data are often unavailable or unreliable. In the absence of suitable data, judgments are based on perceptions or trends. Potentially, unreliable data can be used, but only if proper consideration is given to consequences of error. Too often this consideration is absent.

Analytical techniques should be used only after critical examination of the data. It is important not only that data meet the assumptions of these techniques, but also that the investigator be aware of whether or not they do.

Validation or corroboration of results should be attempted

when possible. Frequently, this can be done quite simply, e.g., literature reference to other studies (taking into account possible variation), or collection of additional length-frequency samples - particularly over time. Ideally, information from more than one type of analysis should be obtained. For example, one might supplement a catch-and-effort survey with a mark-recapture study or in-depth interviews with fishermen.

Finally, it is important to incorporate into any analysis the possibility of error. This should include, if possible, an assessment of both the consequences of errors, and the likelihood of their occurrence. Results that are less likely to be in error, or more likely to have severe repercussions should be given greater weight during assessment and subsequent management.

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