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The Generation of Input Parameters for Sequential Population Analysis

by

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ABSTRACT

Sequential population analysis (SPA) has, since the inception of CAFSAC in 1977, played a key role in roughly 50% of the fish stock assessments presented to that body. Of the two types available, Pope's cohort analysis is the most popular. Both require as input, a catch-at-age matrix, an estimate of the natural mortality M, estimates of the instantaneous fishing mortalities both for the oldest age groups and the most recent fishing year, and finally, an estimate of the partial recruitment pattern of the fishery in the most recent fishing year. All estimated inputs require careful consideration. The catch-at-age matrix must be conditioned to ensure that only individual cohorts are used in the calculations. The fishing mortality on the oldest age groups is generally calculated using the self-correcting features of the cohort analysis. The fishing mortalities in the most recent fishing year are generated through the use of linear relationships between either commercially or research derived estimates of population size and the numbers produced by the cohort analysis. The estimation of the partial recruitment pattern is potentially the most important process in influencing management advice in both the short and long-term. Presently, five different procedures are being employed. Overall, the assessment process requires the intimate interaction of a large suite of procedures. This is illustrated through the example assessment of a simulated population. It is evident from this exercise that one of the most important features of assessment evaluation is the adequate documentation on the detailed methodology used. Only in this manner can management bodies critically review stock assessment advice.

RESUME

Depuis la formation du CSCPCA en 1977, l'analyse séquentielle des populations (SPA) a servi dans environ 50 des évaluations des stocks de poissons présentées à ce comité. Des deux types disponibles, l'analyse des cohortes de Pope est la plus communément employée. Les deux requièrent comme entrées une matrice des prises par âge, une estimation de la mortalité

naturelle M, des estimations de mortalité instantanée par pêche à la fois des groupes les plus âgés et durant l'année de pêche la plus récente et, finalement, une estimation des modalités du recrutement partiel dans l'année de pêche la plus récente. Toutes ces entrées doivent être examinées avec soin. La matrice des prises par âge doit être traitée afin de s'assurer que seules les cohortes individuelles entrent dans les calculs. La mortalité par pêche des plus vieux groupes d'âge est ordinairement calculée en faisant appel aux propriétés autocorrectives de l'analyse des cohortes. Celle de l'année de pêche la plus récente s'obtient à l'aide des relations linéaires entre les estimations d'effectifs des populations, soit par navire de recherche, soit par pêche commerciale, d'une part, et les nombres obtenus par analyse des cohortes, d'autre part. L'estimation du recrutement partiel est probablement celle qui influe le plus sur les conseils de gestion, tant à court qu'à long termes. On dispose présentement de cinq méthodes. L'evaluation d'une population simulée sert ici d'illustration. Il est évident, à la suite de cette opération, que l'une des plus importantes caractéristiques de l'évaluation est une documentation adéquate sur la méthodologie employée. C'est seulement de cette façon que les gestionnaires pourront porter un jugement critique sur les conseils qui leur sont offerts pour la gestion des stocks.

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1. INTRODUCTION

Sequential population analysis is presently being employed by CAFSAC (Canadian Atlantic Fisheries Scientific Advisory Committee) to assist in the determination of the size of many of Canada's east coast fish stocks. The most common form currently in use is cohort analysis, as derived by Pope (1972). Virtual population analysis (Gulland, 1965), which Pope's model appoximates, is less extensively used. Both models require the same input, these being a catch-at-age maxtrix, a fishing mortality estimate for the last exploited age in every year and a fishing mortality estimate for all ages of the most recent year of stock exploitation.

Since the inception of CAFSAC in 1977, there has been a variety of procedures developed to aid in the generation of these input parameters. Often, these procedures are introduced for the first time at the assessment meeting. This allows subcommittee participants little time to reflect on the full ramifications of use of the stated method.

It is the purpose of this document to outline which procedures have been used by CAFSAC since 1977 in the generation of these input parameters and to provide, where possible, guidance on proper methodology to be employed.

2. VIRTUAL POPULATION AND COHORT ANALYSIS

Before considering the input parameters themselves, it might be well to review the differences between virtual population and cohort analysis.

Virtual population analysis was originally developed by Gulland (1965) to calculate, using a recursive process, the instantaneous fishing mortality and population at each age of a cohort, given the catch-at-age and the natural mortality. It makes use of two well-known equations:

(1) $$N_{t+1} = N_t \, e^{-Z_t}$$

(2) $$C_t = \frac{F_t}{Z_t} N_t \, (1-e^{-Z_t})$$

the latter being Baranov's catch equation (Ricker, 1975). As the purpose of the exercise is to project back along the cohort, it is necessary to have an equation containing estimates at two separate times t and t+1. Thus equations (1) and (2) can be combined as:

(3) $$C_t = \frac{F_t}{Z_t} N_{t+1} \, (e^{-Z_t}-1)$$

Thus if one has an estimate of N_{t+1}, M and C_t, F_t can be calculated. Note that since (3) has no analytical solution i.e. F_t cannot be separated out as one term, it must be solved numerically. This is easily done on a computer. Rivard (1980) for instance, chose the Newton-Raphson iteration method (Stark, 1970) for his VPA program.

The steps in the calculation are thus:

1) With inputs F_t, M and C_t (derived independently of the VPA), calculate an initial estimate of N_t using equation (2).

2) Using equation (3), F_{t-1} can be calculated by iteration.

3) Using equation (1), N_{t-1} can be calculated, then used in equation (3) to generate F_{t-2} and so on.

Pope (1972) developed cohort analysis to simplify the calculation and, more importantly, to allow a sensitivity analysis of the input parameters. Equation (1) can be rewritten as:

$$(4) \quad N_{t+1}\, e^{M} = N_t\, e^{-F_t}$$

or

$$(5) \quad N_{t+1}\, e^{M} = N_t - N_t\, (1-e^{-F_t})$$

Substituting equation (2) into (5), we get,

$$(6) \quad N_{t+1}\, e^{M} = N_t - C_t \left(\frac{Z_t\, (1-e^{-F_t})}{F_t\, (1-e^{-Z_t})} \right)$$

Pope found that, for M less then 0.3 and F less than 1.2, the term,

$$\frac{Z_t\, (1-e^{-F_t})}{F_t\, (1-e^{-Z_t})}$$

could be approximated by $e^{M/2}$. Thus, the now familiar cohort analysis equation,

$$(7) \quad N_t = N_{t+1}\, e^{M} + C_t\, e^{M/2}$$

was created.

The steps in cohort analysis are:

1) As in VPA, obtain initial N_t through input of estimate of F_t into equation (2).

2) Using equation (7), calculate N_{t-1} which can again be used in equation (7) to yield N_{t-2} and so on.

3) Using equation (1), F_{t-1} can be found.

Note that in each step of the VPA, F_t is calculated and from it N_t is then derived whereas in cohort analysis, it is the reverse.

Pope (1972) compared the results from the two procedures carried out on the same data set. In no case were the differences greater than 2%. Therefore, in most situations either method may be used. However, two points must be considered:

1) Cohort analysis is only an approximation of VPA and thus is only valid for $M < 0.3$ and $F < 1.2$.

2) Since VPA employs a numerical solution, computing costs will probably be higher, although by how much depends on the size of the catch-at-age matrix.

Whichever procedure is used, it should be explicity stated.

To give some idea as to how widespread the use of sequential population analysis has been in CAFSAC, the method of analysis for the 1977-80 assessments were reviewed and noted by stock. In 1977, 50% of 24 assessments employed cohort analysis (Table 1). In 1980, 50% of 30 employed sequential population analysis, only one of these being a VPA, the rest, cohort analysis. Thus the use of these procedures has not increased since 1977. However, as will be shown below, the way of estimating input parameters has.

3. THE GENERATION OF INPUT PARAMETERS TO SPA

3.1. THE CATCH-AT-AGE MATRIX

The construction of the catch-at-age maxtrix can be a long, laborious task and, especially when sampling of the fishery has been poor, requires careful consideration and in some cases, ingenuity. This process will not be completely discussed here. However, one aspect of its construction important to the application of sequential population analysis sometimes goes unnoticed. Pope (1972) distinguishes between the situation in which the catch of the oldest age of a cohort includes only the catch for the current year (fishing incomplete) and the situation in which this catch includes all subsequent catches at age from that cohort (fishing complete). In the case of fishing incomplete, N_t for the final year and age is calculated in a straight forward manner using,

$$(8) \quad N_t = \frac{C_t Z_t}{F_t\,(1-e^{-Z_t})}$$

In the fishing complete situation N_t can be calculated as,

$$(9) \quad N_t = \frac{C_t Z_t}{F_t}$$

since, as the number of subsequent years of catch included in C_t increases, e^{-Z_t} approaches zero (Pope, 1972) (Table 2). Note that at the relatively low Z values of 0.3.-0.4, up to five years of catch would have to be included in C_t for equation (9) to be valid (Table 3). With commonly encountered Z values of 0.5-0.7, inclusion of at least 2-3 years of catch is necessary to make equation (9) valid. For higher Z values, only 1-2 years of catch data are needed to make equation (9) usable in a fishing complete situation.

Equation (9) has two underlying assumptions. The first is that only fish from one cohort have been lumped into C_t. Often this is not the case. Lumping of catch along the bottom of the catch matrix more frequently is carried out across ages within one year and not by cohort. With flatfish, it is often difficult to age otoliths beyond a certain age, say 12, so that all fish above this otolith ring count are designated as 12+. This procedure lumps fish from many cohorts into one "age group" in the catch matrix.

The second assumption states that, even when catches from only one cohort are included, the Z_t is considered to be the same for all subsequent years of exploitation of that cohort. In many fisheries, this is unrealistic. Trends in effort often occur over time and can sometimes be very dramatic.

In virtually all cases, lumping of catch is done across age groups. This fact alone prevents the use of this data in the backcalculation of historical population sizes along one cohort. If the percentage of catch biomass in these lumped groups is small, it may be better to drop the last row of the catch matrix (the lumped data) and use equation (8). This was in essence done by Maguire (1980).

Alternatively, equation (8) can be used on the lumped data to obtain a, say 10+ population size for a particular year, without using this data to backcalculate along a cohort. In other words, the information in the last row of the matrix is used only once (S. Clark, pers. comm.). Only the unlumped cohort by cohort catch statistics, in the next row up would be used to backcalculate cohort size with equation (7). The input fishing mortality would be the same for both the lumped and last row of unlumped data.

3.2. ESTIMATION OF INSTANTANEOUS FISHING MORTALITIES OF OLDEST AGE GROUPS (F_B)

In the CAFSAC assessments where methodology is outlined, one of two procedures was generally employed (Table 4).

The simpler method involves estimating F_B by first using catch curves and Paloheimo's method (Ricker, 1975) to provide yearly estimates of the total mortality (Z), and then subtracting off natural mortality (M). These F_B estimates are then used directly in the SPA.

In the second procedure, initial estimates of F_B are generated as outlined above and used in initial SPA run. Updated estimates of F_B values generated by the analysis are then repeatedly submitted in the SPA. This iterative process is stopped when the input and output F_B values of the SPA are not significantly different.

The iterative process is dependent upon the "self-correcting" qualities of the sequential population analysis. As the analysis works back along a cohort, the estimates of F increase in accuracy. For cumulative fishing mortalities greater than 2.0, the errors in the estimates of N and F are relatively small (Pope, 1972). Thus, it is reasonable to assume that this iterative procedure converges on correct input values of F_B. However, there must be a considerable interaction between this process and the one used in the generation of fishing mortalities for the most recent exploited year. For this reason, details of these and the procedures reviewed next are deferred to a simulation analysis given later in this document.

3.3. ESTIMATION OF INSTANTANEOUS FISHING MORTALITIES FOR FULLY RECRUITED AGE GROUPS IN THE MOST RECENT FISHING YEAR (F_E)

Although it appears that many procedures have been employed by CAFSAC to estimate F_E (Table 5), in reality all are based on describing some output parameter of the SPA as a linear function of some independently derived variable. The most commonly used relationships are discussed in the following sections.

3.3.1. Fully Recruited Fishing Mortality vs. Fishing Effort: Theoretically, F should be some linear function of fishing effort. This procedure is the oldest in use. Typically, an SPA is run and the weighted (on population numbers) F for the fully recruited year-classes determined for each year. The correlation of F_E with an effort series for the same period is then examined.

After an initial run, the relationship is used to predict a new F_E and the analysis is rerun. The process is carried out until the R^2 of the relationship between F and effort is maximized.

A number of problems plague this relationship. First, it is often difficult to obtain an effort series which is completely independent of the catch matrix and thus of the SPA. Typically the catch rate from the fishery is divided into the total catch to provide an estimate of total effective effort. However, as this effort is now derived from the same catch which is employed in the SPA, the F from SPA and derived effort may be correlated. The degree of correlation depends to a large extent on just how much of the fleet was used in generating the catch rate index.

Another problem concerns the appropriate weighting to use to obtain a mean fishing mortality with which to correlate effective effort.

Theoretically, for one age, i, and year, t,

(10) $F_{it} = q_{it} E_{it}$ or,

(11) $F_{it} = q_i q_t E_{it}$

where F_{it} is the fishing mortality, E_{it} the effective effort and q_{it} the catchability coefficient. The last consists of two components -- one age (q_i), and one year specific (q_t). Summing across age within one year, one obtains,

(12) $\Sigma F_{it} = \Sigma q_i q_t E_{it}$

(13) $\Sigma F_{it} = q_t E_t \Sigma q_i$

thus

(14) $\dfrac{\Sigma F_i}{\Sigma q_i} = q_t E_t$

This essentially states that the summation of the fishing mortalities-at-age divided by the summation of the partial recruitment at age is correlated to the effective effort. Unfortunately, estimates of the partial recruitments q_i, for the youngest age groups are often the most unreliable due to commercial sampling problems for these age groups. The best estimates of fishing mortality are for fully recruited age group i.e. where q_i equals one. Thus, if one choses only the fully recruited age groups to carry out the correlation, equation (14) reduces to the arithmetic mean of the fully recruited fishing mortality being correlated with the total annual effective effort.

The F vs. E relationship has been replaced gradually in importance by ones in which the correlation between commercial catch rate and fishable biomass (as derived from the SPA) or the correlation between the research survey catch rates and the SPA population numbers estimates are examined.

3.3.2. Commercial Catch Rate vs. SPA Derived Fishable Biomass: Using of this relationship eliminates the problem of correlation of data sets discussed in the section 3.3.1. Rather than derive effort from the CPUE, the latter is used directly.

Typically the SPA is run and the fishable biomass (BIO) calculated for each year as:

$$(15) \quad BIO = \sum_{i=1}^{n} \overline{N}_i \overline{W}_i q_i$$

where N_i is the mean numbers-at-age i in the population.

Note that a mean must be used as the commercial CPUE index is considered as a mid-year estimate. This value is calculated as,

$$\overline{N}_i = N_i e^{-Z_i x 0.5}$$

w_i is the mean weight-at-age for a fish in the population as derived from the commercial samples. Research weights-at-age should be avoided as they are obtained by a gear which has a different selectivity ogive from the commercial fishing fleet.

The partial recruitment pattern q_i for the year in question is calculated as,

$$(16) \quad q_i = F_{i,t}/F_{max,t}$$

Thus for each year, t, the F's at age are divided by the maximum F for that year.

Terminal F's are then adjusted to maximize the R^2 of the relationship between CPUE and BIO. Note that in this, as in the other correlations used, the final year's point is not included in the regression, but predicted from the line. The terminal F is normally adjusted by a straight proportion of deviation from the predictive line, i.e. if BIO needs to be lowered by 20%, then F is raised by 20%. This follows from

(17) $C/E = q\bar{N}$ and $F = qE$

(18) $C/E = \frac{F}{E}\bar{N}$

3.3.3. Research Survey Abundance Estimates vs. SPA Abundance Estimates: Mainly on account of the problem with the reliability of the commercial statistics, more and more emphasis is being placed on the use of research survey data to assist in the SPA.

Generally the numbers-at-age from the SPA are grouped over the fully recruited ages only. The correlation of these with the research cruise numbers-at-age estimates for the same cohorts is then determined. If the fishery is primarily in spring then the summer survey results represent the stock size after the major occurence of mortality for that year. Thus the correlations are best done as ages i and t from the survey versus ages i + 1 and t + 1 from the SPA. Alternatively, if fishing is mainly in the fall, then the same ages and years are employed in both data sets.

"Ageing" the SPA estimates to the summer through use of equation (8) requires a knowledge of the seasonal distribution of F, and is a considerably more complex, albeit more correct, way of handling the time discrepancy.

In practice, a relationship between the two sets of data, excluding that of the last year's point, is obtained and the N for the SPA predicted. Then, by solving the catch equation, the desired F is obtained. This is input into the SPA and process is repeated. A Newton-Raphson procedure, (Stark, 1970) is suitable for this solution.

3.4. ESTIMATION OF THE PARTIAL RECRUITMENT PATTERN FOR THE MOST RECENT FISHING YEAR

A wide variety of techniques has been employed by CAFSAC in determining the current year's partial recruitment pattern (Table 6). The most common is historical averaging of SPA results. Recently, direct comparison of commercial catch-at-age and research survey abundance-at-age has appeared. These procedures are important in determining both historical stock sizes and, through the dynamic pool models and catch projections, future yields. Details of their use are discussed below.

3.4.1. The Cohort Method: This method, employed early in CAFSAC, involves following the catch of one cohort through the fishery. The procedure is normally carried out on a gear by gear basis and the partial recruitment patterns for each gear subsequently combined.

1) Collect all age-length samples for one gear over all available years and for one chosen chort, create one age-length sample (Figure 1).

2) Obtain a combined length-frequency distribution for this cohort by adding across ages (Figure 2).

3) Run an SPA using the most reliable fishing mortalities available. The choice of the cohort for this method is determined in part by the accuracy of the SPA. Choose a cohort with a long sampling history and not presently in the fishery. This allows two things. First, the cohort results are based solely on estimates of F_B and second, if the F's are high, they should converge on a relatively good estimate of N in just a few years (Figure 3).

4) Using the combined age-length sample, plot the mean length of each age of the cohort versus its abundance as estimated by the SPA (Figure 4).

5) Divide each abundance at length by the initial value of N and use multipliers to adjust the combined length-frequency in Figure 2.

6) Normalize adjusted length-frequency to highest value.

7) Finally, read partial recruitment-at-age from the normalized length-frequency by reference to the mean lengths-at-age.

This is done for a number of cohorts and the results combined.

The main drawback of the procedure is its dependence on the SPA. The SPA, which has a built-in partial recruitment pattern, is influencing the results of this method. The method has only been used twice and holds promise but must be rigorously evaluated before being used further.

3.4.2. The Historical Averaging Method: This procedure is the most commonly used. It depends on the "self-correcting" quality of the SPA for accuracy. For this reason, only the youngest ages of the oldest cohorts in the SPA are employed. This is often the only part of the F matrix in which the cumulative F is greater than 2.0 (Pope, 1972).

Needless to say, this procedure, like the former one, is useless for short time-series of data.

The procedure is:

1) Run an SPA using the best available input values.

2) Choose the most appropriate part of the F matrix either by examining the cumulative F values or carrying out a sensitivity analysis (Rivard 1980).

3) Divide each year of F values by the maximum F for that year, paying close attention not to include the oldest age groups. This produces a matrix of partial recruitment values over years.

4) Average this matrix across years, divide by largest observed partial recruitment to normalize data to 1.0 and plot versus age. This provides a mean partial recruitment-at-age curve for the years studied. Examine the plot for irregularities; smooth if necessary.

If there has been little or no change in the fishery since the studied period, then the PR (partial recruitment) pattern can be used in the most recent year. If changes have occurred, the pattern must be changed to reflect this. The following modification can be used to do this.

1) Carry out the procedure as outlined above for the years during which gear proportions have been relatively stable.

2) Obtain from published literature, selection at age curves for the various gears used during the historical period.

3) Combine these, weighting on catch, by gear to obtain one overall selection at age pattern and normalize to the highest value.

4) Divide this series into the historical PR series. The resulting vector represents availability at age for the historical period.

5) Assuming that the availability has not changed, multiply the availability at age vector by the selection at age pattern for the most recent years. Again renormalize to 1.0.

This adjustment depends a lot on the availability assumption and should only be used when no other method of obtaining PR is available.

3.4.3. Comparison of Research and Commercial Data: In many of the 1980 assessments, a new procedure was used to calculate PR values for the most recent SPA year. Basically, the research survey abundance-at-age data is taken as being representative of the stock's entire age structure. These estimates are divided into the commercial catch-at-age to obtain an estimate of the partial recruitment.

Mathematically, this depends on the relationship, for each age,

(19) $C/E = q\overline{N}$

and

(20) $F = qE$

Therefore,

(21) $C = F\overline{N}$

and

(22) $C/\overline{N} = F$

Substituting (19) into (22) we get,

$$(23)\quad q \times \frac{C}{C/E} = F$$

Note that q here is the catcability of the fish by the survey and not involved with the fishery partial recruitment. Therefore, dividing the survey estimates into the catch will generate a set of values directly proportional to the fishing mortality (by q), which can be normalized to obtain the partial recruitments. However, the catchability-at-age of the fish by the research gear must be constant. With many surveys, the age 1-2 animals tend to have low q values. This would, by the above procedure tend to produce relatively high partial recruitments for these ages.

It can be readily seen that this procedure is critically dependent on the q-at-age for the survey gear. Unfortunately an evaluation of this aspect of the surveys has not been carried out and thus use of this technique to generate PR values is strongly discouraged until it has.

3.4.4. Comparison of Recruitment in Surveys to that in the SPA:

3.4.4.1. Unnormalized method: This and the following procedure were developed to handle the most difficult part of the SPA - the determination of the strengths of the most recent year-class (the upper right-hand corner of the catch matrix). They are most important in allowing reliable longer-than-two year yield projections.

This first procedure uses the survey numbers-at-age data, which may or may not have been smoothed. Smoothing moderates temporal changes in availability to the research gear and is thus recommended. Various smoothing techniques are available, the most suitable being that on the median (S. Smith, pers. comm.).

The procedure is illustrated in Figure 5.

1) First examine the survey data to decide the age at which abundance becomes indicative of year-class strength. This can be done by simply plotting age t estimates against age t+1 estimates for the same cohort.

2) Add consecutive estimates of a cohort for the chosen ages. In the figure, ages 2 and 3 were added. The age one indices were not indicative of year-class strength. The addition of two estimates for the same cohort smooths the index and makes it less susceptible to variation in availability, sampling, etc.

3) Plot the survey indices of year-class strength versus the SPA estimates for the same cohorts. As there should be, in most cases, hardly any exploitation on these younger age groups, the correction for time of year is relatively unimportant (for a summer survey).

4) Adjust the last year's partial recruitments to maximum the above relationships paying strict attention to the historical recruitment

pattern for these age groups. Adjustments should produce a reasonable partial recruitment pattern.

This procedure has been employed in CAFSAC assessments with varying amounts of success. The main problem with it is that the partial recruitment pattern must be changed to optimize the relationship. If one has no idea what a reasonable PR pattern should be for these age groups, the adjustments can lead to erroneous results. Certainly it is very easy to optimize the relationship when the SPA entries are so dependent on the input data. Although no strict guidelines are available at present, the author recommends that the historical PR pattern and its variation be examined and adjustments only be made within the observed variation.

3.4.4.2. Normalized Method: This procedure is a variant of the previous one and employs a technique to circumvent the problem of partial recruitment to the research gear.

1) First normalize both the survey and SPA estimates at each age by a value determined from past estimates (the mean of 1970-74 estimates was used Figure 5.) Normalizing eliminates the partial recruitment trends in the data and provides serial estimates, with equal weight, of year-class strength.

2) Average the normalized estimates for the first two ages of each cohort.

3) Plot the normalized survey estimates versus the SPA year-class strength estimates and maximize the relationship as in section 3.4.4.1.

This technique has not been employed often but in some respects is superior to the unnormalized method as each entry of the table is an equal estimator of year-class strength. Its use is preferable to the previous one.

4. A HYPOTHETICAL ASSESSMENT

Many of the procedures discussed in Section 3 are interdependent. To demonstrate the use of these procedures together, it was thought worthwhile to "create" a population, fish it and then, using the procedures outlined in Section 3, evaluate the size of the original population from the catch statistics.

4.1. CREATION OF THE POPULATION AND THE FISHERY

A variant of the APL program, MPROJECT (Rivard, 1980) was used to simulate a population for ten years (1979-88) using as input, values for 4X haddock (Table 7.).

For recruitment, $e^{10.6 \pm 1}$ was used over a series of five replicate runs. The results of these runs were averaged to give the final outputs.

The fully recruited fishing mortalities for the ten years of the projection (1979-88) was generated by,

$$F = 0.3 + 0.4 \left(\sin \frac{\pi}{q} t\right) \text{ where } 1<t<9.$$

The pattern created is shown in Figure 7a. For the relationship of F vs. E described in Section 3.3.1, an estimate of effort is necessary. This series was generated by,

$$E = F \div (0.0025 + 0.000625 \times \text{GAUSS seed})$$

where 0.0025 is the mean catchability q.

The APL function GAUSS provides a random standard normal deviate for a normally distributed population with a mean of 0 and a standard deviation of 1. The catchability was given a CV of 25% through use of 0.000625 as a value for the standard deviation.

The smooth and "real" effort series are compared in Figure 7b. There appear to be no obvious trends in the "real" q (F/real E) for the period of the projection (Figure 8). This is both expected and desired.

Population numbers, catch numbers and fishing mortalities-at-age were also generated (Tables 8-10).

The population size was backcalculated as follows:

1) Using initial estimates of F_B for the oldest age groups, calculate an initial population size.

2) From the first SPA, update the input PR pattern and the F_B values and iterate until the F_B values do not change more than 0.01.

3) Using the F vs. E relationships adjust the F_E values.

4) Finalize the F_B values using a final iteration.

5) Finalize the F_E values using updated PR estimates.

As no survey data is "available" for this population, only commercial data was used to key in the cohort, in this case F vs. E. However, the principles are the same.

4.2. INITIAL ESTIMATES OF F_B AND PR

Using the catch-at-age matrix and the generated effort, between year total mortality coefficients, Z, were estimated using Paloheimo's method (Ricker, 1975 p. 171-172) (Table 11). These were not corrected for yearly rather than between year estimates as only starting values were desired.

Since only estimates of fully recruited F are required, some idea of the PR pattern is necessary. For the first run, this was obtained by examination of the catch-curves which showed that recruitment is probably complete by age 5. A simple PR pattern was made by assuming a linear increase in PR from ages 1 through 5 and flat thereafter (Figure 9a).

From the PR curve, recruitment was assumed to be complete for age 5-8. Therefore the arithmetic mean Z for these age groups was used in each year. F was estimated by subtracting 0.2. for natural mortality. The 1988 F was assumed to be the same as that in 1987.

4.3. THE SPA RUNS

4.3.1. The First Run: The first SPA (in this case CA) run was undertaken using the above F_B values and the PR x 1988 F_B for the F_E values. Upon completion of this run, the historical partial recruitment pattern for 1979-83 was calculated and using the procedures in Section 3.4.2. a mean recruitment pattern generated (Figure 9b). Recruitment drops off in the older ages. As well, fish appear to be fully recruited only for ages 5-7. Therefore, in all later runs, this recruitment pattern was used with the recruitment values for ages 11 and 12 taken, by eye from Figure 9, as 0.65 and 0.60 respectively.

4.3.2. The First Set of Iterations of F_B: The weighted (on population numbers) fishing mortality for ages 5-7 was calculated using the first SPA results. These were multiplied by 0.6 (See Section 4.3.1.) and a second run made. The F_E value was input as the new PR pattern times the previous fully recruited F for 1988.

Three iteration were carried out, with changes only being made in the F_B rather than F_E values. The changes in the terminal F_B values were very small (Table 12) and convergence occurred rapidly.

The first F vs. E plot made using the weighted (on population numbers) F for ages 5-7 and the generated "real" effort series (Figure 10) showed that the F_E value was too high. The SPA was rerun with an F_E of 0.4.

4.3.3. The Second Set of Iterations of F_B: Changing the F_E values from 0.581 to 0.400 affects the F_B values also, particularly those for 1984-1987. Thus, before examining another F vs. E plot with F_E = 0.400, the same iteration process as outlined above was followed for F_B. The changes in F_B were again minor (Table 13). However it is important to note that, a change in F_E will almost always demand changes in F_B.

The resulting F vs. E. plot was good (Figure 11). The regression equation was,

$$F = 0.172 + 0.00178\ E \quad R^2 = 0.71,\ p < 0.05$$

However, the 1981 and 82 points are not being predicted adequately (Figure 11). At this stage other sources of data, such as research surveys, would be useful in the choice of a new F_E. Here, trial runs were made with F_E = 0.3.

4.3.4. The Third Set of Iterations of F_B: As before, the F_B values were allowed to stabilize before plotting F versus E. Again, convergence was rapid (Table 14). The regression for the relationship was,

$$F = 0.107 + 0.0019\ E \quad R^2 = 0.739,\ p < 0.05$$

A run made at F_E = 0.2 gave a poor relationship. For this exercise, F_E = 0.3 was taken as the first terminal fishing mortality.

4.4. FINAL CALCULATION OF THE PARTIAL RECRUITMENT PATTERN AND THE FINAL SPA RUN

The historical (1979-83) partial recruitment pattern was again calculated for the last SPA run. This vector is compared to the one used to create the catch-at-age (Figure 12). Except at the oldest ages, there is a close agreement between the two vectors.

The last PR curve, the F_B values and F_E = 0.3 were used to make the final SPA run (Table 15). The regression equation for the F vs. E relationship was,

$$F = 0.107 + 0.0019\ E \quad R^2 = 0.744,\ p < 0.05$$

Interestingly enough, this is idential with the relationship calculated on the original, generated data set (Figures 13 and 14). Comparison of the results (Table 15) with the original data (Tables 8-10) reveals that the above procedure estimated the population reasonably well.

The most important point in the above process is that there is constant adjustment made to all input parameters throughout.

5. SUMMARY

The techniques used to generate fishing mortalities for both the oldest ages and the most recent fishing year, as well as partial recruitment patterns are outlined. An example assessment was run to illustrate how some of the procedures interact during the analytical process.

The process can be quite involved and often the order in which procedures are used can influence the final outcome. Thus, when carrying out an assessment, it is most important to document which procedures were used and how they were employed. This should be a minimum requirement for all assessment reports.

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Table 1. Use of Virtual Population Analysis (VPA) and Cohort Analysis (CA) in CAFSAC groundfish and pelagic stock assessments, 1977-80. (NU = Not Used)

Species	Stock	Area	1977	1978	1979	1980
COD	2GH	Northern Labrador	-	-	-	NU
	3Ps	St. Pierre B.	CA	CA	CA	CA
	4RS + 3Pn	N.E. Gulf of St. Lawrence	NU	CA	CA	CA
	4Vn (May - Dec.)	Sydney B.	NU	NU	NU	NU
	4T - 4Vn	Gulf of St. Lawrence	CA	CA	CA	CA
	4VsW	Banquereau - Sable	CA	CA	CA	CA
	4X	Brown's B.	NU	NU	NU	NU
POLLOCK	4VWX + SA5	Scotian Shelf & George's B.	NU	CA	CA	CA
HADDOCK	4VW	Banquereau - Sable	NU	NU	NU	NU
	4X	Brown's B.	CA	CA	CA	CA
REDFISH	2 + 3K	Labrador - N.E. Nfld.	-	NU	NU	NU
	3O	S.W. Grand B.	-	NU	NU	NU
	3P	St. Pierre B.	CA	CA	CA	CA
	4RST	Gulf of St. Lawrence	CA	CA	CA	CA
	4VWX	Scotian Shelf	NU	NU	NU	NU
WHITE HAKE	4T	Gulf of St. Lawrence	-	-	-	NU
	4VWX	Scotian Shelf	-	-	-	-

Table 1. (CONTINUED)

Species	Stock	Area	1977	1978	1979	1980
AMERICAN PLAICE	2 + 3K	Labrador & N.E. Nfld.	-	NU	NU	NU
	4T	Gulf of St. Lawrence	NU	CA	CA	CA
	3Ps	St. Pierre B.	CA	CA	CA	CA
WITCH	3Ps	St. Pierre B.	NU	NU	NU	NU
	4Rs	Gulf of St. Lawrence	NU	NU	NU	NU
FLATFISH	4VWX	Scotian Shelf	NU	NU	NU	NU
GREENLAND HALIBUT	4RST	Gulf of St. Lawrence	-	-	NU	NU
HERRING		E. Nfld.	CA	CA	CA	CA
		W. Nfld.	CA	CA	CA	CA
		S. Nfld	-	-	-	-
	4T - 3Pn	Gulf of St. Lawrence	CA	CA	CA	CA
	4WX	Scotian Shelf	CA	CA	CA	CA
	4V	Sydney B.	NU	NU	NU	NU
MACKEREL	3 - 6	Northwest Atlantic	CA	CA	CA	VPA
CAPELIN	4T	Gulf of St. Lawrence	NU	-	NU	NU

Table 2. Value of e^{-z} with number of lumped years and Z value.

number of lumped years of catch	Z value .3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2
1	0.741	0.670	0.607	0.549	0.497	0.449	0.407	0.368	0.333	0.301
2	0.549	0.449	0.368	0.301	0.247	0.202	0.165	0.135	0.111	0.091
3	0.407	0.301	0.223	0.165	0.122	0.091	0.067	0.050	0.037	0.027
4	0.301	0.202	0.135	0.091	0.061	0.041	0.027	0.018	0.012	0.008
5	0.223	0.135	0.082	0.050	0.030	0.018	0.011	0.007	0.004	0.002
6	0.165	0.091	0.050	0.027	0.015	0.008	0.005	0.002	0.001	0.001
7	0.122	0.061	0.030	0.015	0.007	0.004	0.002	0.001	0.000	0.000
8	0.091	0.041	0.018	0.008	0.004	0.002	0.001	0.000	0.000	0.000
9	0.067	0.027	0.011	0.005	0.002	0.001	0.000	0.000	0.000	0.000
10	0.050	0.018	0.007	0.002	0.001	0.000	0.000	0.000	0.000	0.000

Table 3. Value of population estimate, N, with number of lumped years and Z value

number of lumped years of catch	Z value .3	.4	.5	.6	.7	.8	.9	1.0	1.1	1.2
1	1157	607	424	332	278	242	217	198	183	172
2	665	363	264	215	186	167	154	145	137	132
3	506	286	215	180	160	147	138	132	127	123
4	429	251	193	165	149	139	132	127	124	121
5	386	231	182	158	144	136	130	126	123	120
6	359	220	175	154	142	134	129	125	122	120
7	342	213	172	152	141	134	129	125	122	120
8	330	208	170	151	141	134	129	125	122	120
9	322	206	169	151	140	133	129	125	122	120
10	316	204	168	150	140	133	129	125	122	120

Table 4. Procedures used by CAFSAC (1977-80) to generate instantaneous fishing mortalities of the oldest age groups. (NS = not specified in assessment)

Specie	Stock	Area	1977	1978	1979	1980
COD	3Ps	St. Pierre B.	NS	Vague	F's from Prev. assessment	NS
	4RST	N.E. Gulf of St. Lawrence	-	Vague	NS	NS
	4T-4Vn	Gulf of St. Lawrence	Iteration Procedure plus PR	Iteration Procedure plus PR	NS	NS
	4VsW	Banquereau - Sable	NS	Regression Relationships	Regression Relationships	NS
POLLOCK	4VWX	Scotian Shelf	Catch Curves	NS	F's from Prev. assessment	NS
HADDOCK	4VW	Banquereau - Sable	-	-	-	Iteration Procedure
	4X	Brown's B.	Catch Curves & Iteration Procedure	F's from Prev. assessment	F's from Prev. assessment	Iteration Procedure plus PR
REDFISH	2+3K	Labrador - N.E. Nfld.	-	-	-	NS
	3P	St. Pierre B.	NS	NS	NS	NS
	4RST	Gulf of St. Lawrence	Based on Preliminary Run	NS	NS	NS
AMERICAN PLAICE	4T	Gulf of St. Lawrence	-	NS	NS	NS
	3Ps	St. Pierre B.	NS	NS	NS	NS
HERRING		E. Nfld.	Paloheimo Z	NS	NS	NS
		W. Nfld.	NS	NS	NS	NS
	4T-3Pn	Gulf of St. Lawrence	Vague	NS	NS	NS
	4WX	Scotian Shelf	Based on Preliminary Run	Iteration Procedure	Iteration Procedure	NS
MACKEREL	3-6	Northwest Atlantic	NS	NS	NS	NS

Table 5. Procedures used by CAFSAC (1977-80) to generate instantaneous fishing mortalities for the fully recruited age groups in the most recent fishing year. (NS = not specified in assessment)

Species	Stock	Area	1977	1978	1979	1980
COD	3Ps	St. Pierre B.	NS	Paloheimo Z & F vs E	F vs E	F vs E & CPUE vs BIO
	4RST	N.E. Gulf of St. Lawrence	-	Vague	CPUE vs BIO	CPUE vs BIO
	4T-4Vn	Gulf of St. Lawrence	F vs E	F vs E	CPUE vs BIO	CPUE vs BIO
	4VsW	Banquereau - Sable	NS	F vs E & CPUE vs BIO	N. Res vs N. SPA	N. Res. vs N. SPA
POLLOCK	4VWX	Scotian Shelf	Vague	Constant q & F	Constant q & F	F vs E, CPUE vs BIO & N. Res vs N. SPA
HADDOCK	4VW	Banquereau - Sable	-	-	-	N. Res vs N. SPA
	4X	Brown's B.	Paloheimo Z & N. Res. vs N. SPA	Paloheimo Z & F vs E & CPUE vs BIO N. Res. vs N. SPA	Paloheimo Z & F vs E CPUE vs BIO N. Res. vs N. SPA	Paloheimo Z CPUE vs BIO N. Res vs N. SPA
REDFISH	2+3K	Labrador - N.E. Nfld.	-	-	-	CPUE vs BIO
	3P	St. Pierre B.	NS	F vs E	F vs E & CPUE vs BIO	F vs E, N. Res. vs N. SPA
	4RST	Gulf of St. Lawrence	F vs E	F vs E & CPUE vs BIO	F vs E & CPUE vs BIO	CPUE Res. vs BIO SPA
AMERICAN PLAICE	4T	Gulf of St. Lawrence	-	F vs E	F vs E & CPUE vs BIO	F vs E, CPUE vs BIO & N. Res vs N. SPA
	3Ps	St. Pierre B.	F vs E	NS	F vs E	CPUE vs BIO N. Res. vs N. SPA
HERRING		E. Nfld.	Paloheimo Z	Paloheimo Z	Paloheimo Z	Paloheimo Z
		W. Nfld.	F vs E	Paloheimo Z & F vs E	Paloheimo Z & F vs E	CPUE vs BIO
HERRING	4T-3Pn	Gulf of St. Lawrence	F vs E	F vs E	F vs E	F vs E & CPUE vs
	4WX	Scotian Shelf	Vague	F vs E	F vs E & CPUE vs BIO	F vs E & CPUE vs BIO
MACKEREL	3-6	Northwest Atlantic	NS	NS	CPUE vs BIO & N. Res. vs N. SPA	CPUE vs BIO & N. Res. vs N. SPA

Table 6. Procedures used by CAFSAC (1977-80) to generate the partial recruitment pattern experienced by the stock in the most recent exploited year. (NS = not specified in assessment)

Specie	Stock	Area	1977	1978	1979	1980
COD	3Ps	St. Pierre B.	NS	NS	Rec. Res. vs Res. SPA Hist. Avg.	% Com./% Res. Hist. Avg.
	4RST	N.E. Gulf of St. Lawrence	-	Vague	NS	% Com./% Res. Hist. Avg.
	4T-4Vn	Gulf of St. Lawrence	Cohort Method	Cohort Method	Rec. Res. vs Rec. SPA	Rec. Res. vs Rec. SPA
	4VsW	Banquereau - Sable	NS	Vague	Ratio Method	Ratio Method & % Com./% Res.
POLLOCK	4VWX	Scotian Shelf	Vague	Hist. Avg.	Previous	Rec. Res. vs Res. SPA
HADDOCK	4VW	Banquereau - Sable	-	-	-	Hist. Avg.
	4X	Brown's	Cohort Method	Adj. Hist. Avg. Rec. Res. vs Rec. SPA	Previous & Rec. Res. vs Rec. SPA	Previous & Res. Res. vs Res. SPA
REDFISH	2+3K	Labrador & N.E. Nfld.	-	-		% Com./% Res.
	3P	St. Pierre B.	NS	Hist. Avg.	% Com./% Res.	% Com./% Res.
	4RST	Gulf of St. Lawrence	NS	Hist. Avg.	% Com./% Res.	% Com./% Res.
AMERICAN PLAICE	4T	Gulf of St. Lawrence	-	Rec. Res. vs Rec. SPA	Rec. Res. vs Res. SPA	Rec. Res. vs Rec. SPA
	3Ps	St. Pierre B.	Hist. Avg.	Hist. Avg.	Hist. Avg.	Hist. Avg. & % Com./& Res.
HERRING		E. Nfld	Vague	Previous	Previous	Previous
		W. Nfld	Hist. Avg.	Hist. Avg.	Previous	Hist. Avg. & % Total/% PS
	4T-3Pn	Gulf of St. Lawrence	Hist. Avg.	% Total/% PS	% Total/% PS	% Total/% PS
	4WX	Scotian Shelf	Previous	Previous	Hist. Avg.	Hist. Avg. & Rec. Adj.
MACKEREL	3-6	Northwest Atlantic	NS	Vague	% Total/& Maritime & Rec. Res. vs Rec. SPA	Hist. Avg.

Table 7. Parameters used in catch projection to create hypothetical stock and its fishery.

AGE	Population Numbers x 10^{-3} in 1979	Catch Numbers x 10^{-3} in 1979	Partial Recruitment for 1979-88
1	12170	0	0.0001
2	41214	97	0.008
3	27613	1729	0.220
4	36317	6723	0.700
5	15413	3897	1.000
6	5173	1308	1.000
7	6145	1487	0.950
8	1681	377	0.870
9	394	73	0.700
10	384	59	0.570
11	81	14	0.650
12	7	1	0.540

Table 8. Simulated numbers-at-age matrix.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	12170	12687	84227	66435	27468	30150	50930	65413	207671	84441
2	41214	9964	10387	68955	54389	22488	24683	41695	53553	170019
3	27613	33656	8130	8467	56165	44284	18309	20104	33986	43692
4	36317	21048	25031	5888	6013	39474	31123	13003	14562	25276
5	15413	23684	12693	13876	3067	3029	19884	16208	7209	8781
6	5173	9118	12529	5954	5952	1255	1239	8529	7602	3813
7	6145	3061	4824	5876	2554	2435	514	532	4001	4021
8	1681	3695	1655	2327	2604	1082	1032	228	257	2163
9	394	1038	2069	835	1086	1166	485	482	115	144
10	384	257	626	1147	435	547	588	253	267	70
11	81	262	164	373	650	240	302	333	151	171
12	7	54	162	94	201	339	125	163	190	93

Table 9. Simulated catch-at-age matrix.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0	1	5	4	2	2	3	4	9	3
2	97	32	42	323	273	113	116	169	170	370
3	1729	2800	852	1020	7226	5697	2205	2107	2827	2532
4	6723	5052	7374	1957	2114	13877	10344	3831	3495	4355
5	3897	7652	4960	6052	1407	1390	8672	6333	2329	2074
6	1308	2946	4895	2597	2731	576	541	3333	2456	901
7	1487	949	1813	2469	1130	1077	216	200	1240	909
8	377	1066	581	916	1081	449	406	80	74	453
9	73	249	610	278	382	410	161	142	28	25
10	59	52	156	323	130	163	165	63	54	10
11	14	59	46	117	216	80	95	93	34	28
12	1	11	39	26	58	87	34	39	37	13

Table 10. Simulated instantaneous fishing mortality matrix.

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.003	0.003	0.004	0.005	0.006	0.006	0.005	0.004	0.003	0.002
3	0.071	0.096	0.123	0.142	0.153	0.153	0.142	0.123	0.096	0.066
4	0.228	0.306	0.390	0.452	0.486	0.586	0.452	0.390	0.306	0.210
5	0.325	0.437	0.557	0.646	0.694	0.694	0.646	0.557	0.437	0.300
6	0.325	0.437	0.557	0.646	0.694	0.694	0.646	0.557	0.437	0.300
7	0.309	0.415	0.529	0.614	0.659	0.659	0.614	0.529	0.415	0.285
8	0.283	0.380	0.485	0.562	0.604	0.604	0.562	0.485	0.380	0.261
9	0.228	0.306	0.390	0.452	0.486	0.486	0.452	0.390	0.306	0.210
10	0.185	0.249	0.318	0.368	0.396	0.396	0.368	0.318	0.249	0.171
11	0.211	0.284	0.362	0.420	0.451	0.451	0.420	0.362	0.284	0.195
12	0.171	0.236	0.301	0.349	0.375	0.375	0.349	0.301	0.236	0.162

Table 11. Total mortality coefficients as calculated by Paloheimo's method.

	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87	1987/88
1/2	-7.659	-3.233	-3.849	-4.511	-3.985	-4.195	-4.027	-3.970	-3.945
2/3	-3.182	-2.778	-2.871	-3.395	-2.989	-3.105	-2.895	-3.037	-2.929
3/4	-0.891	-0.464	-0.512	-1.016	-0.603	-0.731	-0.548	-0.726	-0.661
4/5	0.052	0.523	0.517	0.042	0.468	0.336	0.495	0.278	0.293
5/6	0.461	0.951	0.966	0.508	0.942	0.810	0.960	0.727	0.721
6/7	0.502	0.990	1.004	0.544	0.980	0.847	0.999	0.769	0.766
7/8	0.514	0.995	1.002	0.538	0.972	0.842	0.997	0.774	0.779
8/9	0.596	1.062	1.056	0.587	1.019	0.892	1.055	0.830	0.857
9/10	0.520	0.972	0.955	0.472	0.901	0.776	0.942	0.747	0.801
10/11	0.181	0.627	0.607	0.115	0.535	0.406	0.578	0.397	0.428
11/12	0.422	0.918	0.890	0.414	0.850	0.722	0.895	0.702	0.733

Table 12. F_B values generated during first set of iterations (F_E = 0.581).

Iteration	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0.200	0.268	0.344	0.401	0.443	0.459	0.451	0.436	0.407	0.349
2	0.196	0.265	0.339	0.396	0.435	0.447	0.444	0.429	0.400	0.344
3	0.195	0.265	0.339	0.396	0.435	0.447	0.444	0.429	0.400	0.344

Table 13. F_B values generated during second set of iterations (F_E = 0.400).

Iteration	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0.195	0.265	0.339	0.396	0.435	0.447	0.444	0.429	0.400	0.344
2	0.195	0.265	0.339	0.393	0.427	0.431	0.418	0.381	0.321	0.237
3	0.195	0.263	0.336	0.390	0.425	0.431	0.418	0.381	0.321	0.237

Table 14. F_B values genereated during third set of iterations (F_E = 0.300)

Iteration	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0.195	0.263	0.336	0.391	0.425	0.431	0.418	0.381	0.320	0.180
2	0.195	0.263	0.335	0.386	0.414	0.414	0.393	0.340	0.264	0.180
3	0.194	0.262	0.333	0.385	0.414	0.414	0.393	0.340	0.264	0.180

Table 15. Final SPA population numbers and fishing mortality at age (F_E = 0.3).

POPULATION NUMBERS

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	12293	12809	84859	66835	27608	30225	51111	65399	208879	103962
2	41610	10064	10487	69472	54717	22601	24745	41944	53950	171008
3	27950	33979	8211	8548	56587	44551	13402	20154	34106	44017
4	36582	21287	25296	5952	6075	39791	31321	13071	14595	25366
5	15497	23868	12817	14030	3102	3061	20022	16288	7235	8787
6	5185	9162	12617	6005	6011	1257	1249	8546	7601	3815
7	6122	3062	4885	5901	2567	2450	516	533	3981	4001
8	1663	3667	1648	2318	2597	1079	1032	227	255	2137
9	399	1020	2038	824	1069	1149	477	477	118	142
10	370	253	610	1116	423	530	569	245	262	67
11	80	250	160	358	622	228	296	917	144	166
12	6	52	151	89	187	314	115	148	175	87
	147647	119423	163718	181449	161565	147247	149844	167745	331297	363456

FISHING MORTALITY

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.003	0.004	0.004	0.005	0.006	0.006	0.005	0.004	0.003	0.002
3	0.071	0.095	0.122	0.141	0.152	0.152	0.142	0.123	0.096	0.065
4	0.227	0.305	0.889	0.452	0.485	0.487	0.454	0.391	0.307	0.209
5	0.325	0.437	0.558	0.648	0.696	0.697	0.651	0.562	0.440	0.300
6	0.327	0.489	0.560	0.650	0.697	0.698	0.652	0.564	0.442	0.300
7	0.313	0.419	0.585	0.261	0.667	0.665	0.621	0.536	0.422	0.287
8	0.288	0.888	0.494	0.574	0.616	0.616	0.571	0.484	0.335	0.265
9	0.232	0.814	0.402	0.467	0.502	0.502	0.467	0.399	0.319	0.215
10	0.194	0.253	0.382	0.385	0.415	0.416	0.386	0.334	0.258	0.178
11	0.216	0.808	0.383	0.448	0.484	0.489	0.457	0.392	0.303	0.205
12	0.194	0.262	0.333	0.385	0.414	0.414	0.393	0.340	0.264	0.180
	0.133	0.229	0.181	0.128	0.140	0.222	0.216	0.135	0.050	0.039

Figure 1. The Cohort Method - construction of age-length sample for all years.

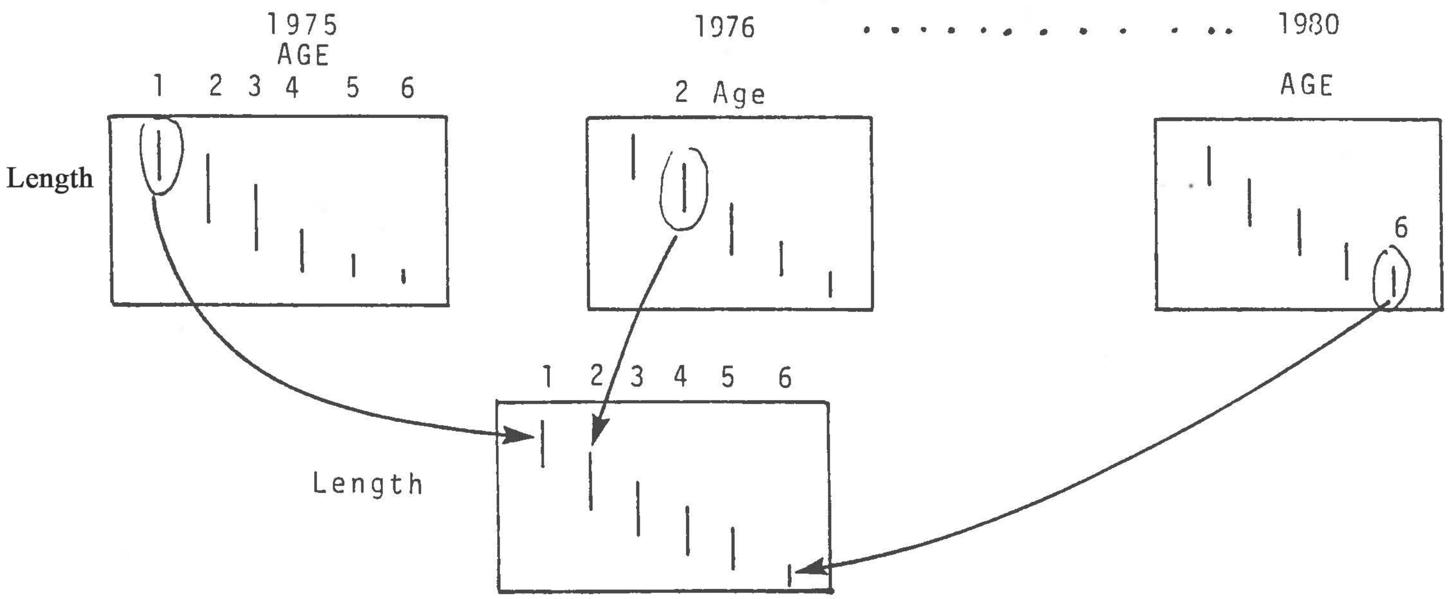


Figure 2. The Cohort Method - the combined age-length sample

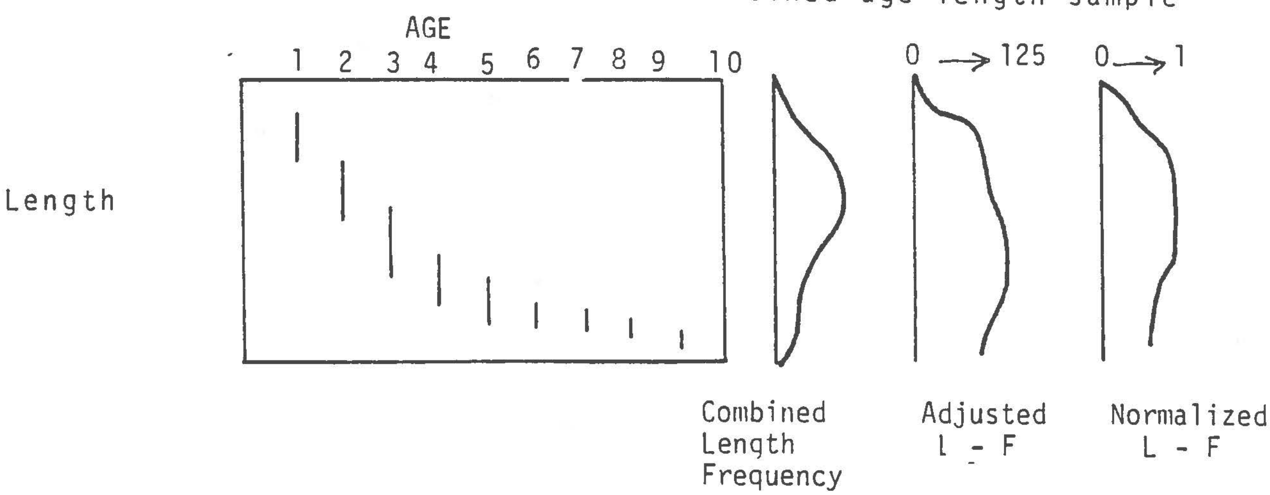
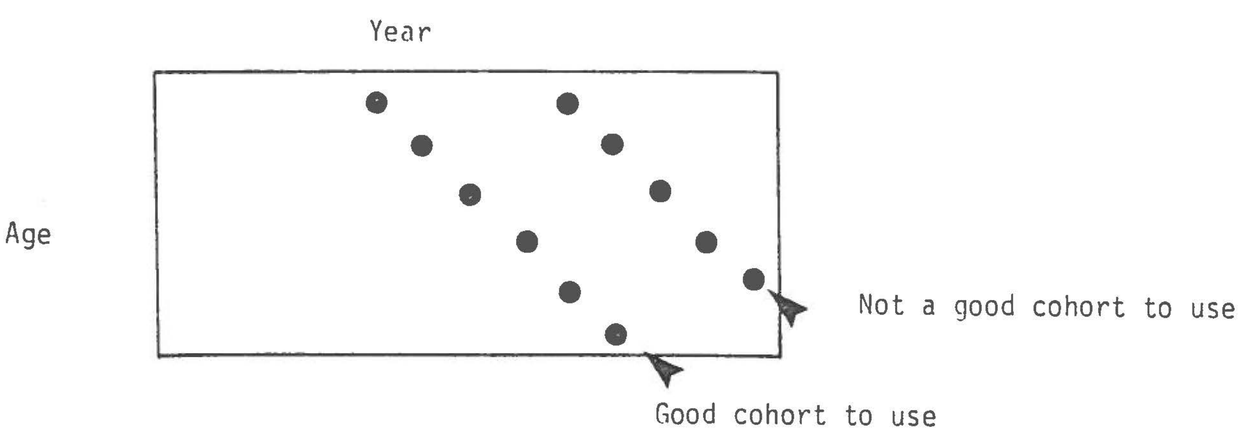


Figure 3. The Cohort Method - the SPA



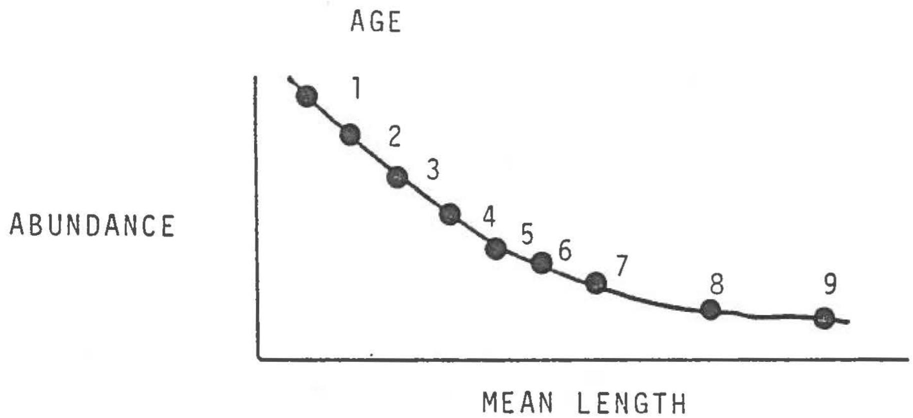


Figure 4. The Cohort Method - Mean Length vs Abundance

Figure 5. Comparison of survey and SPA recruitment estimates. - Unnormalized method.

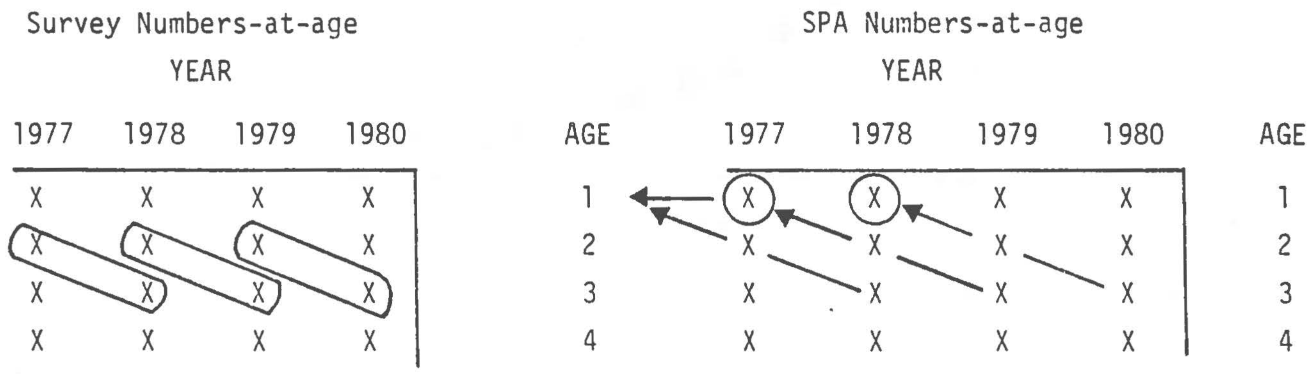
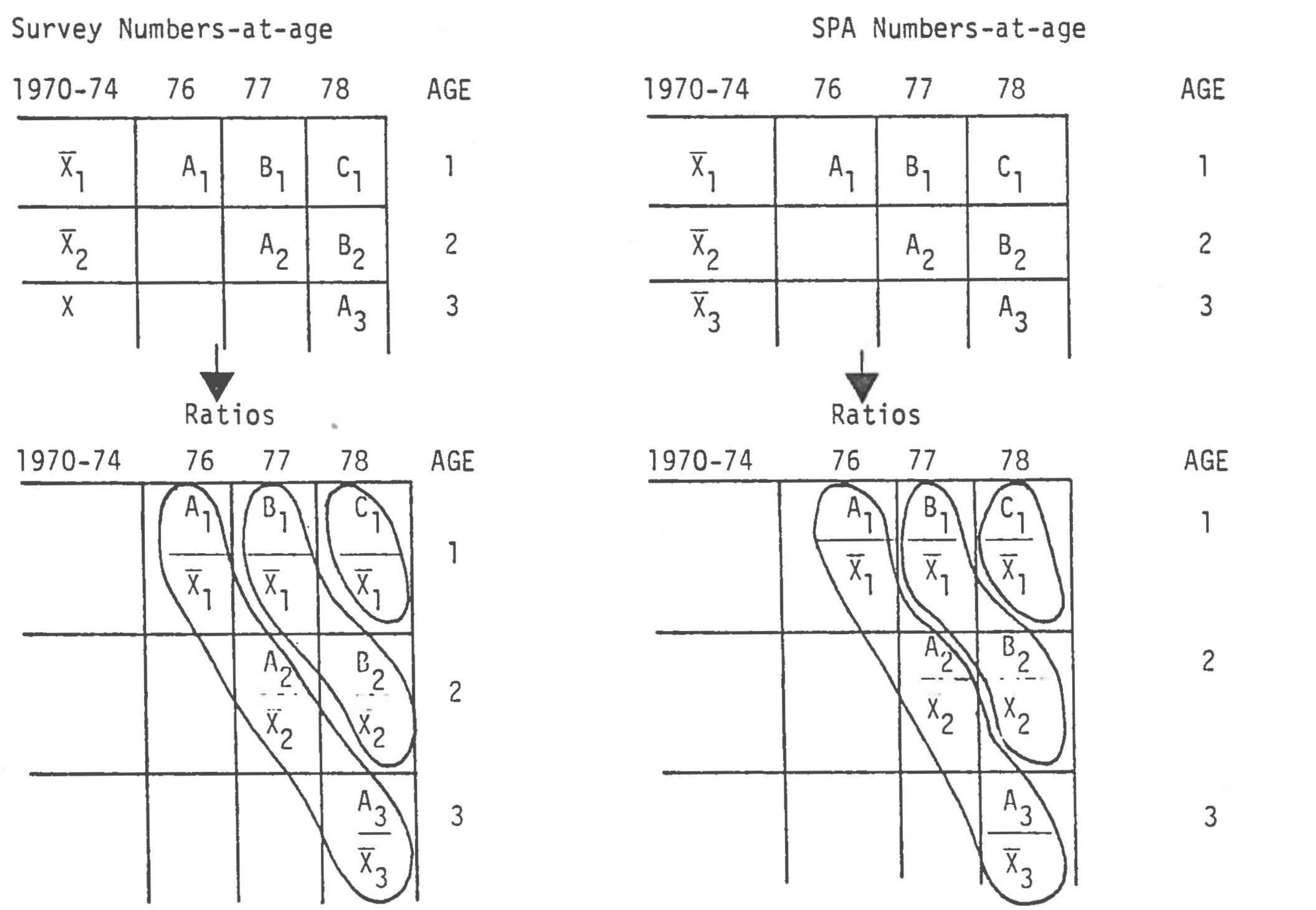


Figure 6. Comparison of survey and SPA recruitment estimates - normalized method.



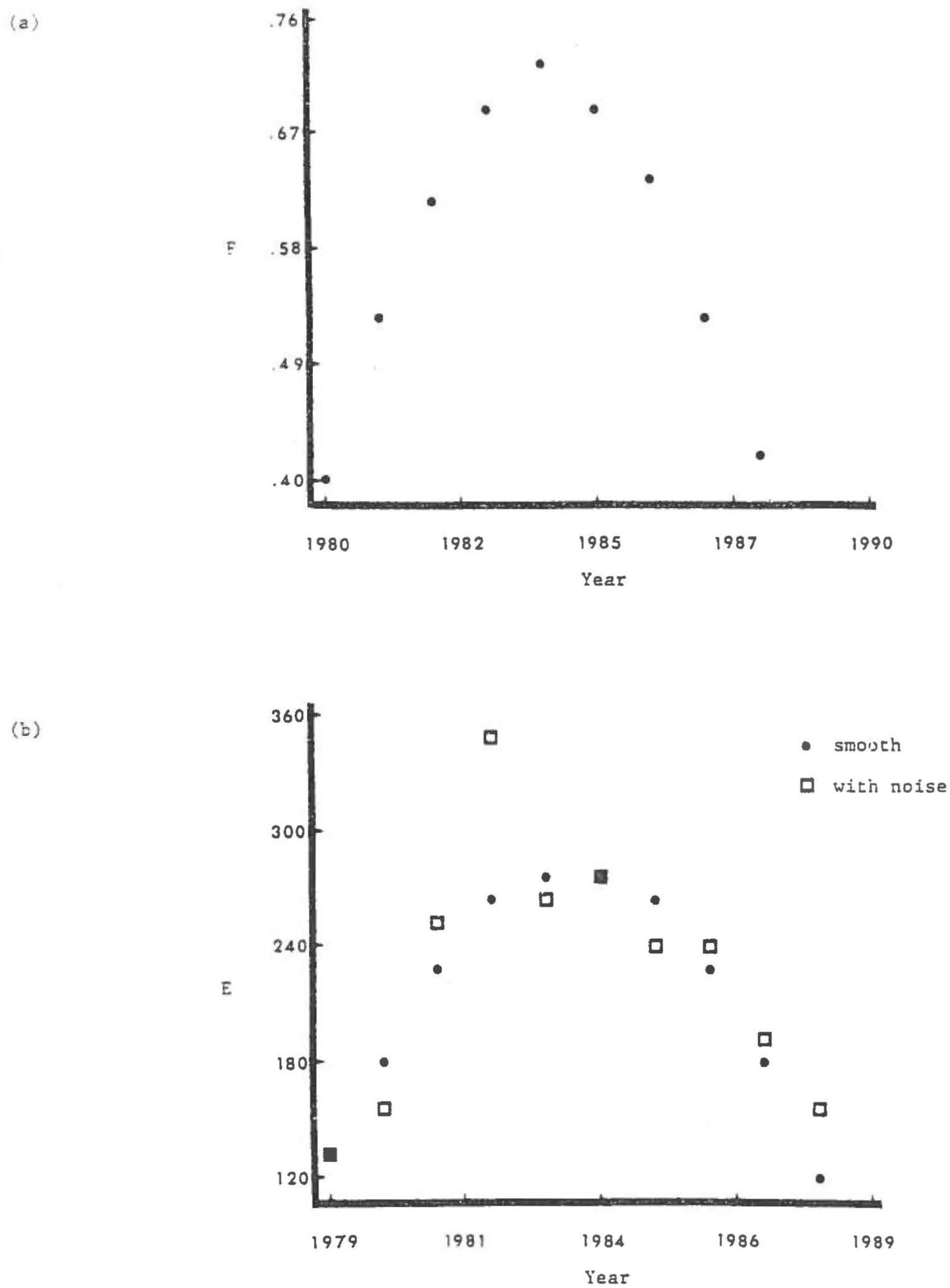


Figure 7. Relationship between F and time (a) and effort and time (b) used in creation of population.

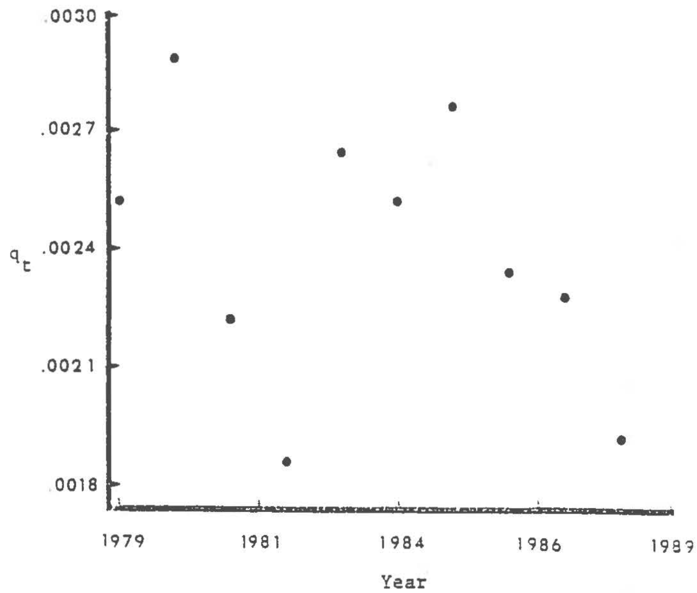
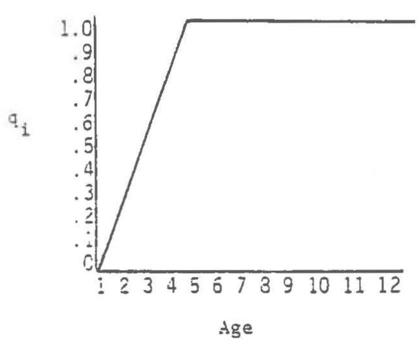


Figure 8. Trend in real q_t over 1979-1988.



Age	1	2	3	4	5	6	7	8	9	10
q_i	0.001	0.25	0.5	0.75	1.00	1.00	1.00	1.00	1.00	1.00

Figure 9a. Initial partial recruitment pattern employed.

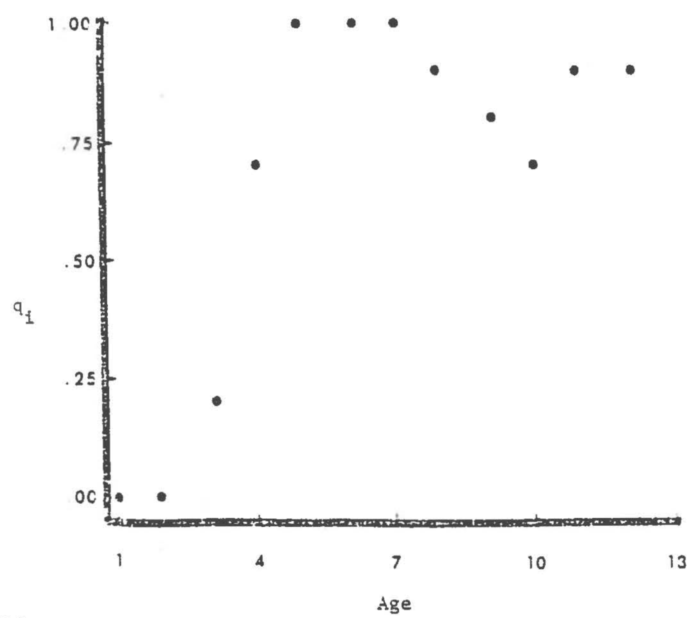


Figure 9b. Partial recruitment pattern generated by first SPA run.

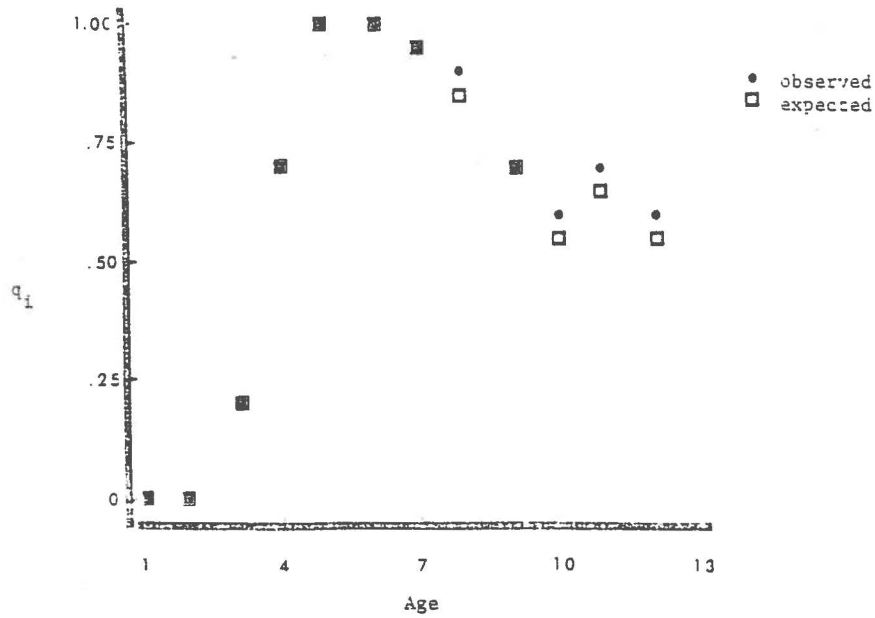


Figure 12. Final partial recruitment pattern derived from the SPA (F_B = 0.3).

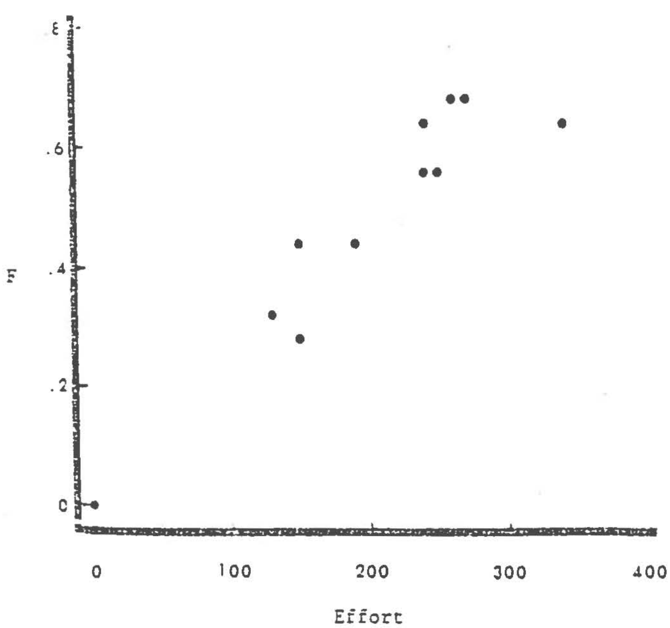


Figure 13. F vs E for final SPA fun (F_E = 0.30).

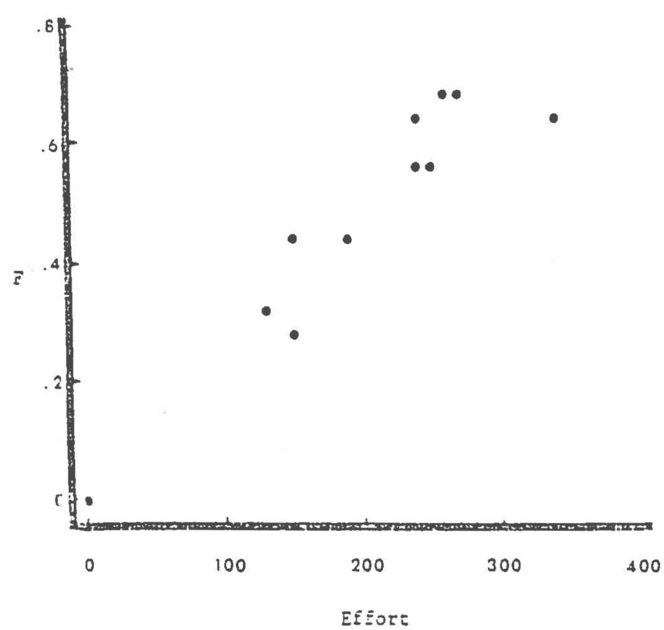
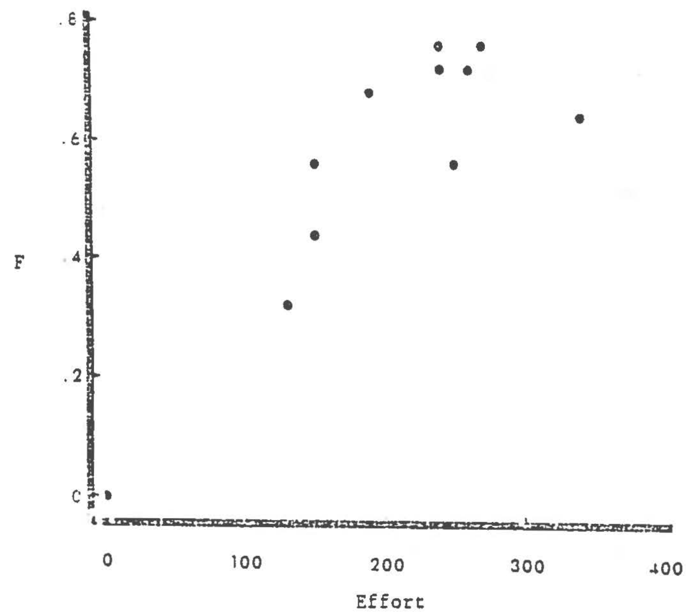
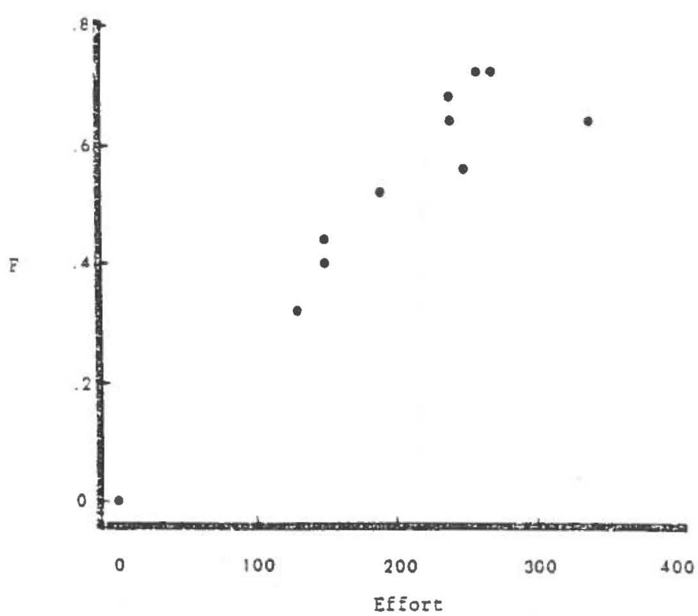


Figure 14. F vs E for original data set.



Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
FWT	0.326	0.441	0.565	0.660	0.725	0.746	0.740	0.715	0.667	0.574
EFF	126	151	250	344	258	271	237	238	191	152

Figure 10. F vs E plot after first set of iterations (F_E = 0.581).



Year	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
FWT	0.324	0.439	0.560	0.651	0.703	0.713	0.697	0.635	0.534	0.395
EFF	126	151	250	344	258	271	237	238	191	152

Figure 11. F vs E plot after second set of iteration (F_E = 0.400).