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SENSITIVITY OF CAL (PARRACK 1986), A METHOD FOR ANALYZING CATCHES AND ABUNDANCE INDICES FROM A FISHERY

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SUMMARY

Sensitivity of CAL (Parrack 1986), a tuning procedure for VPA estimates of stock sizes developed from age-specific catches to observed indices of abundance (CPUE), was assessed using deterministic and stochastic simulations. Little inherent bias (<2 percent) in estimates of fishing mortality rate F (age-7 in 1985) was found during the deterministic simulations. Stochastic simulation results suggest the CPUE index based on ages 3-5 summed is generally preferable to CPUE indices based on ages 6-9 and 10-30 summed or to mixing ages in CPUE indices if q is constant. CPUE indices should include most recent years, older index years do not contribute appreciably to calibration process. Recruits to age-1 in 1986 greater than about 85,000 are shown to be detectable in 1988 with CPUE index based on ages 3-5 with relatively large background lognormal error.

RESUME

La sensitivité de CAL (Parrack 1986), une procédure d'ajustement pour estimer les VPA des tailles de stock développées à partir des prises spécifiques de l'âge pour observer les indices de l'abondance (CPUE), a été évaluée en utilisant des simulations déterministiques et stochastiques. Peu de biais inhérents (< 2 %) dans les estimations du taux de mortalité par pêche F (âge 7 en 1985) ont été trouvés durant les simulations déterministiques. Les résultats de simulation stochastique suggèrent que l'indice de CPUE basé sur les âges 3-5 additionnés est en général préférable aux indices de CPUE basés sur les âges 6-9 et 10-30 additionnés ou aux âges mélangés dans les indices de CPUE si q est constant. Les indices de CPUE devraient inclure les années les plus récentes, l'indice des années les plus arriérées ne contribuent pas, d'une façon appréciable, au traitement de calibration. Les recrutements à l'âge 1 de 1986, qui représentent plus de 85.000 ,sont détectables en 1988 avec un indice de CPUE basé sur les âges 3-5 avec des erreurs lognormal relativement importantes.

RESUMEN

Se evaluó la sensibilidad del CAL (Parrack, 1986), un procedimiento de ajuste de las estimaciones VPA de tamaños del stock, desarrollado a partir de capturas específicas de la edad a índices observados de abundancia (CPUE), empleando simulaciones deterministas y estocásticas. Se encontró un escaso sesgo inherente (<2%) en estimaciones de la tasa F de mortalidad por pesca (edad-7 en 1985) durante las simulaciones deterministas. Los resultados de la simulación estocástica sugieren que el índice de CPUE basado en las edades 3-5, sumadas, es generalmente preferible a los índices de CPUE basados en edades 6-9 y 10-30 sumados, o a los índices de CPUE de edades mezcladas si q es constante. Los índices de CPUE deberían incluir los años más recientes; los índices de años antiguos no contribuyen, de forma apreciable, al proceso de calibración. Los reclutamientos a la edad 1 en 1986, superiores, aproximadamente, a 85.000, han demostrado ser detectables en 1988 con índice CPUE basado en edades 3-5 con error logarítimico-normal relativamente importante.

INTRODUCTION

Parrack (1986) describes a procedure (CAL) for calibrating virtual population analysis estimates of stock size and fishing mortality rates developed from age-specific catches to observed indices of abundance (i.e., catch per unit effort, CPUE) and demonstrates this procedure with Lake Opeongo lake trout data from Fry (1949). Given some criticism of this approach (Nagai and Miyabe 1986), a computer simulation study was initiated to investigate the sensitivity of this procedure to error in the input parameters and to assumptions concerning the form of the CPUE indices.

The types of computer simulations fall into two general areas: deterministic and stochastic. The deterministic simulations show whether CAL can recover the correct estimates of stock size and fishing mortality rates under various scenarios, but with no stochastic error. Subsequent stochastic simulations show the effect of increasing error in one of the components of input data (i.e., catch matrix, partial recruitment vector, or CPUE indices) on the accuracy (bias: estimated value minus true value) and precision (dispersion: 75th percentile minus 25th percentile) of estimates of stock size or fishing (and natural) mortality rate.

Important statistics for several output parameters are obtained from the stochastic simulations and discussed in this report. Output parameters retained include F at age-7 for final fishing year (1985), total sum of squares from CPUE tuning, and correlation between observed and estimated CPUE for each abundance index. Estimated natural mortality rate (M) is retained for one set of simulations, while recruits to age 1 in 1986 (N) is retained for another set of simulations.

METHODS

CAL employs an iterative grid search procedure for determining the level of F (and M) at which the minimum total sum of squares occurs. The range of F (and M) examined are defined by the user as is the number of decimal places searched. F was searched from 0.0 to 3.0, and when M was estimated, it was searched from -0.1 to 1.0. Searches were conducted to the second decimal place. Because CAL first searches the total sum of square surface at the first decimal place, and subsequently conducts a finer search at higher decimal places, CAL can search negative values of F. Negative F's produce negative estimates of population size and cause the program to terminate. Code was added to CAL to insure that only F's of 0 (0.00000001) and above were searched.

The original data set is that used by ICCAT's SCRS in 1986 for its final west Atlantic bluefin tuna analyses and consists of a catch matrix (ages 1-30 and fishing years 1970-85), partial recruitment vector (the vector M1 for ages 1-30 in 1985), natural mortality rate (M = 0.1/yr), and five sets of CPUE indices (ICCAT 1987). As a basis for development of all subsequent deterministic and stochastic simulations, an initial computer run was made using the original catch matrix, M, CPUE's, and a smoothed, domed-shape partial recruitment vector in place of the original partial recruitment vector (Fig. 1). The resulting estimated numbers at age was subsequently used as the "known" stock size and the estimate of F for age-7 in 1985 (hereafter referred to simply as F) served as the basis for estimating bias in F (estimated F minus "true" F determined from this deterministic computer run) for all simulations using the same smoothed, dome-shaped partial recruitment vector.

CPUE indices for this study were created directly from the "known" stock size. Abundances were summed over three age ranges (3-5, 6-9 or 10-30 years old) and divided by 200,000, so that the CPUE index values generally fell in the range 0.1 to 1.0.

Deterministic Solutions

Several deterministic solutions were made to determine the effect on the estimate of F (or F and M) when perfect or nearly perfect information was used. For these simulations no random variation was introduced into the catch matrix, CPUE indices, or the partial recruitment vector.

Deterministic simulations were made exploring M, the natural mortality rate. First, simulations were made by changing the fixed value of M used in the basic deterministic simulation (perfect CPUE indices based on ages 6-9 summed and the smoothed, dome-shaped partial recruitment vector). Second, simulations were made to determine if the program could estimate jointly F and M for different sets of CPUE (sums based on 3-5, 6-9, and 10-30 in separate runs and then mixed together in a single simulation; i.e., "all").

Deterministic simulations were made to gain insight into the effect of using different forms of the partial recruitment vector other than the smoothed, domed-shape partial recruitment vector; i.e., with increasing recruitment for bluefin tuna older than 7 (full recruitment). Partial recruitment values for ages greater than or equal to age-7 were increased incrementally from

0.61 ("dome-shaped") to 1.0 ("asymptotic") as: 0.7, 0.8, and 0.9 (Fig. 1). These simulations were made with the artificial CPUE index from the sum of abundance for ages 6-9.

Since CAL "tunes" or calibrates its estimates of population size and fishing mortality rates to one or more CPUE indices, it was naturally expected that the technique would be particularly sensitive to assumptions concerning these indices. Hence, several sets of deterministic simulations were made to explore these scenarios:

1. Three simulations each using a single CPUE index for 1970-1985. The indices were for ages 3-5, 6-9, and 10-30 summed.
2. Three simulations each using multiple indices for 1970-1985. Each index was standardized so that its largest value was 1.0, so that equal weight would be given to each index in the sum of square. The simulations included:
   a) one index each for the age ranges 3-5, 6-9, and 10-30 summed,
   b) one index each for ages 3, 4, and 5, and
   c) one index each for ages 6, 7, 8, and 9.
3. Three simulations each using an index for ages 6-9 summed. The duration of the index was limited to the years 1975-1985, 1975-1980, and 1980-1985.

Stochastic Simulations

The deterministic simulations were followed by a series of stochastic simulations with increasing lognormal error to examine the effect of this error in the input parameters on output parameters. This error was incorporated into one of three sets of input parameters: 1) the catch matrix (30 ages, 1-30, and 16 years, 1970-1985), 2) the partial recruitment vector (30 ages only in 1985), or 3) the catch per unit effort (CPUE) index (maximum of 16 years, may be more than one index). Independent, identically distributed error was introduced as follows:

$$y' = y*\exp(s*n(0,1) - s2/2), \quad (1)$$

where n(0,1) is normally distributed with mean 0 and variance 1, s is the input standard deviation, and y' is lognormally distributed with mean y and variance which is a function of y and s (Aitchison and Brown 1969). Subtracting the quantity s2/2 in Eq. 1, corrects the expected value of the exponential term so that it equals 1 and the expected value of y' then equals y. Simulations were made with increasing error by increasing the standard deviation (s in Eq. 1) for the underlying normal distribution as follows: 0.01, 0.032, 0.1, 0.32, and 1.0. Each simulation consisted of 100 iterations. One set of simulations with a standard error of 0.32 was run for 1000 iterations to examine whether the results were influenced by the number of iterations. For that set of simulations an abundance index for ages 6-9 in 1980-1985 was used.

An additional scenario was investigated, assessing the ability of CAL to detect good recruitment to age-1 in 1986. Three additional years of catch and corresponding CPUE data were added. Recruitment to age-1 in 1986 was varied between the recent estimated 5-year average (approx. 45,000 for 1981-85) and the highest estimated recruitment to age-1 (approx. 385,000 in 1974) in separate simulations. The recent 5-year average was used for recruitment to age-1 in 1987 and 1988. The smoothed, dome-shape partial recruitment vector for 1985 was applied to years 1986-88. Since recruits at age-1 in 1986 are age-3 in 1988, a CPUE index based on ages 3-5 for 1980-88 (s = 0.32) was used in these stochastic simulations. Estimates of population numbers of age-1 fish in 1986 (N) were retained and 90% empirical confidence intervals based on the 5th and 95th percentiles were computed and compared to the 5-year average (45,000).

RESULTS AND DISCUSSION

This section is divided into three parts. The first part describes the results from the deterministic simulations, indicating the ability of the program to recapture underlying parameters for the different scenarios when no error is present. The second part describes the results from the stochastic simulations, reflecting the the effect of increasing error in different input variables both on error in output parameters and on possible defects inherent in CAL under different scenarios. The final part describes the results from a separate stochastic simulations for which the catch matrix and CPUE index for ages 3-5 summed were expanded to include simulated data for 1986-1988, assessing the ability of CAL to estimate recruitments above the average for the last 5 years.

Deterministic Simulations

For the original computer run, estimated F was 0.46, total sum of squares was 0.580, and the correlation between observed and estimated CPUE was 0.791 (ICCAT 1987). For the computer run with smoothed, dome-shaped partial recruitment vector, estimated F was 0.42, total sum of squares was 0.580, and the correlation between observed (inputted) and estimated (from catchability coefficient q and stock size estimates) CPUE was 0.790. The individual correlations between estimated and observed CPUE indices range from 0.66 to 0.99 and the probabilities of positive correlation range from 0.86 to 0.96 for the original mixed set of five CPUE indices (ICCAT 1987).

All of the deterministic simulations recovered the underlying fishing mortality factor F (0.42, for age 7 in year 1985) except (Table 1):

1) M different from 0.1 (F: 0.05-0.78),
2) partial recruitment vectors different from the smoothed, dome-shaped vector with the asymptote at 0.61 (F: 0.30-0.38),
3) CPUE for ages 10-30 summed (M fixed or estimated jointly with F, F: 0.417),
4) separate CPUE for ages 7, 8, and 9 (F: 0.410-0.429), and
5) CPUE for duration 1975-80 (ages 6-9 summed, F: 0.426).

Bias in estimated F was large for exceptions 1 and 2 above, similar to results expected from other VPA techniques (e.g., Ulltang 1977). Bias in exceptions 3-5 above was small (<2%), resulting from subtle problems in CAL. Unbiased estimates of M were obtained when jointly estimating M with F.

In general the deterministic simulations demonstrate the ability of CAL to adequately recover F (age 7 in 1985) in the absence of error (Table 1). CAL is very sensitive to gross errors in M and the partial recruitment vector, as are all VPA techniques.

Stochastic Simulations

Although each stochastic simulation consisted of 100 iterations, occasionally a boundary value of F (or M when estimated jointly with F) was obtained. The number of non-boundary solutions are summarized in Table 2, and this number decreases with increasing lognormal error. Within CAL the input partial recruitment vector is standardized so that 1.0 is the largest selectivity for cohorts which occur in the most recent year and in the abundance index or indices (case 1 cohorts). For two sets of simulations (ages 10-30 summed and duration 1975-80 with ages 6-9 summed) this caused the upper bound of the range of F searched to be larger than for other ages. Since non-parametric methods are used to summarize the results of the simulations, all estimates, including boundary values, are used.

Tables 3 through 7 summarize the results from the stochastic simulations in terms of median bias and dispersion in estimated fishing mortality rate F, median calibration total sums of squares (also referred to as system error), median estimates of correlation between estimated and observed abundance (CPUE) indices, and an empirical estimate of probability that this correlation is positive based on the 100 iterations. Median bias and dispersion in estimated natural mortality rate M is also presented when jointly estimating F and M.

The information provided in tables 2-7 are intended primarily for internal comparisons. For example, system error (Table 5) is in part a function of the number of input parameters multiplied by lognormal error (Eq. 1). Comparisons in this table are limited to within ages summed or within indices of the same duration.

In no instance is the bias in F (Table 3) significantly different from zero based on 90% empirical confidence intervals (5th and 95th percentiles), although the bias generally increases with increasing underlying normal error. The median bias in F is positive 67% of the simulations made, and is generally much higher than the corresponding bias in M (this is partly due to true M - 0.1 - being smaller than true F - 0.42).

Figures 2-3 visually illustrate the effects of increasing the amount of variation in the CPUE indices, including more frequent solutions at the boundaries of range of F searched, the increase in dispersion in estimated F, and the increase in bias in estimated F observed in most simulations. Frequency histograms of estimated F are shown for the three highest levels of error introduced into the abundance index for ages 6-9 summed in 1970-1985 (Figure 2). Box and whisker plots for each level of introduced error are shown for each of the durations (1970-1985, 1975-1985, 1980-1985 and 1975-1980) of the index for ages 6-9 summed in Figure 3.

With few exceptions, dispersion in estimated F (Table 4) and median total sum of squares (Table 5) increased with increasing standard deviation of the underlying normal distribution. Total sum of squares did decrease for increasing lognormal error (0.32 to 1.0) in CPUE with mixed ages (all, ages 3-5 and ages 6-9). Median estimated correlation between the observed CPUE index (or indices) and that estimated by CAL from stock size (Table 6) and probability that the correlation is positive (Table 7) decreased with increasing lognormal error. The probability of positive correlation drops below 1.0 only for a standard deviation of 1.0 for the underlying normal error.

The total sum of squares, the correlation between estimated and observed CPUE indices, and the probability of positive correlation from the deterministic solutions are approximate measures of values estimated from the final runs at ICCAT (1987), and can serve as approximate benchmarks for the stochastic simulations. The total sum of squares (Table 5), which represents the amount of error in the system, was

0.580 for both of the deterministic runs using the original and the smoothed, dome-shaped partial recruitment vectors. Estimates of correlation between observed and estimated CPUE indices were 0.791 for the original and 0.790 for the smoothed, dome-shaped deterministic computer runs (Table 6). The probability of positive correlation ranged from 0.86 to 0.96 (Table 7) based on the deterministic solution with original data from ICCAT (1987). However, the stochastic simulations presented in this study are not intended to be real, but to aid in investigating the effects of error on CAL's ability to perform for specific scenarios.

Simulations with error in the catch matrix and partial recruitment vector show the least amount of system error, except the asymptotic partial recruitment vector at small levels of error (less than 0.1) (Table 5). Greater error is generally associated with CPUE indices. This occurs in spite of the fact that more terms are multiplied by lognormal error for the catch matrix (480) and partial recruitment vector (30 ages) than for the CPUE index (16 or less fishing years, except for mixed CPUE indices runs). For CPUE indices with shorter duration (6 or 11 years versus standard 16 years) comparisons of system error are only valid among those CPUE indices of equal duration. Hence, in general CAL appears more sensitive to variations in CPUE indices than in the catch matrix or partial recruitment vector elements.

For simulations with lognormal error in CPUE indices with ages summed, the indices for ages 3-5 and 10-30 have lower dispersion in estimated F than CPUE index for ages 6-9 (Table 4), and the dispersion in estimated F is lower at high lognormal error (s = 1) for CPUE for ages 3-5 than for ages 10-30. But simulations with error in CPUE for ages 6-9 have less system error than CPUE indices for ages 3-5 or 10-30 (Table 5). Furthermore, higher correlations between estimated and observed CPUE indices (Table 6) and probabilities of positive correlations (Table 7) are also associated with CPUE indices for ages 6-9. However, more boundary solutions (Table 2) occur with CPUE indices for ages 6-9 (34) and less boundary solutions occur with CPUE indices for ages 3-5 (12).

Simulations with error in mixed CPUE indices show some reduction in dispersion in estimated F (Table 4) compared to one index summed across the ages (ages 3-5 or 6-9), although not at high levels of underlying normal error (s > 0.32) (i.e., at high levels of underlying normal error it may not be worth trying to separate out individual ages if q is constant across them). More boundary solutions in estimating F (Table 2) are produced by simulations for CPUE indices with ages 6-9 mixed (29) than CPUE indices with ages 3-5 mixed (12) or 3-5, 6-9, and 10-30 mixed (21, "all"), but fewer boundary solutions than from simulations for CPUE indices with ages 6-9 summed (34). Less system error is present for the simulations with error in summed CPUE indices for ages 3-5 or 6-9 than for the mixed CPUE index for ages 3-5 or 6-9 for small underlying normal error ($s < 0.32$) but the reverse holds for high underlying normal error ($s > 0.32$) (Table 5). Similar correlations between observed and estimated CPUE indices (Table 6) and probabilities of positive correlations (Table 7) are noted when comparing summed to mixed ages. No significant gain is apparent from mixing separate ages over summing across ages if q is constant.

Both the duration and currentness of the CPUE index can influence the parameters and associated statistics produced by CAL (Table 3-7 and Figs. 2-6). The dispersion in estimated F for duration 1980-85 is considerably lower than that for 1975-85, or even for duration 1970-85 at higher levels of underlying normal error. But higher error in the earlier years (1975-79) can significantly increase the dispersion in estimated F (Table 4). Large numbers of boundary solutions (Table 2) occur for shorter duration CPUE indices, especially if current years are not included (89 boundary solutions for duration 1975-80). System error (Table 5) for CPUE indices with different durations also reflects both the duration (shorter durations have fewer terms multiplied by lognormal error) and currentness of the index. System error is least for duration 1980-85 (six terms multiplied by lognormal error) and most for duration 1975-85 (11 terms). Correlation between observed and estimated CPUE indices (Table 6) are generally lowest for duration 1975-80 and generally highest for 1980-85, and the probability of positive correlation is generally lowest for duration 1975-1980 and highest duration 1975-85.

A simulation was run for 1000 iterations using an abundance index for ages 6-9 summed in 1980-1985 with a standard deviation of 0.32 in the lognormal error and M of 0.1. Very similar results were obtained with 100 and 1000 iterations (Figure 4). The median bias in estimated F was slightly higher (0.0) than with 100 iterations (-0.005, Table 3), the dispersion was larger (0.515 compared to 0.450, Table 4), there were 929 solutions between but not at the boundary conditions (compared to 97, Table 2). The remaining parameters (the median estimated total sum of squares, the median estimated correlation between observed and estimated abundance indices, and the probability that that correlation was positive) were the same for 100 (Tables 5, 6 and 7) and 1000 iterations.

When estimating F and M jointly, the dispersion in estimated F (Table 4) and correlation between observed and estimated CPUE (Table 6) increase slightly when compared to estimating just F, while total sum of squares (system error,

Table 5) actually is reduced slightly. The probability of positive correlation (Table 7) remains the same when estimating F alone or jointly with M. The reduction in total sum of squares results from an added degree of freedom to the tuning process. Bias (Table 3) in M remains small, but a large increase in boundary solutions (Table 2) occurs at the highest level of underlying normal error (s = 1, from from 34 boundary solutions when estimating only F to 61 boundary solutions when estimating F and M jointly).

The final estimates of F and M from the 100 iterations at each level of introduced lognormal error are generally highly correlated. At s of 0.01 with little variation in estimates of F and M, the correlation of F and M is -0.49. Maximum correlation between estimates of F and M is -0.77 at s = 0.032, but declines afterwards with increasing s (-0.65 at s = 0.1, -0.36 at s = 0.32, and +0.03 at s = 1). These correlations do not appear to interfere with CAL's ability to jointly estimate F and M.

The sum of squares surface (averaged across the 100 iterations for each level of introduced lognormal error) with respect to F and M was investigated for the abundance index for ages 6-9 summed in 1970-1985. F's of 0.0 to 1.6 and M's of -0.1 to 1.1 were used, and the results indicated that the correlation of M and F is influenced by the magnitude of those parameters (Figure 5). At the lowest values of F and M (generally 0.0 to 0.2 and -0.1 to 0.1, respectively) M and F are highly correlated. At higher levels of F (generally 0.3 - 1.6) the correlation is lower or nonexistent.

These correlations do not appear to interfere with CAL's ability to jointly estimate F and M, when error is introduced into a single index. The more realistic situation in which error occurs in all indices, in the catch at age, and in the partial recruitment, was not examined here. Collie (1987) attempted to evaluate a more realistic situation using the western Atlantic bluefin tuna data from the 1986 SCRS and examining the sum of squares isopleths of F and M. F and M were found to be highly correlated so that a wide range of F-M combinations were equally probable. He concluded that F and M could not be estimated simultaneously with that bluefin tuna data.

Simulation of Recruitment to Age-1 in 1986

Results for the deterministic and stochastic simulations with the expanded catch matrix (1970-88) and CPUE index for ages 3-5 summed (1980-88) are presented in Table 8. Estimates of both F (age-7 in 1985) and N (recruits to age-1 in 1986) are retained. The median of the bias in estimates of F is uniformly positive both for deterministic and stochastic simulations, but the median of the bias in estimates of N is uniformly negative. The stochastic simulations produce increasing underestimates of N with increasing size of true N. Based on an underlying normal standard deviation of 0.32 for the CPUE index, these stochastic simulations demonstrate that recruitment to age-1 in 1986 (N) greater than 85,000 can be detected after 1988 with a CPUE index based on ages 3-5 summed. Recent recruitment to age-1 has averaged about 45,000 (ICCAT 1987), while the greatest recruitment to age-1 estimated for the period 1970-85 was about 385,000 in 1974. Subtle increases in recruitment to age-1 can not be easily detected (e.g., N < 65,000).

CONCLUSIONS

In conclusion, some inherent bias is noted in deterministic estimates of the fishing mortality rate F (age-7 in 1985) when older ages (ages > 6) are used in the CPUE index (< 2% deviation from the reference level 0.42) or when recent years are not included in CPUE index (e.g., 1.5% for 1975-80). As is typical for all VPA techniques, when gross errors occur in the natural mortality rate or partial recruitment vector, then gross errors will result in estimates of stock size and fishing mortality rates.

The theoretical levels of variation used in these simulations (standard deviation ranging from 0.01 to 1.0) can be put into context using the levels of variation observed in standardized abundance estimates developed for various large pelagic species. The standard deviations about the standardized estimates of logged bluefin tuna catch rates by Japanese longliners in 1983-1985 reported by Turner (1987) averaged 0.33 for the 3-5 (range 0.20-0.56) and 6-7 (range 0.20-0.55) year olds, and they averaged 0.11 (range 0.07-0.17) and 0.15 (range 0.09-0.26) for the estimates for 8-9 year olds from the model with year and area and the model with year, month, area, and month-area interactions, respectively. The standard deviations about the standardized estimates of logged catch rates of medium bluefin tuna on the Grand Banks in 1971-1981 (Anonymous 1986) averaged 1.27 (range 0.88-2.44). The standard deviations about the standardized estimates of logged swordfish catch rates from single sets by U. S. longliners (SEFC 1987) in 1974-1982 averaged 0.51 (range 0.50-0.53). The levels of variation in abundance indices from other fisheries may be more or less precise than these, depending on the nature of the fishery and the quality of the information used in developing them.

Stochastic simulations demonstrate that increasing independent, identically distributed lognormal error in certain input variables (i.e., catch matrix, partial recruitment vector, or CPUE indices) has the following effects on estimates of specified output parameters:

1. Bias in F (age-7 in 1985) is not significantly different from 0 for any of the stochastic simulations,
2. bias and dispersion in estimated F (and M), and calibration total sum of squares increase with increasing lognormal error,
3. correlation between estimated and observed abundance (CPUE) indices and probability that this correlation is positive decrease with increasing lognormal error,
4. dispersion in estimated F from the CPUE index for ages 3-5 summed is generally smaller than from the CPUE index for ages 6-9 or 10-30 summed and produces fewer boundary solutions,
5. minor reduction in dispersion about estimated F results from using one CPUE index for each age in an age range, but there appears to be little gain compared to using a single index for the age range if q is constant,
6. CPUE indices must include most recent years, older index years do not contribute appreciably to calibration process, and
7. natural mortality rate M can be adequately estimated jointly with fishing mortality rate F.

For the expanded data set (1970-88), recruits to age-1 in 1986 greater than about 85,000 are shown to be detectable in 1988 with CPUE index based on ages 3-5 with relatively large background lognormal error. However, recruits to age-1 less than 65,000 (increase of 20,000 over recent 5-year average) would require less background error ($s < 0.32$) or additional years of data (1989+) if it is to be detected.

COMPARISON OF THE RESULTS OF THIS PAPER AND SCRS/87/63

Both this paper and SCRS/87/63 (Collie 1987) concluded that CAL is a valid method for estimating mortality rates and abundance trends over time. Both also noted that CAL was less sensitive to lognormal error introduced into the west Atlantic bluefin tuna catch at age from the 1986 SCRS than to lognormal error introduced into the indices of abundance. Therefore, when indices of abundance are presented, the variation about the estimated values should be reported.

The two papers contain different recommendations on the inclusion of abundance indices which end several years before the most recent year in the catch at age. This paper shows that, if VPA's are calibrated with abundance indices ending 5 years before the most recent year in the catch at age, there is a substantial increase in the dispersion of the estimated F's compared to VPA's tuned to indices which end in the most recent year in the catch at age. SCRS/87/63 suggests that such indices should be included to constrain the estimates of N in earlier years, though no supporting analyses were presented. Therefore, until analyses are performed which show benefits from inclusion of indices which end several years before the most recent year in the catch at age, it is recommended that indices which end more recently should be selected over indices for the same age range which end in an earlier year, assuming that other factors (such as the variation about the indices) are equal.

The criteria used by the SCRS to select indices for inclusion in final runs of CAL were criticized in SCRS/87/63, and it was recommended that the criteria be eliminated. As an alternative, it was suggested that the sum of squares from each index be weighted and all indices included in the analysis.

The two papers also conclude that F and M can both be estimated when the variation in the inputs are limited (this paper) or eliminated (Collie 1987). SCRS/87/63 concludes that with the data used by the 1986 SCRS, it is not possible to accurately estimate both F and M, because they are highly correlated when estimated jointly. As a result of that correlation, the joint confidence region estimated with traditional non-linear regression methods (such as linearization) may not be meaningful (Draper and Smith 1981).

In SCRS/87/63 it is also suggested that the SCRS consider conducting catch at age analyses with an alternative method.

LITERATURE CITED

Aitchison, J., and J. A. C. Brown. 1969. The lognormal distribution with special reference to its use in economics. Cambridge University Press, London.

Anonymous. 1986. Report of the meeting of the bluefin working group. Int. Comm. Conserv. Atl. Tunas, Col. Vol. Sci. Pap. 24:1-110.

__________. 1987. 1986 SCRS Report A. Int. Comm. Conserv. Atl. Tunas, p. 47-94.

Collie, J. S. 1987. Evaluation of virtual population analysis tuning procedures as applied to Atlantic bluefin tuna. SCRS/87/63:33p.

Draper, N. and H. Smith. 1981. Applied regression analysis. John Wiley and Sons, N.Y. 709p.

Fry, F. E. J. 1949. Statistics of a lake trout fishery. Biometrics 5:26-27.

Nagai, T., and N. Miyabe. 1986. Comments on Parrack's VPA tuning program. Int. Comm. Conserv. Atl. Tunas, Col. Vol. Sci. Pap. 26(2):283-292

Parrack, M. L. 1986. A method of analyzing catches and abundance indices from a fishery. Int. Comm. Conserv. Atl. Tunas, Col. Vol. Sci. Pap. 24:209-221.

Southeast Fisheries Center (SEFC). 1987. Report of the swordfish assessment workshop. Int. Comm. Conserv. Atl. Tunas, Col. Vol. Sci. Pap. 26:339-395.

Turner, S. C. 1987. Catch rates of bluefin tuna in the Japanese longline fishery recorded by United States observers. Int. Comm. Conserv. Atl. Tunas, Col. Vol. Sci. 26(2):323-328.

Ulltang, O. 1977. Sources of errors in and limitations of virtual populatioon analysis (cohort analysis). J. Cons. Int. Explor. Mer 37(3):249-260.

Table 1. Results of deterministic simulations including estimates of fishing mortality rate F for age-7 in 1985 and natural mortality rate M (when estimated jointly with F). Catch matrix from ICCAT (1987), smoothed, dome-shaped partial recruitment vector (except with different partial recruitment vectors), and artificially generated CPUE indices (1970-85, except under durations of CPUE) used.

Run Type	F(7,85)	M[a]
	Differences in Fixed M	
0.05	0.780	NE
0.10	0.420	NE
0.20	0.210	NE
0.40	0.050	NE
	Estimate M with Differences in CPUE	
Summed Ages:		
3-5	0.420	0.1
6-9	0.420	0.1
10-30	0.417	0.1
Mixed Ages, All[b]	0.420	0.1
	Differences in Partial Recruitment[c]	
0.61	0.420	NE
0.70	0.380	NE
0.80	0.350	NE
0.90	0.320	NE
1.00	0.300	NE
	Differences in CPUE	
Summed Ages:		
3-5	0.420	NE
6-9	0.420	NE
10-30	0.417	NE
Mixed Ages:		
All[b]	0.420	NE
3-5	0.420	NE
6-9	0.420	NE

Table 1. (continued).

Run Type	F(7,85)	M^a
Differences in CPUE (cont.)		
Separate Ages:		
3	0.420	NE
4	0.420	NE
5	0.420	NE
6	0.420	NE
7	0.410	NE
8	0.421	NE
9	0.429	NE
Duration of CPUE:		
1975-85	0.420	NE
1975-80	0.426	NE
1980-85	0.420	NE

[a] M fixed equal to 0.1 when not estimated (NE).

[b] All for mixed ages refers to a set of three CPUE indices based on ages 3-5, 6-9, and 10-30 summed.

[c] partial recruitment values greater than or equal to listed value for ages greater than 7 years.

Table 2. Number of estimated fishing mortality rates F (age-7 in year 1985) calculated from stochastic simulations that are between but not at the boundary conditions as a function of input standard deviation of underlying normal distribution.

Run Type	Standard Deviation				
	0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	100	100	100	100	91
Error in Partial Recruitment					
Dome	100	100	100	100	91
Asymptote	100	100	100	100	96
Error in CPUE					
Ages Summed:					
3-5	100	100	100	100	88
6-9	100	100	100	89	66
10-30	100	100	100	100	77
Ages Normalized and Mixed:					
All	100	100	100	100	79
3-5	100	100	100	100	88
6-9	100	100	100	98	71
Index Duration (CPUE for ages 6-9 summed):					
75-85	100	100	100	90	51
75-80	100	100	85	39	11
80-85	100	100	100	97	50
M Estimated (CPUE for ages 6-9 summed):					
F/M	100	100	100	85	39

Table 3. Median estimated bias in fishing mortality F (age-7 in year 1985) calculated from stochastic simulations as a function of input standard deviation of underlying normal distribution.

Run Type	Standard Deviation				
	0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	0.000	0.000	0.010	0.020	0.012
Error in Partial Recruitment					
Dome	0.000	0.000	-0.001	0.050	0.352
Asymp.[a]	0.005	0.003	0.002	0.035	0.232
Error in CPUE					
Ages Summed:					
3-5	0.000	0.000	0.010	0.010	0.030
6-9	0.000	0.010	-0.015	-0.005	-0.120
10-30	-0.003	-0.003	0.004	-0.010	-0.003
Ages Normalized and Mixed:					
All	0.000	0.000	0.005	0.000	0.010
3-5	0.000	0.000	-0.005	0.010	0.130
6-9	0.000	0.000	0.010	-0.015	-0.020
Index Duration (CPUE for ages 6-9 summed):					
75-85	0.000	0.005	-0.010	-0.060	-0.015
75-80	-0.010	0.031	-0.027	-0.010	4.662[b]
80-85	0.000	-0.005	-0.010	-0.050	-0.165
M Estimated (CPUE for ages 6-9 summed):					
F	0.000	0.000	-0.010	0.115	0.155
M	0.000	0.000	0.010	0.010	0.055

---

[a] Median bias is calculated from the deterministic run with asymptotic partial recruitment (F=0.30) rather than with dome-shaped partial recruitment (F=0.42).

[b] Boundary solution.

Table 4. Estimated dispersion (75th - 25th percentiles) in fishing mortality rates F (age-7 in year 1985) calculated from stochastic simulations as a function of input standard deviation of underlying normal distribution.

Run Type	Standard Deviation				
	0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	0.000	0.010	0.035	0.150	0.755
Error in Partial Recruitment					
Dome	0.000	0.020	0.055	0.208	1.148
Asymptote	0.004	0.012	0.037	0.147	0.852
Error in CPUE					
Ages Summed:					
3-5	0.000	0.020	0.075	0.245	0.710
6-9	0.015	0.040	0.130	0.530	2.990
10-30	0.007	0.014	0.076	0.188	1.667
Ages Normalized and Mixed:					
All	0.000	0.020	0.040	0.135	1.025
3-5	0.000	0.020	0.050	0.160	0.900
6-9	0.000	0.020	0.050	0.260	2.900
Index Duration (CPUE for ages 6-9 summed):					
75-85	0.020	0.050	0.165	0.570	3.035
75-80	0.098	0.361	0.869	5.033	5.082[a]
80-85	0.020	0.050	0.115	0.450	1.445
M Estimated (CPUE for ages 6-9 summed):					
F	0.020	0.050	0.180	0.835	3.140
M	0.000	0.000	0.030	0.060	0.245

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[a] Boundary range.

Table 5. Median of estimated total sum of squares calculated from stochastic simulations as a function of input standard deviation of underlying normal distribution [deterministic computer runs on original data set (ICCAT 1987) and set with smoothed, dome-shaped partial recruitment gave value of 0.580].

Run Type	Standard Deviation 0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	0.0000	0.0000	0.0004	0.0036	0.0360
Error in Partial Recruitment					
Dome	0.0000	0.0000	0.0002	0.0015	0.0192
Asymptote	0.0024	0.0024	0.0026	0.0034	0.0185
Error in CPUE					
Ages Summed:					
3-5	0.0006	0.0055	0.0501	0.5836	5.1670
6-9	0.0001	0.0013	0.0132	0.1334	1.3012
10-30	0.0004	0.0037	0.0335	0.3873	3.3723
Ages Normalized and Mixed:					
All	0.0014	0.0131	0.0995	0.3498	0.1651
3-5	0.0010	0.0088	0.0665	0.2461	0.1501
6-9	0.0019	0.0158	0.1130	0.3871	0.2584
Index Duration (CPUE for ages 6-9 summed):					
75-85	0.0001	0.0006	0.0062	0.0510	0.4294
75-80	0.0000	0.0005	0.0043	0.0407	0.2937
80-85	0.0000	0.0001	0.0005	0.0045	0.0290
M Estimated (CPUE for ages 6-9 summed):					
F/M	0.0001	0.0012	0.0117	0.1218	1.0901

Table 6. Median of estimated correlation between observed and estimated abundance (CPUE) indices calculated from stochastic simulations as a function of input standard deviation of underlying normal distribution. Overall correlation for deterministic computer run on original data set was 0.791 (ICCAT 1987) and with smoothed, dome-shaped partial recruitment vector was 0.790. Correlations with individual abundance indices for the deterministic computer run on the original data set ranged from 0.66 to 0.99.

Run Type	Standard Deviation 0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	1.00	1.00	1.00	1.00	0.96
Error in Partial Recruitment					
Dome	1.00	1.00	1.00	1.00	0.98
Asymptote	1.00	1.00	1.00	1.00	0.98
Error in CPUE					
Ages Summed:					
3-5	1.00	1.00	0.98	0.86	0.48
6-9	1.00	1.00	0.98	0.87	0.53
10-30	1.00	1.00	0.98	0.81	0.37
Ages Normalized and Mixed[a]:					
All	1.00	1.00	0.99	0.91	0.59
	1.00	1.00	0.98	0.87	0.43
	1.00	1.00	0.98	0.85	0.39
3-5	1.00	1.00	0.98	0.86	0.45
	1.00	1.00	0.98	0.85	0.47
	1.00	1.00	0.97	0.81	0.41
6-9	1.00	1.00	0.98	0.85	0.46
	1.00	1.00	0.98	0.89	0.47
	1.00	1.00	0.99	0.88	0.45
	1.00	1.00	0.99	0.89	0.52

Table 6. (continued)

Run Type	Standard Deviation 0.01	0.032	0.1	0.32	1.0
Index Duration (CPUE for ages 6-9 summed):					
75-85	1.00	1.00	0.99	0.89	0.59
75-80	1.00	0.99	0.94	0.71	0.33
80-85	1.00	1.00	0.99	0.94	0.68
M Estimated (CPUE for ages 6-9 summed):					
F/M	1.00	1.00	0.99	0.88	0.58

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[a] Separate correlations for each abundance index (all: 3-5, 6-9, and 10-30; 3-5: 3, 4, and 5; and 6-9: 6, 7, 8, and 9).

Table 7. Probability that correlation between observed and estimated abundance (CPUE) indices is positive calculated from stochastic simulations as a function of input standard deviation of underlying normal distribution. Probability for correlations with individual abundance indices for the deterministic computer run on the original data set ranged from 0.86 to 0.96.

Run Type	Standard Deviation 0.01	0.032	0.1	0.32	1.0
Error in Catch Matrix					
Ages 6-9	1.00	1.00	1.00	1.00	1.00
Error in Partial Recruitment					
Dome	1.00	1.00	1.00	1.00	1.00
Asymptote	1.00	1.00	1.00	1.00	1.00
Error in CPUE					
Ages Summed:					
3-5	1.00	1.00	1.00	1.00	0.98
6-9	1.00	1.00	1.00	1.00	1.00
10-30	1.00	1.00	1.00	1.00	0.96
Ages Normalized and Mixed[a]:					
All	1.00	1.00	1.00	1.00	0.97
	1.00	1.00	1.00	1.00	0.99
	1.00	1.00	1.00	1.00	0.94
3-5	1.00	1.00	1.00	1.00	0.98
	1.00	1.00	1.00	1.00	1.00
	1.00	1.00	1.00	1.00	0.94
6-9	1.00	1.00	1.00	1.00	0.98
	1.00	1.00	1.00	1.00	0.98
	1.00	1.00	1.00	1.00	0.97
	1.00	1.00	1.00	1.00	0.99

Table 7. (continued)

Run Type	Standard Deviation 0.01	0.032	0.1	0.32	1.0
Index Duration (CPUE for ages 6-9 summed):					
75-85	1.00	1.00	1.00	1.00	0.98
75-80	1.00	1.00	1.00	1.00	0.69
80-85	1.00	1.00	1.00	1.00	0.85
M Estimated (CPUE for ages 6-9 summed):					
F/M	1.00	1.00	1.00	1.00	1.00

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[a] Separate correlations for each abundance index (all: 3-5, 6-9, and 10-30; 3-5: 3, 4, and 5; and 6-9: 6, 7, 8, and 9).

Table 8. Deterministic estimate (d) and median estimate from stochastic (m, s = 0.32) simulations of fishing mortality for age-7 in 1985 (F) and recruits to age-1 in 1986 (N) are calculated based on CPUE index for ages 3-5 (summed) from 1980-88. Recruits to age-1 in 1987 and 1988 are based on 5-year mean for 1981-85 (approx. 45,000). Catch matrix was expanded based on M = 0.1 and F = 0.42 (age-7 for 1986-88), and dome-shaped partial recruitment vector for 1986-88 identical with 1985.

Recruits to Age 1 in 1986 (1000)	F_d	F_m	N_d (1000)	N_m (1000)	90% C.I.(N_m) (1000)
45	0.426	0.421	43.2	44.5	(23.2, 74.4)
50	0.426	0.423	48.0	48.9	(26.5, 82.7)
65	0.423	0.428	63.6	61.8	(36.9,105.6)
85	0.423	0.431	83.2	79.4	(48.7,146.2)
130	0.420	0.434	129.7	119.3	(72.2,237.9)
385	0.420	0.431	384.1	359.5	(183.9,791.5)

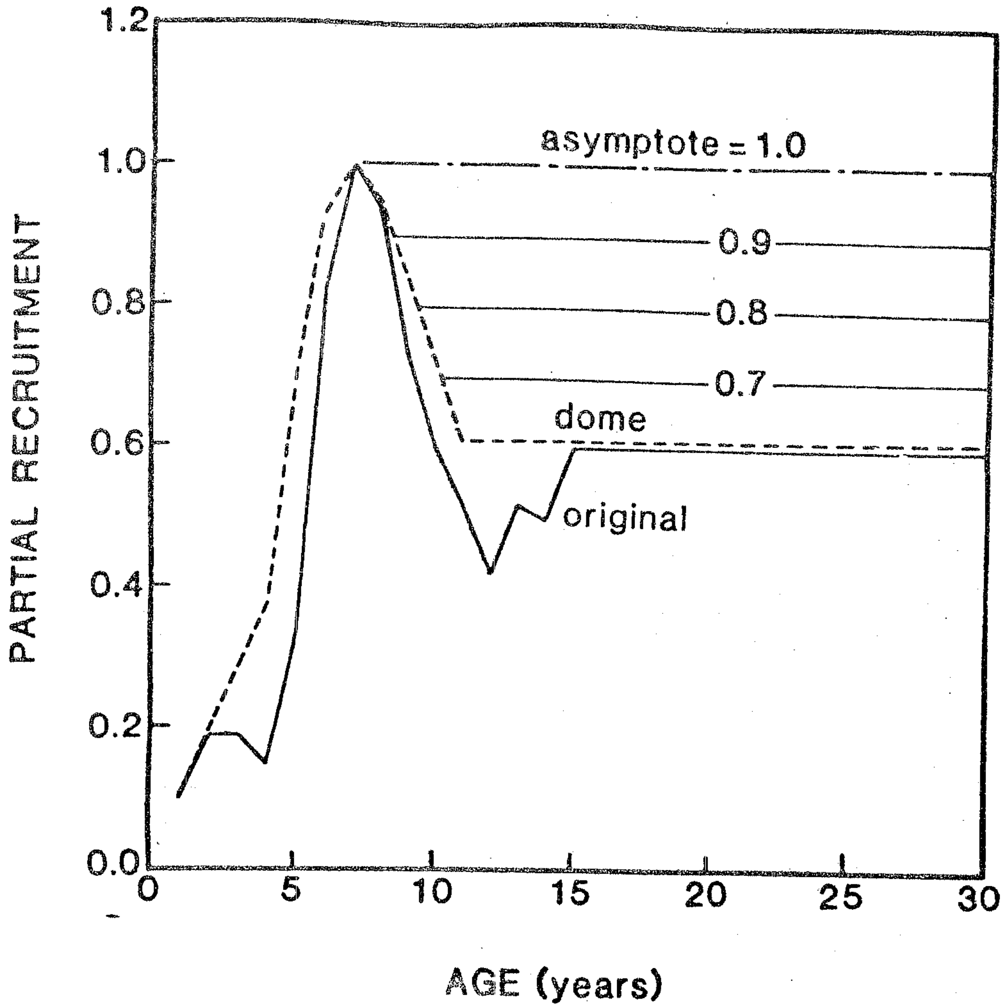


Figure 1. Original, dome, and asymptotic partial recruitment vectors are compared. Dome and asymptotic partial recruitment vectors coincide for ages less than and equal to age 7. Additional deterministic computer runs were made with intermediate asymptotic values to the right of the descending limb (0.7, 0.8, and 0.9).

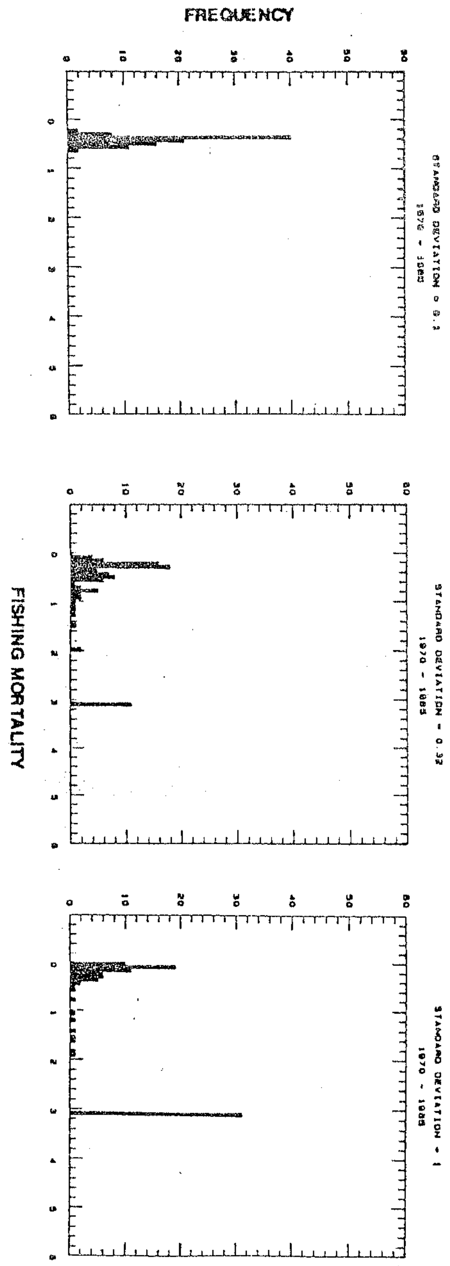


Figure 2. Frequency distributions of estimated fishing mortality rates (F) from simulations using the dome-shaped partial recruitment vector, M of 0.1, and one abundance index for 6-9 year-olds in 1970-1985. Distributions are shown for three simulations in which the lognormal error introduced into the abundance index had standard deviations of 0.1, 0.32 or 1.0. Sample size is 100 for each distribution and the expected F is 0.42.

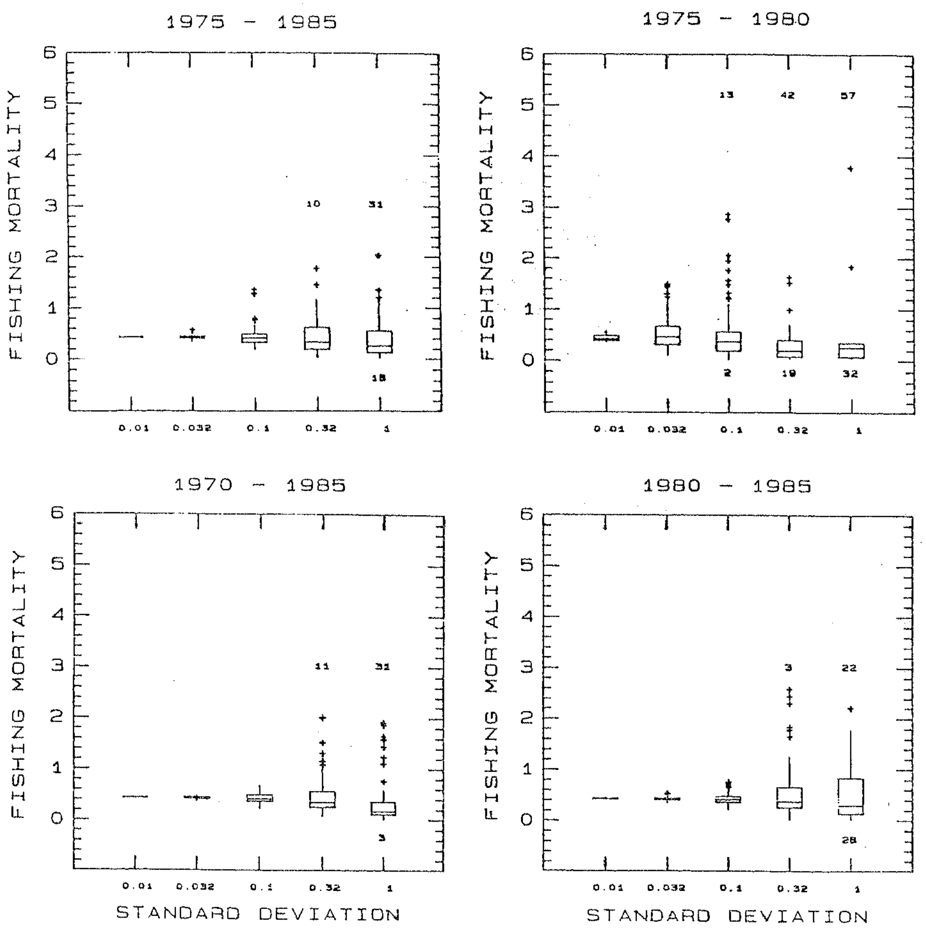
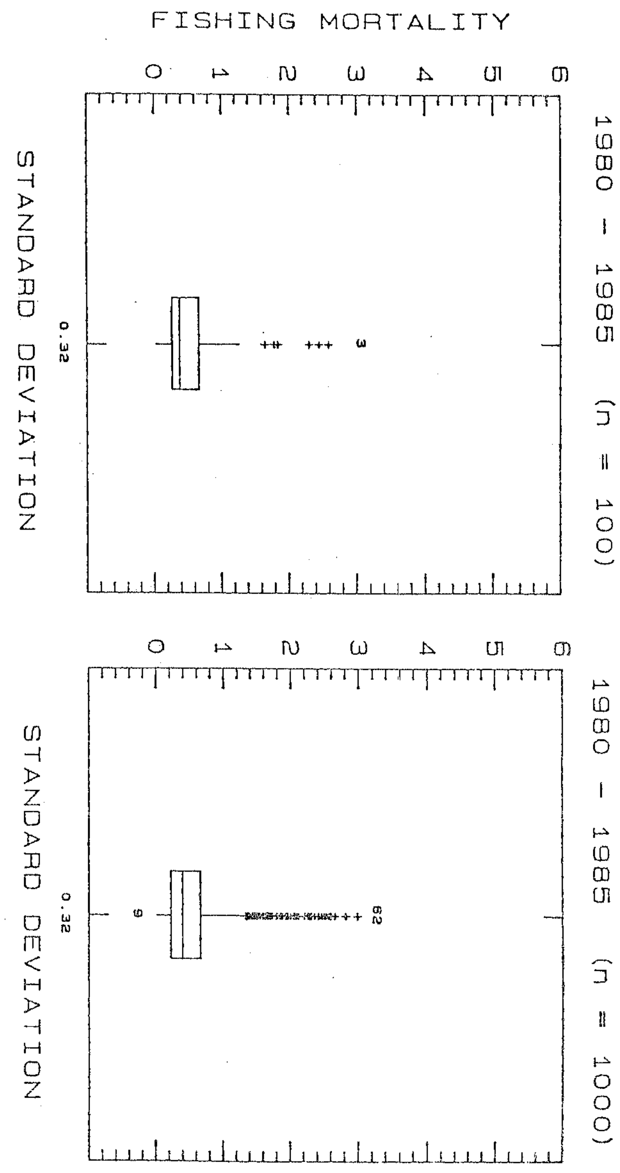


Figure 3. Box and whisker plots of the estimated fishing mortality rates (F) from simulations using the dome-shaped partial recruitment vector, M of 0.1 and one abundance index for ages 6-9. Only F's between but not at a boundary of the range of F searched were included in a plot, though the number of boundary solutions are shown. Results from four durations (1970-1985, 1975-1985, 1980-1985 and 1975-1980) of the abundance index are shown; and for each duration, 5 simulations (100 iterations each) were made. The simulations differed in the standard deviations (0.01, 0.032, 0.1, 0.32, and 1.0) of the lognormal error introduced into the abundance index. The line within the box is the median F, and the lower and upper boundaries of the box show the first and third quartiles, respectively. The whiskers (the lines running vertically from the box) provide information on the F's outside the first and third quartiles. They extend either 1) to the maximum (or minimum) F or 2)to the largest (or smallest) F within 1.5 times the interquartile range (third minus first quartile), whichever is smaller. The + signs indicate the position of F's beyond the whisker. The number below F of 0.0 is the number of solutions at the lower boundary of the search range, and the number above the plot is the number of solutions at the upper boundary.

FIGURE 4. Box and whisker plot of the estimated fishing mortality rates (F) from simulations using the dome-shaped partial recruitment vector, M of 0.1 and one abundance index for ages 6-9 in 1980-1985 with a standard deviation of 0.32 in the lognormal error. Only F's between but not at a boundary of the range of F searched were included in the plots; the number of boundary solutions are shown above and below the plot. For an explanation of the box and whiskers see Figure 3.



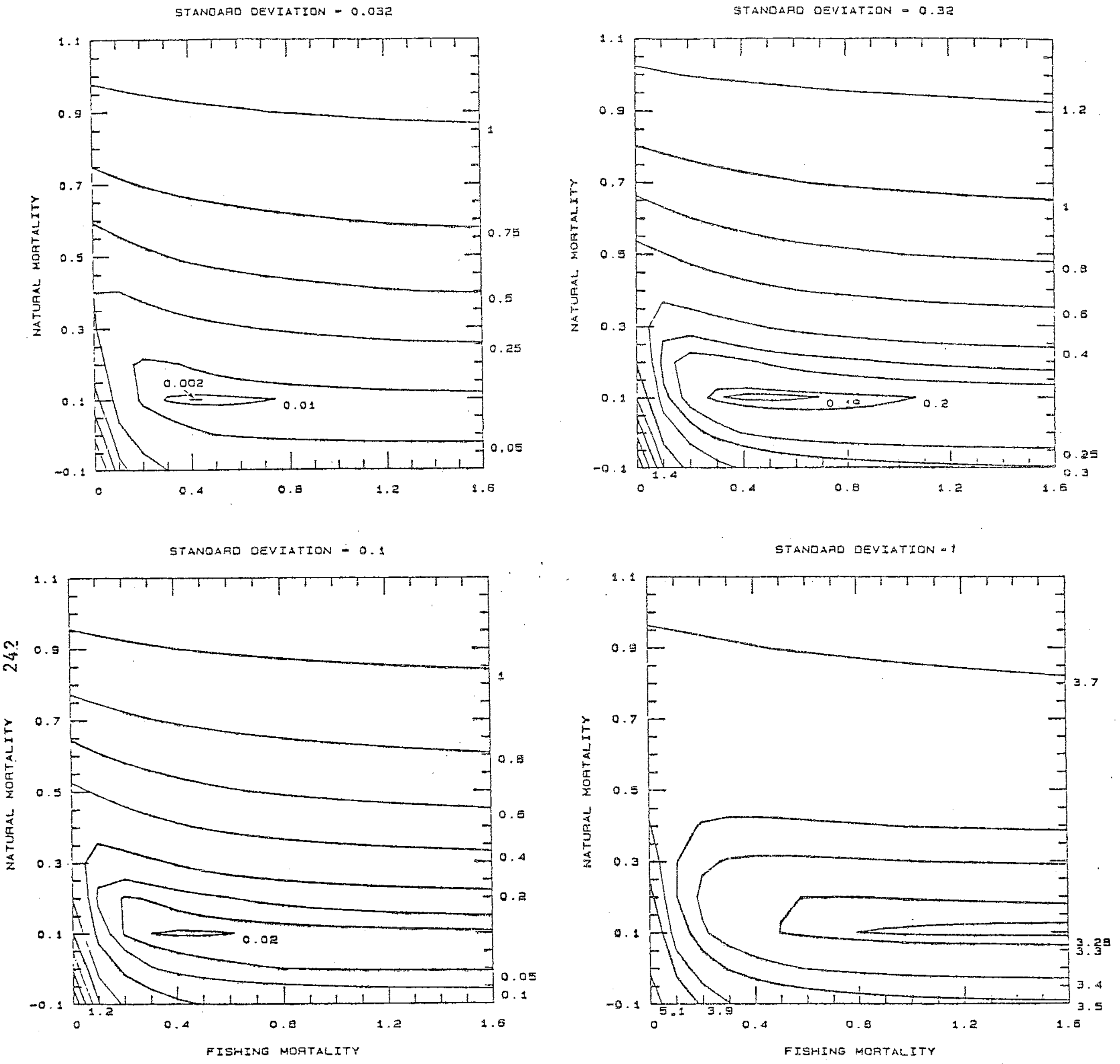


Figure 5. Isopleth diagrams of the average sum of squares at levels of F from 0.0 to 1.6 and M from -0.1 to 1.1 from simulations using the generalized dome-shaped partial recruitment vector and an abundance index for ages 6-9 in 1970-1985. There are four diagrams; one for each of the highest standard deviations of lognormal error (0.032, 0.1 0.32, 1.0) introduced into the abundance index.