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OF ATLANTIC TUNAS

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COMISION INTERNACIONAL PARA LA CONSERVACION
DEL ATUN ATLANTICO

ASSESSMENT PROGRAM DOCUMENTATION

Program: **ASPIC (ver. 3.82)**

Fits a logistic (Schaefer-form) stock production model to catch and effort data without making an equilibrium approximation.

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External: David Die (U. Miami, USA) and Jaime Mejuto (IEO, Spain)
ICCAT Secretariat: Victor Restrepo

NOTE: As part of its efforts to carry out Quality Management, ICCAT´s Standing Committee on Research and Statistics is developing a catalog of stock assessment applications. The purpose of the catalog is not to evaluate the relative merits of various assessment methods, but rather whether the software implementing the method works as intended and is adequately documented.

1. PROGRAM NAME

ASPIC

2. VERSION (DATE)

Version 3.82, dated June, 2000

3. LANGUAGE

FORTRAN 90

4. PROGRAMMER / CONTACT PERSON

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5. DISTRIBUTION LIMITATIONS

Only executable code can routinely be distributed, along with manual and sample files. However, source code is available from the author upon written request and with agreement to certain restrictions.

6. COMPILER NEEDS / STAND-ALONE

Does not require other software, except operating system. Presently available from author for 32-bit Windows (Windows 9x and Windows NT). Versions for Linux or other operating systems may be available on request.

Users must be able to print and edit ASCII files and enter commands at a command prompt to use ASPIC.

7. PURPOSE

Fits a logistic (Schaefer-form) stock production model to catch and effort data without making an equilibrium approximation; uses observation-error estimator with weighted least-squares.

8. DESCRIPTION

The program uses forward projection methods to fit a logistic (Schaefer) stock-production model to catch and effort data without making an equilibrium approximation. A Nelder-Mead (1965) Apolytope@ or Asimplex@ optimizer is used to minimize the sum of squared residuals in catch, CPUE, or effort; in each case, minimization is done in log transform, under assumption of lognormal observation error and no process error. To increase the chance of locating a global minimum (in the objective function), the optimizer is repeatedly restarted until it converges to the same solution three times in a row. The program uses an analytical solution of the catch and biomass projection equations of the logistic model. Numerous data checking features are used to promote reliable estimation.

Please see equations and description in Prager (1994) and Prager (1995) for a complete description of the method. The method is also described in Quinn and Deriso (1999), p. 77. The following is a brief description of the basic method.

The first-order differential equation describing the rate of change of stock biomass (B_t) due to production and fishing mortality (F_t) is

$$\frac{dB_t}{dt} = (r - F_t)B_t - \frac{r}{K}B_t^2 \ ,$$

where r represents the intrinsic rate of increase and K represents the maximum population size (carrying capacity). Defining $\alpha_t = r\text{-}F_t$ and $\beta = r/K$ simplifies the above equation to

$$\frac{dB_t}{dt} = \alpha_t B_t - \beta B_t^2 \qquad (1)$$

Equation (1) has the solution (assuming time steps of one unit)

$$B_{t+1} = \begin{cases} \dfrac{\alpha_t B_t e^{\alpha_t}}{\alpha_t + \beta B_t (e^{\alpha_t} - 1)} & when \quad \alpha_t \neq 0, or \\ \dfrac{B_t}{1 + \beta B_t} & when \quad \alpha_t = 0. \end{cases} \qquad (2)$$

If the fishing mortality rate is known, the yield obtained during the time period t is given by

$$Y_t = \begin{cases} \dfrac{F_t}{\beta} \ln\left[1 - \dfrac{\beta B_t (1 - e^{\alpha_t})}{\alpha_t}\right] & when \quad \alpha_t \neq 0, or \\ \dfrac{F_t}{\beta} \ln(1 + \beta B_t) & when \quad \alpha_t = 0. \end{cases} \qquad (3)$$

Alternatively, if the yield is known, the fishing mortality can be computed as

$$F_t = \begin{cases} \dfrac{\beta Y_t}{\ln\left[\dfrac{\beta B_t (e^{\alpha_t} - 1)}{\alpha_t} + 1\right]} & when \quad \alpha_t \neq 0, or \\ \dfrac{\beta Y_t}{\ln[1 + \beta B_t]} & when \quad \alpha_t = 0. \end{cases} \qquad (4)$$

The basic fitting approach depends on whether the catch or the fishing effort is considered to be known without error. If the application is conditioned on effort then the objective function to be minimized is

$$\sum_{t=1}^{T} \left[\ln(Y_t) - \ln(\hat{Y}_t)\right]^2 . \qquad (5)$$

If, on the other hand, the application is conditioned on yield, the objective function becomes

$$\sum_{t=1}^{T} \left[\ln(f_t) - \ln(\hat{f}_t)\right]^2 \ .$$

Either objective function is equivalent to $\sum_{t=1}^{T} \left[\ln(C_t / f_t) - \ln(C_t / \hat{f}_t)\right]^2$, where (C_t/f_t) denotes catch per unit of effort. This approach assumes that fishing mortality is proportional to fishing effort $F_t = q f_t$, through a constant catchability coefficient q.

Appendix 1 provides additional details on fitting.

The following MSY-related statistics are computed:

$$M\hat{S}Y = \frac{\hat{K}\hat{r}}{4},$$
$$\hat{B}_{MSY} = \frac{\hat{K}}{2},$$
$$\hat{F}_{MSY} = \frac{\hat{r}}{2},$$
$$\hat{F}_{0.1} = 0.45\hat{r}.$$

Series weighting and iterative reweighing

When two or more data series are analyzed, the program can assign a statistical weight ϕ_i for each series so that the objective function becomes (in the case that fitting is conditioned on effort):

$$\sum_{i=1}^{I}\sum_{j=1}^{N}\phi_i\left(\ln\frac{Y_{ij}}{\hat{Y}_{ij}}\right)^2 .$$

where I is the number of data series and N the number of years of data available. The weights can be assigned by the user. Alternatively, the program can estimate them (iterative reweighing) by computing

$$\hat{\phi}_i = \frac{1}{N-1}\sum_{j=1}^{N}\left[\ln(Y_{ij}) - \ln(\hat{Y}_{ij})\right]^2 .$$

Penalties

The term $\psi\left[\ln(\hat{B}_1) - \ln(\hat{K})\right]^2$,is optionally added to the objective function to discourage solutions in which the initial biomass is larger than the carrying capacity. The value of ψ is equal to a positive number input by the user. The penalty applies if $\hat{B}_1 > \hat{K}$.

Bootstrapping

Bootstrapping is based on constructing synthetic series of observations based on the set of residuals from the original fit. The model is then refit to each of the synthetic series. Bias-corrected estimates of and confidence intervals on the parameters are computed as explained in Prager (1994).

Summary of major assumptions:

1. Single, closed population that follows the dynamics of equation (1).
2. The fishable population is a constant fraction of the population (selectivity remains constant through time, or there are no age-structured effects).
3. Constant catchability through time.
4. No time lags in recruitment or in density-dependent growth, natural mortality and reproduction.
5. No population effects from environmental variation or interspecies effects.

6. The data accurately represent the population, except for lognormal observation error in catch or fishing effort (depending on the operational mode of the program).

9. REQUIRED INPUTS

1. One to ten series of data on CPUE (or effort) and removals
2. Starting guesses and constraints on parameters (*r, K, MSY, q*)
3. Some control parameters are required (e.g., convergence criteria), but the sample input files provide values that are sufficient, and most changes result in worse results.
4. Items for user convenience, such as run title and text description of each data series.

10. PROGRAM OUTPUTS

An ASCII file (120 columns wide) is written after each run. It contains the following information

For all runs:

1. ASPIC version information, author contact information, run date and title of run
2. Program status information (i.e., did the program seem to converge on estimates?)
3. Goodness of fit information (ANOVA table and R^2 for each data series)
4. Estimates of the following: Starting biomass, MSY, *K* (carrying capacity), *r* (intrinsic rate of increase), *Bmsy, Fmsy*, ratio of *B*(final) to *Bmsy*, ratio of *F*(final) to *Fmsy*, equilibrium yield available in next year, and for each data series, *q* (catchability) and *fmsy* (effort for MSY).
5. Estimated population trajectory through time, both absolute (not recommended for assessment use) and relative to *Bmsy*.
6. Estimated F trajectory through time, both absolute (not recommended for assessment use) and relative to *Fmsy*.
7. For each data series, trajectories of estimated and observed CPUE through time.
8. For each data series, plot of residuals through time.

For non-bootstrapped runs:

1. For each data series, plot of observed and fitted CPUE over time.
2. Plot of the estimated population trajectory (*B*) and fishing mortality (*F*) over time. These quantities are plotted relative to their respective benchmarks (*Bmsy* and *Fmsy*).

For bootstrapped runs:

1. A table of conventional and bias-corrected parameter and benchmark estimates. For each estimate, nonparametric 50% and 80% confidence intervals.
2. Files with detailed data on the bootstrap, for use by ASPICP in making projections.

11. DIAGNOSTICS

1. Goodness-of-fit information (ANOVA table and R^2).
2. Plots of estimated vs. observed CPUE.
3. Time plots of residuals for each series.
4. Checks that parameters are not at constraints.
5. Plots of population trajectories.
6. Values of coverage index and nearness index (experimental; see Prager et al. 1996).
7. Limits on number of iterations allowed for convergence.
8. Warning messages if any parameter estimates are at constraints.

12. OTHER FEATURES

ASPIC is the main program in a related set of four programs, sometimes called the "ASPIC Suite." The four programs are

ASPIC	Fits stock-production model to data
ASPICP	Makes stochastic projections from ASPIC bootstrap runs
FTEST	Compares two statistically nested ASPIC runs
AGRAPH	GUI program to make simple, publication-quality graphs of ASPIC runs (NOTE: AGRAPH is provided by the author as a useful tool to view results but is not considered to be part of this catalogue)

Special features of ASPIC include the following

1. Can analyze up to 10 data series, including series with removals (fisheries) and series without removals (indices)
2. Can set any parameter constant, rather than estimating it
3. Can apply constraints to most parameters
4. Can condition fit on either catch or effort
5. When conditioning on catch, can estimate missing values of effort or CPUE
6. When conditioning on effort, can estimate missing values of catch
7. In multi-data-series problems, can use iteratively reweighted least squares to obtain maximum-likelihood estimates of appropriate statistical weights for each series
8. Uses bootstrapping to obtain nonparametric confidence intervals and bias corrections

13. HISTORY OF METHOD PEER REVIEW

The basic model underlying ASPIC was described by Lotka (1924). It was introduced to fishery science in a quantitative way by Schaefer (1954, 1957). The fitting algorithm (forward projection) was applied to this problem by Pella (1967), who also derived the analytical solution conditioned on effort, and by Pella and Tomlinson (1969). Both of the preceding authors described applications to yellowfin tuna. A system of equations similar to that used in ASPIC was described by Schnute (1977). The polytope optimization method is described in Nelder and Mead (1965). The specific combination of theory, fitting algorithm, and optimization technique, along with several characteristic extensions, are detailed in Prager (1994), with additional practical details given in Prager (1995). Some aspects of application to Atlantic swordfish are described in Prager et al. (1996).

All the above references are peer-reviewed publications.

14. STEPS TAKEN BY PROGRAMMER FOR VALIDATION

The author has written a simulation program that has been used to generate numerous simulated data sets. These are then analyzed by ASPIC to verify that correct answers are obtained. In addition, the author has offered to correct any bug encountered or suspected by others, and has analyzed several such incidents.

Prager et al. (1996) also used ASPIC in controlled simulation experiments.

15. TESTS CONDUCTED BY OTHERS

Several simulation studies have been published using ASPIC. One that comes to mind is Cadrin et al. (1999). Also, Polacheck (1993) compared statistical assumptions and preferred observation-error estimators such as ASPIC to process-error estimators.

16. NOTES BY ICCAT

(in prep.)

17. SOURCES CITED

Cadrin, S. X., S. H. Clark, et al. 1999. Application of catch-survey models to the northern shrimp fishery in the Gulf of Maine. North American Journal of Fisheries Management 19: 551-568.

Lotka, A. J. 1924. Elements of physical biology. Reprinted 1956 as AElements of mathematical biology@ by Dover Press, N.Y., 465 p.

Nelder, J. A., and R. Mead. 1965. A simplex method for function minimization. Comp. J. 7:308B313.

Pella, J. J. 1967. A study of methods to estimate the Schaefer model parameters with special reference to the yellowfin tuna fishery in the eastern tropical Pacific ocean. Doctoral Dissertation, University of Washington, Seattle. 156 p.

Pella, J. J. and P. K. Tomlinson. 1969. A generalized stock production model. Bull. Inter-Am. Trop. Tuna Comm. 13:419B496.

Polacheck, T. , R. Hilborn, and A. E. Punt. 1993. Fitting surplus production models: comparing methods and measuring uncertainty. Canadian Journal of Fisheries and Aquatic Science 50:2597B2607.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fish. Bull. 92374-389.

Prager, M. H. 1995. User's manual for ASPICA stock-production model incorporating covariates, program version 3.6x. NMFS Southeast Fisheries Science Center, Miami Laboratory Document MIA-2/93-55, 4th ed. Available from the author.

Prager, M. H., C. P. Goodyear, and G. P. Scott. 1996. Application of a surplus production model to a swordfish-like simulated stock with time-changing gear selectivity. Transactions of the American Fisheries Society 125~729--740.

Quinn, T. J., and R. B. Deriso. 1999. Quantitative fish dynamics. Oxford University Press, NY.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Comm. 1(2):27B56.

Schaefer, M. B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Bull. Inter-Am. Trop. Tuna Comm. 2:247B268.

Schnute, J. 1977. Improved estimates from the Schaefer production model: theoretical considerations. J. Fish. Res. Board Can. 34:583B603.

18. AUTHOR=S NOTES

A revised version of ASPIC is in preparation as of June, 2000. This will incorporate the following additional features:

1. Generalized production model in addition to logistic model
2. Comparison of logistic and generalized models on a given data set
3. Additional forms of objective function
4. Usability features to facilitate simulation studies
5. Corresponding revisions to ASPICP

As of June, 2000, items (1) through (4) are working but require refinement, and work on (5) has yet to begin. It is hoped that the revised version will be suitable for distribution within 12 months.

APPENDIX 1. ALGORITHM

The basic parameters to be estimated are: r, K, q and B_1 (note that one q needs to be estimated for each effort or catch-per-unit-effort series). Assuming that fishing effort is known exactly, the steps used for estimation are (from Prager 1994):

A1: Obtain starting guesses for r, K, q and B_1. (NB: The user actually supplies a guess for MSY and ASPIC converts this internally to a starting value for K).
A2: Beginning with the current estimate of B_1, project the population through time according to equation (2). For each year, compute predicted yield according to equation (3).
A3: Compute the objective function, equation (5).
A4: Monitor the objective function for convergence. If achieved, end. Otherwise, revise the estimates of r, K, q and B_1 according to the minimization scheme (Nelder and Mead 1965).

In case the yield is assumed to be known exactly, the second and third steps of the algorithm are modified as follows:

A2´: Beginning with the current estimate of B_1, compute the estimated fishing effort each year by solving equation (4) and dividing by $\hat{q}$. Project the population to year end with equation (2).
A3´: Compute the objective function, equation (6).

Because the optimization method used tends to stop at local minima, the optimizer is repeatedly restarted until it converges to the same solution three times in a row.

User's Manual for ASPIC: A Stock-Production Model Incorporating Covariates, Program Version 3.82

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Table of Contents

* Please review the sections marked with an asterisk (*) before you use ASPIC.

Preface to Fourth and Fifth Editions

This is the user's manual for ASPIC (version 3.82), a computer program to estimate the parameters of a non-equilibrium logistic surplus-production model from one or more series of data on catch and effort (or catch and CPUE). The program can also tune the model to one or more data series on a biomass index or biomass estimate. Two utility programs (ASPICP, FTEST) are also provided.

Development of ASPIC and related programs is ongoing. Current versions are provided to scientists in a cooperative spirit, but the programs are not warranted in any way, either by the author or by the U.S. government. *These programs are intended as research tools, and those who use them do so at their own risk.* The author appreciates receiving notification of suspected bugs and will attempt to correct any bugs promptly.

This fifth edition of this manual is prepared in anticipation of ASPIC's inclusion in a catalog of assessment software made by the International Commission for the Conservation of Atlantic Tunas (ICCAT). This is appropriate, as ASPIC has been used in ICCAT assessments of several species since about 1992. The manual was not thoroughly revised for this event, but several changes and additions were made.

Formal description of the theory behind ASPIC is given in (Prager 1994). Further references are given in the bibliography (p. 24). The author requests that this manual and Prager (1994) be cited in any report or published article that uses ASPIC.

Many colleagues have given valuable technical suggestions or assistance. Chief among them are R. Deriso, K. Hiramatsu, J. Hoenig, R. Methot, C. Porch, J. Powers, A. Punt, V. Restrepo, G. Scott, and P. Tomlinson.

Typographical symbols: In the body of this manual, a few critical paragraphs or sections are marked by the following symbol in the left margin: ✪. Attention to such material is especially important to obtaining good results from ASPIC. Material that is new or substantially changed from the previous version of this Manual is marked with this symbol in the left margin: ◆. Finally, in the description of input files, quantities for which ASPIC can provide a default value are marked with the following symbol: ◗.

Michael H. Prager
Beaufort, North Carolina
June, 2000

Introduction

The surplus-production model has a long history in fishery science and has proven useful in management of fish stocks. (In particular, production models have had a long association with yellowfin tuna.) A major appeal of this class of models, compared to such models as tuned cohort analyses, is simplicity.

Many treatments of surplus-production models, including the work of Schaefer (1954, 1957), have assumed that the yield taken each year could be considered the equilibrium yield, at least for the purposes of parameter estimation. A notable exception is the GENPROD model of Pella and Tomlinson (1969), which does not use the equilibrium assumption (see also Pella 1967). ASPIC is a computer program that fits a non-equilibrium logistic (Schaefer) production model to catch and effort data in a manner similar to GENPROD. For a stock that is heavily exploited, the results of a non-equilibrium model can differ markedly from those of an equilibrium model. In general, equilibrium models can overestimate MSY when used to assess a declining stock.

ASPIC incorporates several extensions to classical stock-production models. A major extension is that ASPIC can fit data from up to 10 data series. These may be catch-effort series (from different gears or different periods of time), biomass indices, or biomass estimates made independently of the production model. This feature is descriped on page 4, and suggestions for its proper use are provided on page 17. A second major extension is the use of bootstrapping for bias correction and construction of approximate nonparametric confidence intervals. A third change is that, unlike GENPROD, ASPIC can fit a model under the assumption that yield in each year is known more precisely than fishing effort (or CPUE).

The theory behind ASPIC and several worked examples were reviewed in Working Documents of the International Commission for the Conservation of Atlantic Tunas (ICCAT) by Prager (1992a, 1992b). A more formal and complete treatment has recently been published (Prager 1994). Although refinements to both theory and practice are ongoing, the computer program as described here has been used by several assessment groups.

Program Requirements

In this section, hardware and software necessary to use ASPIC are described. The general data requirements for running the program are also given. A detailed description of the input file format is found in a later section.

Computer Hardware and Software Requirements

This version of ASPIC runs on standard microcomputers (PC's) running the Microsoft Windows-9x[1] or Windows NT operating systems (including Windows 2000). It is believed to be compatible with under IBM OS/2, but that has not been tested.

Interface and Portability

There is no graphical user interface to ASPIC; the program runs as a console-mode (character) program that takes all input from and writes all output to ASCII (text) files. The screen is used only for error and advisory messages.[2] Thus, the user is expected to use a simple text editor to create and edit ASCII input and output files. The same holds for the auxiliary program ASPIC-P (described later), which is used after a bootstrap run.

Because ASPIC is written in standard Fortran 95 (with the exception of a single extension: taking the input file name from the command line), it is easily portable to other operating systems. Indeed, the author ported earlier version of ASPIC several times.

Data Needs

✪ Data needed for parameter estimation are a series of observations on catch (yield in biomass) and corresponding fishing effort or CPUE. Effort data should represent effort directed towards the subject species. ASPIC assumes that effort divided by catch, or a supplied CPUE series, is a reasonable index of the stock's abundance in biomass.

In addition to data, ASPIC requires starting guesses for its estimated parameters. Parameters directly estimated are *r*, the intrinsic rate of increase; MSY, maximum

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[1] Reference to trade names does not imply endorsement by NMFS, NOAA, or the author.

[2] The National Marine Fisheries Service is developing a set of assessment programs that will be provided with graphical interfaces. The set includes a recent version of ASPIC, for which a specialized input-file editor has been provided.

sustainable yield; the ratio B_1/B_{MSY}, the ratio of the biomass at the beginning of the first year to the biomass at which MSY can be attained; and q, the catchability coefficient. A separate estimate of q is made for each data series, if more than one series is used. Description of the input file format, given later, includes suggestions for starting guesses.

✪ The nonlinear fitting method used by ASPIC is relatively insensitive to starting values, so that successful estimation is possible even from poor guesses, assuming that a reasonable solution exists. However, any method to solve nonlinear estimation problems may stop at local (rather than global) minima of the objective function, and ASPIC is no exception. Additional runs with different starting values can be used to assess model sensitivity to starting values.

Program Use

Modes of Operation

ASPIC has three modes of operation. In FIT mode, basic parameter estimates are provided, and execution time is relatively short. This mode is especially useful when fitting the first models of a population.

In BOT mode, ASPIC fits the model (as in FIT mode), but also computes bootstrap estimates of precision for estimated parameters and benchmarks; the bootstrap also provides an approximate correction for estimation bias. Because computations are extensive, execution time in BOT mode is much longer than in FIT mode.

The third mode, IRF mode, conducts an iteratively reweighted fit. This mode is used only when two or more data series are analyzed. It performs an iterative reweighting of the I data series (see next section) to approach a maximum-likelihood solution (inverse-variance weighting). At present, the program cannot perform bootstrap runs with iterative reweighting, but this capability is being considered.

Table 1. Codes for the eight types of data series allowed in ASPIC

Code	Data type	When measured
CE	Effort and catch (weight)	Totals for year
CC	CPUE (weight-based) and catch (weight)	Catch: total for year CPUE: average for year
B0	Estimate of biomass	Start of year
B1[a]	Estimate of biomass	Average for year
B2	Estimate of biomass	End of year
I0	Index of biomass	Start of year
I1	Index of biomass	Average for year
I2	Index of biomass	End of year

[a] Not the same as the estimated parameter B_1.

Fitting Several Catch–Effort or Abundance Data Series

ASPIC can fit data on up to I simultaneous or serial fisheries (or biomass estimate series or biomass index series), where $I \leq 10$. Data series may be of several types (Table 1), but at least one series must be type CE (effort and catch) or type CC (CPUE and catch. When more than one series is used, common estimates of B_1/B_{MSY} MSY, and r are made, along with one estimate of q_i for each series. The interpretation of q_i depends on the type of data series to which it pertains. Comments on the use of this feature are given on page 17.

A statistical weight ϕ_i for each fishery is specified by the user. In summing the objective function, each squared residual from fishery I is multiplied by ϕ_i. If the series have equal variances, using weights of 1.0 for each series provides a maximum-likelihood solution under the log error structure used by ASPIC. In IRF mode, these weights are adjusted (estimated) by the program to provide nearly equal estimated variances.

The amount of computer time needed generally increases as more data series are added. The increase is due to two factors, the addition of data and the increased difficulty of optimization.

Input and Output Files—Main ASPIC Program

Here, general concepts are discussed. Specific format of input files is described in a later section in sufficient detail to allow the user to make proper input files..

Disk files are used for all input and output, except for status messages printed to the screen. All data and results files used by ASPIC are in plain ASCII format, which simplifies printing and transfers to and from other programs. The main `FIT` and `BOT` output files, described below, are intended directly for the user, and are written with a maximum line length of 120 characters. The `BIO` and `DET` files (also described below) are intended to be read by other programs and thus may have longer records.

◆ Former versions of ASPIC always used an input file named `ASPIC.INP`. The present version can read the filename from the command line. For example, the command

```
ASPIC sword.inp
```

or just

```
ASPIC sword
```

will cause the program to read an input file named `sword.inp`. If only the command

```
ASPIC
```

is given, the program looks for the default input file, `ASPIC.INP`.

◆ File names used by ASPIC for its output depend on the mode of operation. In FIT and IRF modes, output is written to `nnn.FIT`. In BOT mode, the main output is written to `nnn.BOT`, and detailed results of the bootstrap are written to `nnn.DET` and `nnn.BIO`. Here `nnn` refers to the name of the input file. For example, if the input file is `sword.inp`, the output file will be named `sword.fit` or `sword.bot`. These files can be imported into a spreadsheet or statistical package for further analysis if desired. The `BIO` file is used by the auxiliary program ASPIC-P (described below) in making secondary computations after a bootstrap run.

Primary output from ASPIC includes parameter estimates; measures of goodness of fit; and estimates of population benchmarks, biomass levels, and exploitation levels. Output from a bootstrap run also includes bias-corrected estimates of the parameters with confidence intervals.

The ASPIC-P Program

After a bootstrap run, the ASPIC-P program (`ASPICP.EXE`) can be used to compute estimated trajectories of population biomass and fishing mortality rate with bias-corrected confidence intervals. ASPIC-P is also used for making population projections beyond the observed catch–effort data set, which can be done only after a bootstrap run. The user can specify future harvests or effort levels, and the program projects biomass and fishing-mortality trajectories for up to 10 years past the original data. Printer plots of the trajectories, with confidence intervals, are also provided.

◆ To perform its computations, ASPIC-P uses the data contained in the BIO file of the corresponding bootstrap run. The user provides instructions to the program and the future yields in a simple control file whose default name is `ASPICP.CTL`. The file can instead be named on the command line; for example the command,

```
ASPICP sword
```

or

```
ASPICP sword.ctl
```

would start ASPIC-P for a run described in the control file `sword.ctl`. All output from ASPIC-P is written to a file whose name is supplied by the user within the `CTL` file.

The FTEST Program

A small program called FTEST is provided to perform significance tests when comparing different ASPIC models of a stock. The program is designed for comparing pairs of models that differ only in complexity (number of parameters).

Objective Function and Penalty Term

Parameters are estimated under the assumption that the errors in yield or effort are multiplicative with constant standard deviation. Thus the residuals are accumulated in logarithmic transform. The quantity minimized, then, is

(1) $$\text{Obj. fn.} = \sum_{i=1}^{I} \sum_{j=1}^{N} \phi_i \left(\ln \frac{Y_{ij}}{\hat{Y}_{ij}} \right)^2 ,$$

for errors in yield, or a similar expression for errors in effort. Here, I indexes the data series, j indexes the year, ϕ_i is a statistical weighting factor, Y_{ij} is the observed yield (or biomass index or estimates) from series I in year j, and $\hat{Y}_{ij}$ is the corresponding predicted value. This logarithmic objective function is similar in effect to the additive-proportional objective function of Fox (1971), but is symmetrical in its treatment of positive and negative residuals.

An additional penalty term can be added to the objective function to discourage solutions in which the estimate of the first year's biomass B_1 is greater than the estimate of the carrying capacity K. Such constraints can affect the estimates of the other parameters, so when this term is used, the results should be compared to those obtained by setting the term to zero. The penalty term is also described in more detail in Prager (1994), and its use is described in the section describing the input file format.

ASPIC can consider yield as exact and accumulate residuals in effort, rather than the converse. (This is often known as "conditioning on yield.") The theoretical reason to do so is that effort is usually known less precisely than yield, and it is usually preferable on statistical grounds to compute residuals in the quantity known with greater error. *For these reasons, this method is recommended for most analyses.* An additional advantage is that estimation of missing effort values is quite simple (and is included in this version of ASPIC). With the fitting method used in ASPIC, accumulating residuals in effort is mathematically identical to accumulating them in CPUE, and in each case the catch equation is solved conditional on yield. Because the solution for effort is iterative, computation can be slower.

Bootstrap Estimates of Bias and Variability

In BOT mode, ASPIC uses bootstrapping to estimate the variability of several estimated quantities and to adjust for estimation bias. For this to be done, predicted yields and residuals from the original fit are saved. The residuals are then increased by an adjustment factor (see Stine, 1990, p. 338), which is printed on the output.

Bootstrapped data sets are constructed by combining each saved predicted yield $\hat{Y}_{ij}$ with a randomly-chosen adjusted residual to arrive at a pseudo-yield value Y^*_{ij}. (This procedure assumes that the weights ϕ_i are correct.) The model is then refit, using the pseudo-yields in place of the original observed yields. This process is repeated (always using the original predicted yields) up to 1,000 times. From the results, bias adjustments can be made and bias-corrected (BC) confidence intervals can be computed by standard methods (Efron and Gong 1983). The statistical literature recommends 1,000 bootstrap trials when computing 95% confidence intervals. ASPIC computes 80% confidence intervals, so should require fewer trials. I recommend using at least 500 trials for bootstrap runs.

Limits of the Program

The array limits of ASPIC are as follows:

- Number of years of data: 90
- Number of data series (fisheries or indices): 10
- Number of bootstrap trials: 1,000

Installing ASPIC

Installation consists of copying the executable files (`ASPIC.EXE`, `ASPICP.EXE`, and `FTEST.EXE`) to a directory on the executable PATH or to the directory in which the files to be analyzed will reside. It is highly recommended to install the ASPIC programs into a dedicated directory and then add that directory to your PATH statement, as described by documentation for your operating system. The README file on the distribution diskette contains more detailed installation instructions.

This User's Manual is supplied with all distributions of ASPIC as an Adobe PDF file named `ASPICMAN.PDF`. It can be viewed or printed using the Acrobat Reader supplied free by Adobe, or possibly by using compatible programs.

Running ASPIC

Before starting ASPIC, prepare an input file (in the format described below; samples are provided). Then start the program as described above. Errors detected while ASPIC is reading the input file will cause the program to print a descriptive message and stop. If the message is not clear, comparing the input file to the samples provided may reveal format errors.

Running ASPIC-P

To obtain trajectories or projections following a bootstrap run, use ASPIC-P. First, create a control file with a text editor (a sample file is included). Then start ASPIC-P as described above. Output is written to a file specified in the control file.

Running FTEST

Just type "FTEST". The program is interactive. Enter the data requested at the prompts. No printed output is provided; printing must be done with the Print Screen key or using screen cut and paste.

Input File Structure—ASPIC

As stated above, ASPIC reads its input from a single file containing all control parameters and data. The format of the input file is described here; it can be compared with the two examples (Table 2 and Table 3) provided on the ASPIC diskette.

General Format Guidelines

Because the input file is read by Fortran free-format input statements, its structure must follow certain rules. The exact position of values on a line is not important, but their order is. When a line contains more than one value, they must be separated by spaces (blanks). Further rules depend upon the type of data (integer, real, or character), so the descriptions below give the type of each data item. The major rules enforced by Fortran are—

- Each *real* number should contain a decimal point, an exponent indicated by the letter *d* or *e*, or both a decimal point or an exponent. Examples: 1.0, 1e3, 1.0d6. However, if an integer is provided by the user in place of a real number, it will be converted to a real number by ASPIC with no loss of precision.
- *Integers* must not contain decimal points. Examples: 0, 2, 1065.
- *Character strings* may contain embedded blanks. Each character string must be enclosed in matched apostrophes or quotation marks. For example, 'This is a valid string.' "This is another valid string."
- The correct number of values must be present on each line. Values may not be doubled up or divided among lines except as specified.
- After the specified number of input values have been read from a line, the program does not read the line further. Thus the rest of the line may contain comments. This has been done in the sample file provided, and the comments are preceded by two pound signs, "##". These symbols are a merely convention and have no significance to the program.

Order of Parameters and Data

Values in the input data file must be in the order given here. The order is identical for FIT, BOT, and IRF modes; however, series containing abundance indices or estimates are entered slightly differently from effort–catch or CPUE–catch series.

The program requires several starting guesses and constraints. If zero (0.0d0) is entered for those marked with the symbol (◗), the program will generate a default value. This is not foolproof. Often, better estimates can be obtained with intelligent starting values entered by the user.

Line 1: Program mode (character)

This is a three-character string with value 'FIT' 'BOT', or 'IRF'. FIT mode invokes the basic operation of the program; the model is fit to the data contained in the file. BOT mode fits the data and then implements the bootstrap procedure described above. IRF performs iterative reweighting and then fits the model.

Line 2: Title (character string, length up to 110 characters)

◆ This title can serve to identify the particular analysis. It is written to the main output file. If the first character in the title is an asterisk (*), the main output file will be prefaced by control codes to activate the "lineprinter" font on Hewlett-Packard and compatible laser printers. This can simplify printing ASPIC output files, which are 120 characters wide. Example: `'*This is my title'`.

Line 3: Optimization mode (character)

This is a three-character string, either `'CAT'` or `'EFF'`, that describes in which quantity the residuals will be computed. To clarify, conditioning on effort requires using optimization mode CAT, while conditioning on catch requires using optimization mode EFF.

Line 4: Verbosity level (integer)

An integer value from 0 to 4 that controls the amount of output printed to the screen during execution. When 0, very little is printed. When 4, too much is printed for most uses and execution is quite slow in consequence.

Line 5: Number of bootstrap trials (integer)

Must be 1000 or less. Using at least 500 runs is recommended. This number is used only in BOT mode; in FIT mode, it may be set to any valid value without causing bootstrapping to be done.

✪ **Line 6: Monte Carlo mode; Number of Monte Carlo trials in fitting (2 × integer)**

The first integer is 0 to disable the Monte Carlo search during fitting; 1 to enable the Monte Carlo search; 2 for repeated searches during fitting. The second integer is the initial number of Monte Carlo trials. Turning on the Monte Carlo search is useful when difficulty is experienced in finding a repeatable minimum during parameter estimation; however, the Monte Carlo search may sometimes times trap the solution in a local minimum. It is suggested to leave it off unless difficulties are encountered. When using it, suggested parameters are: 1 10000. If fitting is difficult, consider increasing the number of trials.

Line 7: Convergence criterion for simplex optimization routine (real)

This relative convergence criterion is denoted ϵ_1. After each adjustment of the simplex, the objective function is computed for each vertex of the simplex. Convergence depends on the difference between L_1, the highest (worst) value of these, and L_0, the lowest, relative to the mean of L_0 and L_1. Convergence is defined to occur when the following condition is met:

$$\frac{2|L_1 - L_0|}{L_1 + L_0} < \epsilon_1 .$$

◆ The recommended value is ϵ_1 = 1.0d–8, and changing it is not recommended.

Line 8: Convergence criterion for restarts (real)

◆ Randomized restarts of the simplex method are used in all cases to avoid local minima. This number should be larger than the convergence criterion for the simplex. The recommended value is 3.0d–8, and changing it is not recommended.

Line 9: Convergence criterion for estimating F (real)

In EFF optimization, an iterative method must be used to estimate each year's fishing mortality rate. The recommended value is 1.0d–4.

Line 10: Maximum F allowed (real)

In EFF optimization mode, a limit must be set on the maximum *F* allowed during estimation. This value does not affect the final estimates, but changing it may be helpful when ASPIC cannot converge on a solution. Use a value several times larger than the largest anticipated *F*. The value 8.0 works well in most cases.

Line 11: Statistical weight for B_1 penalty term in objective function (real)

This value should be set to 0.0d0 if the penalty term is not desired or to a positive real number (usually to 1.0) if desired. Use of nonzero values can bias the estimates of management parameters, although usually (but not always) very little, while reducing variance. It is suggested to first fit the model without the penalty.

If the estimate of B_1/B_{MSY} is excessively high (much over 2.0), try using the penalty. In some cases, inclusion of the penalty may cause substantial changes in estimates of MSY and other parameters; this should be checked. The penalty factor is described briefly above and in more detail in Prager (1994).

Line 12: Number of data series (integer)

An integer value ranging from 1 through 10 that indicates how many sets of effort-catch or abundance data are to be analyzed.

Line 13: Series-specific statistical weights (real)

The program reads as many real numbers from this line as series were specified on the preceding line. The weight ϕ_i for series *I* is multiplied by each squared residual for that series when the objective function is computed. The weights are adjusted to implement inverse-variance weighting when IRF mode is used in analyzing several data series. They can all be set to 1.0d0 unless there is reason to set them otherwise.

Line 14: Starting guess for B_1/B_{MSY} (real) ◗

In the absence of other information, a suggested value is 1.0d0. If the population was believed to be at its virgin biomass at the start of the data series, a number between 1.5 or 2.0 might be more appropriate. If the population was believed to be below MSY level at the start of the data series, 0.5 is suggested.

Line 15: Starting guess for *MSY* (real) ◗

A reasonable starting guess is the size of the largest recorded catch.

Line 16: Starting guess for *r* (real) ◗

If you have some idea what level of fishing mortality *F* the stock can absorb on a sustained basis, a good starting guess for *r* is twice this level. Otherwise, a good starting guess might fall between 3.0 (for a very fast-growing stock) and 0.3 (for a long-lived one).

Line 17: Starting guess(es) for *q* (real) ◗

The program reads as many values from this line as there are data series specified on line 11. The meaning of *q* depends on the data type that it refers to. When it refers to an effort-catch data series (code CE, Table 1), *q* is the catchability coefficient. When it refers to a biomass index data series (codes I0, I1, or I2, Table 1), *q* is the constant relating the index data to the internal ASPIC estimates of biomass; e.g., if $q = 2.0$, the index data are divided by 2.0 before being compared to the estimated biomass. When it refers to a biomass estimate series (codes B0, B1, or B2, Table 1), the value of q is ignored (because it is assumed to be exactly 1.0). However, a real number must be present in the input file as a placeholder. If 0.0d0 is used, the program computes a default starting guess.

Line 18: Flags to estimate (or not) estimate individual parameters (integer)

The program reads as many values from this line as there are data series, plus 3. The flags refer, in order, to the ratio B_1/B_{MSY}, MSY, r, and q_i, $I = 1, 2, ..., I$. These flags are set to 1 to estimate the respective parameter, 0 to keep it constant at the starting guess value. A flag must be provided for each data series. Even though q_i is not estimated for series of type B1 or B0 (see Table 1), a flag is required as a placeholder.

Line 19: Minimum and maximum constraints on MSY (2 × real) ◗

The program reads two real numbers from this line. These numbers are used during bootstrap runs to identify and discard any extreme solutions that occasionally occur during random resampling. Such solutions might result, for example, from a result that is a local, rather than a global, minimum. If these numbers are set to 0.0d0, the program computes default values (1/10 the average catch; 10 × the average catch), which are printed on the output.

Line 20: Minimum and maximum constraints on *r* (2 × real) ◗

These numbers are also used during bootstrap runs to identify and discard the erroneous solutions. If these values are set to 0.0d0, the program computes default values, which are printed on the output. Confidence intervals estimated through bootstrapping are conditional upon the true solution's being within these constraints.

Line 21: Random number seed (integer)

Use a large (7-digit) positive integer. Different numbers will result in different random number sequences. Using the same seed allows precise duplication of a previous run. Using a different seed should result in the same answer (within expected computation errors), If the answer is substantially different, at least one of the solutions was a local minimum (false solution). The preferable solution can be chosen by examining the total objective function for the runs. The run with the lower total represents a better solution.

Line 22: Number of years in data set (integer)

The total number of years covered by all data series. There may be overlap. For example, if the first series covers 1960 through 1969 and the second series covers 1965 through 1979, the total number of years is 20. If internal years in a series or between series are missing, they should nonetheless be included in computing this number.

Following lines: Individual data series

There should be one data block (group of lines) for each data series. Each block should include data for the total number of years being analyzed (line 15), with zeros inserted to mark missing values (e.g., years before the series begins or years of closure). Thus, each data block must be the same length. The composition of each block is as follows:

(a) On the starting line, the title for the block *(character, length up to 40)*

(b) On the next line, the code (from Table 1) for the type of data (*character, length 2)*

(c) Starting on the third line of the block, one data line for each year, with the following data on each line, separated by blank spaces:

- (c1) First number: the year or other ID number—*integers* that are consecutive from one line to the next and identical from block to block. The numbers should be four digits or less to print correctly on the output.
- (c2) Second number: a *real number* whose meaning depends on the series type. For type CE, it is the annual fishing effort rate. For type CC, the annual average CPUE (total yield over total effort) or other index of abundance in biomass. For types B0, B1, or B2, it is the stock-size estimate in biomass units. For types I0, I1, or I2, it is the stock-size index in biomass units; *Missing effort*—If the series is type CE or CC and the optimization mode is EFF, a missing value of effort or CPUE may represented here by a putting in a negative number, such as –1.0d0.
- (c3) Third number: a *real number* required for CE or CC series only, containing the total catch (yield in biomass) from the fishery for that year. For other types of series (B*x* or I*x*), this third number is not needed.

NOTE: Although catch-effort data are referred to as type CE, effort comes *before* catch (i.e., yield) on these lines. Similarly, CPUE precedes catch for type CC.

Input File Format—ASPIC-P

Please refer to "General Format Instructions" at the beginning of the preceding section. The control file for ASPIC-P is relatively short.

Line 1: Projection title (character)

A title for this projection run, length 70 characters or less, in single quotation marks. The output will also include the title from the original run, as obtained from the BIO file.

Line 2: Name of BIO file (character)

The name of the file created as ASPIC.BIO by the ASPIC bootstrap run. It may have been renamed. Put the name in single quotation marks. (This file contains the estimated population and mortality trajectories from each bootstrap trial.)

Line 3: Name of output file (character)

The name for the file to contain the output from ASPIC-P. *If the file already exists, it will be overwritten.*

Line 4: Any real number (not used)

A real number must be put here as a placeholder. I suggest using 0.0d0. The number is not used at present, but may be used in the future to specify that more stochasticity be used in the projections.

Line 5: Number of years to skip at beginning of plots (integer)

Recommended values: 0 to 3. The first few years of biomass and mortality estimates are especially imprecise. Also, analysis of certain data sets can give in very high estimated biomasses in the first few years. Omitting the first few years from the plots can be useful, for both these reasons.

Line 6: Number of years of projections (integer)

The maximum number is 10, the minimum is zero.

Following Lines: Projected yields or fishing mortality rates (real) and type indicators (character)

One real number and one character on each line. The number of lines is equal to the integer present on line 6. On each line, the real number represents the projected yield or fishing mortality rate, and the character tells whether the number is a yield or a relative fishing mortality rate. For example, if line 7 of the

CTL file reads

```
1.456d3      'Y'
```

this indicates that in the first projection year, a yield of 1,456 units would be taken. Thus 'Y' lines are used for running projections based on quota (TAC) management measures.

A next line (line 8) that reads

```
0.85d0            'F'
```

indicates that in the second projection year, the fishing effort rate will be 85% of the fishing effort rate in the final year of the original data. Thus 'F' lines are used for running projections based on proportional reductions in fishing mortality rate, even when the absolute present fishing mortality rate might not be known.

It is permissible to intermix 'F' lines and 'Y' lines.

✪ Interpretation of Results

This section explains some features of ASPIC output. In addition, it reviews several points important to remember when using ASPIC and attempting to interpret the results of ASPIC modeling runs. It may be useful to have some ASPIC output at hand while reading this material. Prager (1994) and Prager et al. (1996) contain additional discussion.

Precision of Parameter Estimates

Production models tend to estimate some quantities much more precisely than others. Among the quantities more precisely estimated are maximum sustainable yield (MSY), optimum effort (effort at MSY), and relative levels of stock biomass and exploitation. Relative levels would include the biomass level relative to the level at which MSY is attained and the level of fishing mortality relative to that at which MSY is attained. Thus it is useful to divide the stock-size estimates provided by ASPIC by the corresponding estimate of stock size at MSY (B_{MSY}). Similarly, one should divide estimates of fishing mortality rate F by F_{MSY} to obtain a relative estimate. Such normalization leads, in general, to more a more precise picture of the condition of the stock, because the resulting estimates cancel out the estimate of q, which is usually imprecise. For those reasons, ASPIC prints the normalized estimates on its output; ASPIC printer plots of these trajectories are normalized.

In contrast, absolute levels of stock biomass (and related quantities), which include uncertainty in the estimate of q, are usually estimated much less precisely. One cannot place nearly as much credence in the absolute estimates of stock size or any parameters that depend upon them. This would include estimates of the fishing mortality rate F. Plotting or otherwise using the estimated trajectories of F and B without normalizing them first may lead to false conclusions and is strongly discouraged. These values are provided for the modeler's information and are not intended to be used in assessments.

When two or more data series are analyzed, ratios of catchabilities are typically estimated much more precisely than the individual q's. For that reason, it is unwise to draw inferences from the individual coefficients unless auxiliary information supports the estimates and a bootstrap run of ASPIC shows that the coefficients are estimated precisely. Similar considerations apply to the estimates of K and r; it appears that these may at times be imprecise or biased without causing serious difficulties in estimating MSY and optimum effort.

The estimate of B_1/B_{MSY}, the starting biomass-ratio in the first year, is quite variable. It also tends to be quite high on some data sets, particularly when the initial years of data suggest a sharp decline in population size. For these reasons, it is generally not wise to use the ASPIC output to draw any inferences about the population biomass during the first few (3 to 5) years examined. This indeterminacy in production modeling is similar to the inability of VPA to say much about population dynamics in the most recent years unless auxiliary information is used. In practice, this does not seem to degrade the estimates of MSY and f_{MSY} when a reasonably long time series is used. Punt (1990) recommended fixing this value to 2.0 (rather than estimating it) for the Cape hake stock off southern Africa, but it is not clear that this would be appropriate generally. A similar approach is taken in using the penalty term described above.

Estimating Several Catchability Coefficients

A useful feature of ASPIC is its ability to use more than one data series for estimation. The analyst should be aware that the underlying assumption is that each series measures the abundance of the stock, except for random error. To put it another way, using this feature is similar to deriving an abundance index from each series and averaging them together. It is *not recommended* to use this facility when the series seem uncorrelated or negatively correlated. **It may be preferable to use an ANOVA to remove effects due to vessel type, area, gear, season, etc., before fitting a production model.** The resulting index of yearly abundance can then be used as a ‘CC’ series with the total catch. This provides quicker and more reliable estimation from ASPIC, but more importantly, it removes explainable variation from the data, variation that becomes noise when a population model is applied. On the other hand, using several series allows for iterative estimation of appropriate series weights and also allows examining the departure of each series from model predictions.

One can use ASPIC to estimate separate catchability coefficients for different periods of time. This is accomplished in practice, in ASPIC's terminology, by considering the periods of time to be separate fisheries on the same stock. This procedure can be used to examine hypotheses about changing catchability with time, perhaps as a result of changing fishing gear or changing environmental conditions. In interpreting such models, caution should be exercised in several areas.

An important concern is determining whether the improvement in fit obtained from a more complex model is statistically significant. An ASPIC model with time-varying catchability can be tested against the base model (i.e., the simpler model with constant catchability) with an *F*-ratio test. Here *F* is the *F* distribution of statistics, not to fishing mortality rate. The test statistic is

(2) $$F^{*} = \frac{(SSE_s - SSE_c) / \nu_1}{SSE_c / \nu_2},$$

where SSE_s and SSE_c are is the error sums of squares of the simple and complex models, respectively; ν_1 is the difference in number of estimated parameters between the two models; and ν_2 is the number of data points less the total number of estimated parameters. The quantity F^* can be looked up in standard tables of the *F*-distribution with ν_1 and ν_2 degrees of freedom.

A small program called FTEST is supplied with ASPIC to facilitate making certain such tests. The FTEST program assumes that the same data are used for both models, but just divided into different periods with different estimates of *q*. Theoretically, the weighting for the penalty term (line 11 in the ASPIC input file) should be set to zero when the *F*-ratio test is used; in practice, it is unlikely to make much difference. The FTEST program is interactive; it takes all input from the screen and directs all output there, also.

Three points must be kept in mind when using the *F*-ratio test for a hypothesis test on varying catchability. First, most hypothesis tests are invalid when they are suggested by examination of the data. For the significance probability to be correct, the test should be suggested by external information, such as changes in gear or oceanographic conditions. Second, the significance of a *series* of tests of significance may be exaggerated because of the accumulation of Type I errors. A single *F*-ratio test holds the chance of Type I error to the specified level. However, a series of such tests (for example, a series aimed at determining the exact year in which catchability may have changed) will in general not limit the experiment-wise chance of Type I error to the specified level. Of particular concern are series of tests that are not defined a priori as independent hypotheses to be tested, but rather are performed post hoc to search for a significant result. More information on this point can be obtained from a book on experimental statistics (e.g., Snedecor and Cochran 1980) or one on multiple comparisons (e.g., Klockars and Sax 1986). The third consideration is that all such hypothesis tests (not just those involving ASPIC) assume correct specification of the model. For this reason, significance probabilities obtained for *F*-tests on ASPIC must be considered approximations. This is especially important when there is evidence that the model does not fit well.

A nonparametric test of the null hypothesis $q_1 = q_2$ can be conducted as a supplement to the *F* test. This test is constructed by examining the bootstrap estimates of the ratio of the two catchability coefficients. As an example, assume that the alternative hypothesis is that $q_1 \neq q_2$. Then the null would be rejected at $P < 0.05$ if a bias-corrected 95% confidence interval on q_1/q_2 did not include the value 1.0. Like the *F* test, this test is approximate because of the possibility of specification error. In addition, bootstrapping residuals may underestimate the true variability present in a time series (Freedman and Peters 1984). This has been addressed to some degree in the current version of ASPIC by the adjustment made to the residuals before bootstrapping is begun.

A separate issue involves testing hypotheses involving many different catchability coefficients. An example of this type of test would be a 30-year series with a different q every 5 or 10 years. I suggest that such tests be avoided; estimates of so many different catchability coefficients are likely to be imprecise and may be confounded with changes in biomass over time. Theoretically, ASPIC could be modified to estimate a linear time-trend in catchability; the cost would be only one more parameter. For the reasons just expressed, I have not made this modification. If the modification is made in the future, it will be tested extensively with simulated data before being used on real examples.

✪ Estimation Difficulties

The information in this section is central to obtaining correct results. Please read it thoroughly.

The Nelder-Mead optimization method used in ASPIC is quite robust, but in unmodified form frequently stops at local minima (these represent sub-optimal solutions). This has been addressed in ASPIC by using a restarting algorithm that requires the same solution to be found three times in a row before it is accepted. In the author's experience, the resulting method is effective at avoiding local minima, and the resulting performance in that respect is as good as or better than other nonlinear optimization methods.

◆ Nonetheless, ASPIC, like other programs that attempt complex nonlinear optimization, occasionally finds local minima. Two features of the program—beyond the restarting algorithm already mentioned—are available to detect and remedy this problem. First, solutions obtained at local minima are often not reasonable, and this will often cause one of the parameters to be estimated at either its minimum or maximum constraints. In such a case, a warning message is printed, both on screen and in the output file.

A second feature that can help avoid local minima is an optional Monte Carlo phase of estimation. When enabled, this tries to improve the initial fit by randomly searching for a better one in the "neighborhood" of the initial fit. If multiple searches are enabled, a shorter Monte Carlo search takes place before restarts number 4, 8, 12, etc. Although these searches increase the time required to find a solution, they can be helpful in avoiding local minima. If a solution is difficult to find, it can help to enabling these searches.

When fitting data for which it is difficult to obtain convergence, it can be useful to make several runs with different random number seeds (in the user input file). Agreement among a number of runs suggests that the solution is a good one.

Occasionally ASPIC fails to converge to a minimum at all. This usually indicates one or both of these problems: (I) the data do not fit the model very well; or (ii) there is a wide array of solutions with nearly equivalent solutions. As a first step, it is wise to check the input file for typing errors (e.g., reversed catch and effort values). Occasionally, changing the maximum value of *F* allowed (line 10 of the ASPIC input file) can improve convergence, assuming the problem occurs in EFF optimization mode. If the objective function appears (from the screen output) to have been near convergence, simply trying a second ASPIC run that uses the first run's results as starting guesses can sometimes provide a solution. If the model includes several data sets (fisheries), it can be useful to eliminate one or more of them, at least temporarily, to see if convergence can be achieved.

If none of these suggestions are successful, estimates can often be made with the following strategy. Set one parameter (preferably *r*) to a fixed value by setting the corresponding estimation flag (line 18 of the ASPIC input file) to zero. A solution might be possible conditional upon that value of *r*. Because the maximum sustainable fishing mortality rate F_{MSY} under the logistic model is $r/2$, a suitable value of *r* for many species will be in the range 0.5 to 4.0. If this technique leads to a solution, a range of fixed values of *r* can be tried and the solutions examined. Similar values of the objective function among solutions indicate that the solutions are nearly equivalent in terms of fit. Although the solutions may show considerable variation in estimating absolute biomass level (for example), the variation in estimates of MSY and optimum effort are often much smaller. Thus conditional estimates may be useful, especially as confirmatory information or if little other information is available for management.

ASPIC has been tested on simulated and real data sets and is believed to operate correctly. However, bugs are possible in any computer program, and ASPIC is no exception. The author asks that users experiencing bugs or suspected bugs send him copies of the input and output files; he will attempt to correct any errors in the program.

Table 2. Sample input file for FIT mode with one catch-effort data series.

```
'FIT'                    ## Mode (FIT, IRF, BOT)
'ASPIC 3.82 Sample Input File (Table 2)'
'EFF'                    ## Error type ('EFF' = condition on yield)
 2                       ## Verbosity (0 to 4)
 600                     ## Number of bootstrap trials, <= 1000
 1 10000                 ## Monte Carlo search enable (0,1,2), N trials
 1.0E-8                  ## Convergence crit. for simplex
 3.0E-8                  ## Convergence crit. for restarts
 1.0d-4                  ## Convergence crit. for estimating effort
 8.0d0                   ## Maximum F when estimating effort
 0.0E+0                  ## Statistical weight for B1 > K as residual
 1                       ## Number of data series (fisheries)
1.0                      ## Statistical weights for fisheries
1.0d0                    ## B1/Bmsy (starting guess)
2.0d5                    ## MSY (starting guess)
0.4d0                    ## r (starting guess)
3.0d-0  3                ## q (starting guess)
1 1 1 1                  ## Flags to estimate parameters
2.0d3  5.0d5             ## Min and max allowable MSY
0.02d0  5.0d0            ## Min and max allowable r
9226738                  ## Random number seed
30                       ## Number of years of data.
'Sample Effort & Catch'  ## Title for first series
'CE'                     ## Type of series ('CE' = effort, catch)
 1960       6.45     5342
 1961       8.54    10189
 1962      24.45    11258
 1963      25.30     8652
 1964      31.39     9338
 1965      28.90     9084
 1966      40.11     9137
 1967      43.23     9138
 1968      38.47     9425
 1969      -1.00     5198
 1970      -1.00     4727
 1971      -1.00     6001
 1972      19.22     6301
 1973      22.97     8776
 1974      21.17     6587
 1975      18.14     6352
 1976      20.40    11797
 1977      40.13    11859
 1978      35.44    13527
 1979      34.85    11126
 1980      40.73    12832
 1981      55.10    14423
 1982      49.44    12516
 1983      59.55    14255
 1984      80.75    18278
 1985      98.91    19959
 1986      97.08    19137
 1987      90.46    17008
 1988      85.86    15594
 1989      69.86    13212
```

Table 3. Sample input file for FIT mode with three catch-effort data series.

```
'FIT'                  ## Mode (FIT, IRF, BOT)
'Run ASPIC 3.82 on Three Simulated Fisheries'   ## Title for run
'EFF'                  ## Error type ('EFF' = condition on yield)
2                      ## Verbosity (0 to 4)
1000                   ## Number of bootstrap trials, <= 1000
1 10000                ## Monte Carlo search enable (0,1,2), N trials
1d-8                   ## Convergence crit. for simplex
5d-8                   ## Convergence crit. for restarts
1.0d-4                 ## Convergence crit. for estimating effort
8.0                    ## Maximum F when estimating effort
0.0                    ## Statistical weight for B1 > K as residual
3                      ## Number of data series (fisheries)
1.0d0  1.0d0  1.0d0     ## Statistical weights for fisheries
1.8d0                   ## B1/Bmsy (starting guess)
2.0d3                   ## MSY (starting guess)
1.3d0                   ## r (starting guess)
4.5d-2  6.0d-2  3.5d-2  ## q (starting guess)
1 1 1 1 1 1             ## Flags to estimate parameters
0d0 0d0                 ## Min and max allowable MSY
0d0 0d0                 ## Min and max allowable K
1964485                 ## Random number seed
9                       ## Number of years of data.
'Simulated Fishery #1'  ## Title for first series
'CE'                    ## Type of series ('CE' = effort, catch)
1980   7.7875 4.2192E+02
1981   11.111 4.4575E+02
1982   16.544 5.7279E+02
1983   16.302 5.3010E+02
1984   19.147 5.2449E+02
1985   14.339 3.9559E+02
1986   20.398 5.6626E+02
1987   9.6367 3.4641E+02
1988   14.905 4.3601E+02
'Simulated Fishery #2'     ## Title for second series
'CE'
1980  1.9750  6.0747E+02
1981  2.8859  9.0609E+02
1982  3.0864  8.7100E+02
1983  4.2575  8.9157E+02
1984  4.5840  8.5011E+02
1985  3.9930  8.6846E+02
1986  3.7409  7.2824E+02
1987  2.3324  4.3912E+02
1988  2.0114  5.0764E+02
'Simulated Fishery #3'
'CE'
1980  1.3533 1.2634E+02
1981  1.5806 1.6050E+02
1982  3.8830 3.9948E+02
1983  2.5157 2.2136E+02
1984  6.3727 3.9617E+02
1985  2.6181 1.4913E+02
1986  1.1858 8.6338E+01
1987  4.8805 4.0916E+02
1988  2.2851 2.0067E+02
```

Sources Cited

Efron, B. E., and G. Gong. 1983. A leisurely look at the bootstrap, the jackknife, and cross-validation. Am. Statistician 47: 36–48.

Fox, W. W., Jr. 1971. Random variability and parameter estimation for the generalized production model. Fish. Bull. (U.S.) 69: 569–580.

Freedman, D. A., and S. C. Peters. 1984. Bootstrapping a regression equation: some empirical results. J. Am. Stat. Assn. 79: 97–106

Klockars, A. J., and G. Sax. 1986. Multiple comparisons. Sage University Paper series on Quantitative Applications in the Social Sciences, No. 07–61.

Pella, J. J. 1967. A study of methods to estimate the Schaefer model parameters with special reference to the yellowfin tuna fishery in the eastern tropical Pacific Ocean. Doctoral dissertation, University of Washington. 156 p.

Pella, J. J. and P. K. Tomlinson 1969. A generalized stock production model. Bull. Inter-Am. Trop. Tuna Comm. 13: 419–496.

Prager, M. H. 1992a. ASPIC: A Surplus-Production Model Incorporating Covariates. Coll. Vol. Sci. Pap., Int. Comm. Conserv. Atl. Tunas (ICCAT) 28: 218–229.

Prager, M. H. 1992b. Recent developments in extending the ASPIC production model. ICCAT Working Document SCRS/92/127. 10 pp.

Prager, M. H. 1994. A suite of extensions to a nonequilibrium surplus-production model. Fish. Bull. (U.S.) 92: 374–389.

Prager, M. H., C. P. Goodyear, and G. P. Scott. 1996. Application of a surplus production model to a swordfish-like simulated stock with time-changing gear selectivity. Trans. Am. Fish. Soc.125:729–740.

Punt, A. E. 1990. Is $B_1 = K$ an appropriate assumption when applying an observation error production-model estimator to catch–effort data? S. Afr. J. Mar. Sci. 9: 249–259.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Bull. Inter-Am. Trop. Tuna Comm. 1(2): 27–56.

Schaefer, M. B. 1957. A study of the dynamics of the fishery for yellowfin tuna in the eastern tropical Pacific Ocean. Inter-Am. Trop. Tuna Comm. Bull. 2: 247–268.

Snedecor, G. W., and W. G. Cochran. 1980. Statistical methods, 7th ed. Iowa State University Press, Ames. 507 pp.

Stine, R. 1990. An introduction to bootstrap methods: examples and ideas. *In* J. Fox and J. S. Long (eds.), Modern methods of data analysis, p. 325–373. Sage Publications, Newbury Park, California. 446 pp.

Appendix I. Program Changes

Changes in Version 3.33

Between version 2.8 and version 3.33, major changes were as follows:

- Addition of EFF mode (i.e., conditioning on yield) and estimation of missing effort
- Bias corrections of parameter estimates and population projections (in bootstrap mode)
- Computation of approximate bias-corrected confidence intervals on parameter estimates in bootstrap mode
- ASPIC-P program for computing bias corrected trajectories and projections with approximate nonparametric confidence intervals
- Plots were added to the program output
- The starting guess and estimate of B_1 are now specified as ratios to B_{MSY}, rather than as absolute quantities.
- Optional Monte Carlo phase to increase resistance to local minima.
- Added iterative reweighting (IRF mode) when analyzing several series
- User-specified limits on MSY and *K*, used to simplify analysis of bootstrapped runs
- Management benchmarks $F_{0.1}$ and $Y_{0.1}$ are computed along with F_{MSY} and MSY
- Added user-specified random number seed
- Added more descriptive error messages when an error is found in the input file

Changes in Version 3.55

Between version 3.33 and version 3.55, major changes were as follows:

- Added more statistics on stock status in final year
- Replaced K with MSY in parameterization
- Added CC series type to avoid manually converting CPUE to effort.
- Added CPUE plots to output
- Added correlation matrix among indices to output and error trap for negative correlations
- Revised IRF mode so that the sum of weights remains equal to the number of data points
- Added residual adjustment factor for bootstrapping

- Added “coverage” and “nearness” statistics
- Improved Monte Carlo search algorithm

Changes in Version 3.82

Between version 3.55 and version 3.82, major changes were as follows:

- Several improvements to Monte Carlo search routine
- Fixed bug in plotting index (I0, I1, I2) series and improved plot layouts
- Increased maximum number of years in data from 60 to 90
- Fixed a bug that didn’t replace bad bootstrap trials
- Added LaserJet code option for output files
- Changed output for CE data series from from observed and estimated effort to observed and estimated CPUE
- Fixed a crash when the number of bootstraps was set to 1
- Added printout of Monte Carlo setting to output file
- Allowed user to specify input file name on command line

APPENDIX 3. WORKED EXAMPLE

Input Data File

```
'FIT'                   ## Mode (FIT, IRF, BOT)
'ASPIC 3.6x Sample Input File (Table 2)'
'EFF'                   ## Error type ('EFF' = condition on yield)
 2                      ## Verbosity (0 to 4)
 600                    ## Number of bootstrap trials, <= 1000
 0 10000                ## Monte Carlo search enable (0,1,2), N trials
 1.0E-8                 ## Convergence crit. for simplex
 3.0E-8                 ## Convergence crit. for restarts
 1.0d-4                 ## Convergence crit. for estimating effort
 8.0d0                  ## Maximum F when estimating effort
 0.0E+0                 ## Statistical weight for B1 > K as residual
 1                      ## Number of data series (fisheries)
1d0                     ## Statistical weights for fisheries
1.0d0                   ## B1-ratio (starting guess)
2.0d5                   ## MSY (starting guess)
0.4d0                   ## r (starting guess)
3.0d-03                 ## q (starting guess)
1 1 1 1                 ## Flags to estimate parameters
2.0d3  5.0d5            ## Min and max allowable MSY
0.02d0  5.0d0           ## Min and max allowable r
9126738                 ## Random number seed
30                      ## Number of years of data.
'Sample Effort & Catch, Table 2' ## Title for first series
'CE'                    ## Type of series ('CE' = effort, catch)
 1960      6.45d0     5342d0
 1961      8.54d0    10189d0
 1962     24.45d0    11258d0
 1963     25.30d0     8652d0
 1964     31.39d0     9338d0
 1965     28.90d0     9084d0
 1966     40.11d0     9137d0
 1967     43.23d0     9138d0
 1968     38.47d0     9425d0
 1969     -1.00d0     5198d0
 1970     -1.00d0     4727d0
 1971     -1.00d0     6001d0
 1972     19.22d0     6301d0
 1973     22.97d0     8776d0
 1974     21.17d0     6587d0
 1975     18.14d0     6352d0
 1976     20.40d0    11797d0
 1977     40.13d0    11859d0
 1978     35.44d0    13527d0
 1979     34.85d0    11126d0
```

```
 1980      40.73d0    12832d0
 1981      55.10d0    14423d0
 1982      49.44d0    12516d0
 1983      59.55d0    14255d0
 1984      80.75d0    18278d0
 1985      98.91d0    19959d0
 1986      97.08d0    19137d0
 1987      90.46d0    17008d0
 1988      85.86d0    15594d0
 1989      69.86d0    13212d0
```

Output File

```
ASPIC 3.6x Sample Input File (Table 2)                                                                Page 1
                                                                                          02 Feb 1995 at 14:48

ASPIC -- A Surplus-Production Model Including Covariates (Ver. 3.61)                                FIT Mode

Author: Michael H. Prager
        National Marine Fisheries Service
        Southeast Fisheries Science Center
        Miami, Florida  33149  USA


CONTROL PARAMETERS USED (FROM INPUT FILE)
------------------------------------------------------------------------------------------------------------------------
Number of years analyzed:                     30            Number of bootstrap trials:                          0
Number of data series:                         1            Lower bound on MSY:                          2.000E+03
Objective function computed:           in EFFORT            Upper bound on MSY:                          5.000E+05
Relative conv. criterion (simplex):    1.000E-08            Lower bound on r:                            2.000E-02
Relative conv. criterion (restart):    3.000E-08            Upper bound on r:                            5.000E+00
Relative conv. criterion (effort):     1.000E-04            Random number seed:                            9126738
Maximum F allowed in fitting:              8.000            Monte Carlo search trials:                           0


PROGRAM STATUS INFORMATION (NON-BOOTSTRAPPED ANALYSIS)                                                     code  0
------------------------------------------------------------------------------------------------------------------------
Normal convergence.


GOODNESS-OF-FIT AND WEIGHTING FOR NON-BOOTSTRAPPED ANALYSIS
------------------------------------------------------------------------------------------------------------------------
                                                    Weighted             Weighted      Current    Suggested    R-squared
Loss component number and title                          SSE    N             MSE       weight       weight      in CPUE

Loss(-1)  SSE in yield                             0.000E+00
Loss( 0)  Penalty for B1R > 2                      0.000E+00    1             N/A    0.000E+00          N/A
Loss( 1)  Sample Effort & Catch, Table 2           1.527E+00   27       6.110E-02    1.000E+00    1.000E+00        0.574
```

```
TOTAL OBJECTIVE FUNCTION:                         1.52743015E+00

Number of restarts required for convergence:              2
Est. B-ratio coverage index (0 worst, 2 best):       1.0781
Est. B-ratio nearness index (0 worst, 1 best):       1.0000

MODEL PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                             Estimate     Starting guess    Estimated   User guess

B1R       Biomass ratio in 1960                      8.567E+00          1.000E+00            1            1
MSY       Maximum sustainable yield                  1.382E+04          2.000E+05            1            1
r         Intrinsic rate of increase                 5.137E-01          4.000E-01            1            1
........  Catchability coefficients by fishery:
q( 1)     Sample Effort & Catch, Table 2             3.541E-03          3.000E-03            1            1

MANAGEMENT PARAMETER ESTIMATES (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------
Parameter                                             Estimate            Formula

MSY       Maximum sustainable yield                  1.382E+04               Kr/4
K         Maximum stock biomass                      1.076E+05
Bmsy      Stock biomass at MSY                       5.381E+04                K/2
Fmsy      Fishing mortality at MSY                   2.569E-01                r/2

F(0.1)    Management benchmark                       2.312E-01          0.9*Fmsy
Y(0.1)    Equilibrium yield at F(0.1)                1.368E+04          0.99*MSY

B-ratio   Ratio of B(1990) to Bmsy                   9.318E-01
F-ratio   Ratio of F(1989) to Fmsy                   1.031E+00
Y-ratio   Proportion of MSY avail in 1990            9.954E-01          2*Br-Br^2    Ye(1990) = 1.376E+04

........  Fishing effort at MSY in units of each fishery:
fmsy( 1)  Sample Effort & Catch, Table 2             7.255E+01          r/2q( 1)      f(0.1) = 6.530E+01
```



```
ESTIMATED POPULATION TRAJECTORY (NON-BOOTSTRAPPED)
------------------------------------------------------------------------------------------------------------------------

           Estimated   Estimated    Estimated     Observed        Model    Estimated      Ratio of      Ratio of
     Year      total    starting      average        total        total      surplus        F mort       biomass
Obs or ID     F mort     biomass      biomass        yield        yield   production       to Fmsy       to Bmsy

  1  1960      0.019   4.608E+05    2.822E+05    5.342E+03    5.342E+03   -2.590E+05     7.370E-02     8.565E+00
  2  1961      0.062   1.965E+05    1.638E+05    1.019E+04    1.019E+04   -4.511E+04     2.422E-01     3.652E+00
```

3	1962	0.088	1.412E+05	1.278E+05	1.126E+04	1.126E+04	-1.251E+04	3.431E-01	2.624E+00
4	1963	0.078	1.174E+05	1.115E+05	8.652E+03	8.652E+03	-2.114E+03	3.021E-01	2.183E+00
5	1964	0.091	1.067E+05	1.028E+05	9.338E+03	9.338E+03	2.322E+03	3.535E-01	1.983E+00
6	1965	0.093	9.965E+04	9.732E+04	9.084E+03	9.084E+03	4.773E+03	3.634E-01	1.852E+00
7	1966	0.097	9.534E+04	9.376E+04	9.137E+03	9.137E+03	6.196E+03	3.794E-01	1.772E+00
8	1967	0.100	9.240E+04	9.131E+04	9.138E+03	9.138E+03	7.103E+03	3.896E-01	1.717E+00
9	1968	0.105	9.037E+04	8.947E+04	9.425E+03	9.425E+03	7.747E+03	4.101E-01	1.680E+00
10	1969	0.058	8.869E+04	8.996E+04	5.198E+03	5.198E+03	7.577E+03	2.249E-01	1.648E+00
11	1970	0.051	9.107E+04	9.217E+04	4.727E+03	4.727E+03	6.790E+03	1.997E-01	1.693E+00
12	1971	0.064	9.313E+04	9.333E+04	6.001E+03	6.001E+03	6.363E+03	2.503E-01	1.731E+00
13	1972	0.067	9.349E+04	9.349E+04	6.301E+03	6.301E+03	6.300E+03	2.624E-01	1.738E+00
14	1973	0.095	9.349E+04	9.238E+04	8.776E+03	8.776E+03	6.713E+03	3.698E-01	1.738E+00
15	1974	0.072	9.143E+04	9.164E+04	6.587E+03	6.587E+03	6.984E+03	2.798E-01	1.699E+00
16	1975	0.069	9.183E+04	9.208E+04	6.352E+03	6.352E+03	6.825E+03	2.686E-01	1.707E+00
17	1976	0.131	9.230E+04	9.001E+04	1.180E+04	1.180E+04	7.554E+03	5.102E-01	1.715E+00
18	1977	0.137	8.806E+04	8.639E+04	1.186E+04	1.186E+04	8.748E+03	5.344E-01	1.637E+00
19	1978	0.163	8.495E+04	8.293E+04	1.353E+04	1.353E+04	9.765E+03	6.350E-01	1.579E+00
20	1979	0.138	8.119E+04	8.077E+04	1.113E+04	1.113E+04	1.035E+04	5.363E-01	1.509E+00
21	1980	0.162	8.041E+04	7.928E+04	1.283E+04	1.283E+04	1.072E+04	6.301E-01	1.494E+00
22	1981	0.188	7.830E+04	7.664E+04	1.442E+04	1.442E+04	1.133E+04	7.326E-01	1.455E+00
23	1982	0.167	7.520E+04	7.478E+04	1.252E+04	1.252E+04	1.172E+04	6.516E-01	1.398E+00
24	1983	0.195	7.440E+04	7.322E+04	1.426E+04	1.426E+04	1.202E+04	7.580E-01	1.383E+00
25	1984	0.264	7.217E+04	6.918E+04	1.828E+04	1.828E+04	1.268E+04	1.029E+00	1.341E+00
26	1985	0.316	6.657E+04	6.307E+04	1.996E+04	1.996E+04	1.339E+04	1.232E+00	1.237E+00
27	1986	0.335	6.001E+04	5.715E+04	1.914E+04	1.914E+04	1.376E+04	1.304E+00	1.115E+00
28	1987	0.321	5.462E+04	5.294E+04	1.701E+04	1.701E+04	1.381E+04	1.251E+00	1.015E+00
29	1988	0.309	5.143E+04	5.047E+04	1.559E+04	1.559E+04	1.377E+04	1.203E+00	9.559E-01
30	1989	0.265	4.960E+04	4.988E+04	1.321E+04	1.321E+04	1.375E+04	1.031E+00	9.219E-01
31	1990		5.014E+04						9.318E-01

RESULTS FOR DATA SERIES # 1 (NON-BOOTSTRAPPED) Sample Effort & Catch, Table 2

Data type CE: Effort-catch series Series weight: 1.000

Obs	Year	Observed effort	Estimated effort	Estim F	Observed yield	Model yield	Resid in log effort	Resid in yield
1	1960	6.450E+00	5.347E+00	0.0189	5.342E+03	5.342E+03	0.18759	0.000E+00
2	1961	8.540E+00	1.757E+01	0.0622	1.019E+04	1.019E+04	-0.72140	0.000E+00
3	1962	2.445E+01	2.489E+01	0.0881	1.126E+04	1.126E+04	-0.01773	0.000E+00
4	1963	2.530E+01	2.192E+01	0.0776	8.652E+03	8.652E+03	0.14354	0.000E+00
5	1964	3.139E+01	2.565E+01	0.0908	9.338E+03	9.338E+03	0.20212	0.000E+00
6	1965	2.890E+01	2.636E+01	0.0933	9.084E+03	9.084E+03	0.09188	0.000E+00
7	1966	4.011E+01	2.752E+01	0.0975	9.137E+03	9.137E+03	0.37657	0.000E+00
8	1967	4.323E+01	2.826E+01	0.1001	9.138E+03	9.138E+03	0.42491	0.000E+00
9	1968	3.847E+01	2.975E+01	0.1053	9.425E+03	9.425E+03	0.25697	0.000E+00
10	1969	*	1.632E+01	0.0578	5.198E+03	5.198E+03	0.00000	0.000E+00

11	1970	*	1.448E+01	0.0513	4.727E+03	4.727E+03	0.00000	0.000E+00
12	1971	*	1.816E+01	0.0643	6.001E+03	6.001E+03	0.00000	0.000E+00
13	1972	1.922E+01	1.903E+01	0.0674	6.301E+03	6.301E+03	0.00972	0.000E+00
14	1973	2.297E+01	2.683E+01	0.0950	8.776E+03	8.776E+03	-0.15532	0.000E+00
15	1974	2.117E+01	2.030E+01	0.0719	6.587E+03	6.587E+03	0.04197	0.000E+00
16	1975	1.814E+01	1.948E+01	0.0690	6.352E+03	6.352E+03	-0.07139	0.000E+00
17	1976	2.040E+01	3.701E+01	0.1311	1.180E+04	1.180E+04	-0.59579	0.000E+00
18	1977	4.013E+01	3.877E+01	0.1373	1.186E+04	1.186E+04	0.03446	0.000E+00
19	1978	3.544E+01	4.607E+01	0.1631	1.353E+04	1.353E+04	-0.26228	0.000E+00
20	1979	3.485E+01	3.890E+01	0.1377	1.113E+04	1.113E+04	-0.11003	0.000E+00
21	1980	4.073E+01	4.571E+01	0.1619	1.283E+04	1.283E+04	-0.11539	0.000E+00
22	1981	5.510E+01	5.315E+01	0.1882	1.442E+04	1.442E+04	0.03607	0.000E+00
23	1982	4.944E+01	4.727E+01	0.1674	1.252E+04	1.252E+04	0.04485	0.000E+00
24	1983	5.955E+01	5.499E+01	0.1947	1.426E+04	1.426E+04	0.07970	0.000E+00
25	1984	8.075E+01	7.462E+01	0.2642	1.828E+04	1.828E+04	0.07893	0.000E+00
26	1985	9.891E+01	8.938E+01	0.3165	1.996E+04	1.996E+04	0.10130	0.000E+00
27	1986	9.708E+01	9.457E+01	0.3349	1.914E+04	1.914E+04	0.02618	0.000E+00
28	1987	9.046E+01	9.073E+01	0.3212	1.701E+04	1.701E+04	-0.00295	0.000E+00
29	1988	8.586E+01	8.725E+01	0.3089	1.559E+04	1.559E+04	-0.01612	0.000E+00
30	1989	6.986E+01	7.481E+01	0.2649	1.321E+04	1.321E+04	-0.06841	0.000E+00

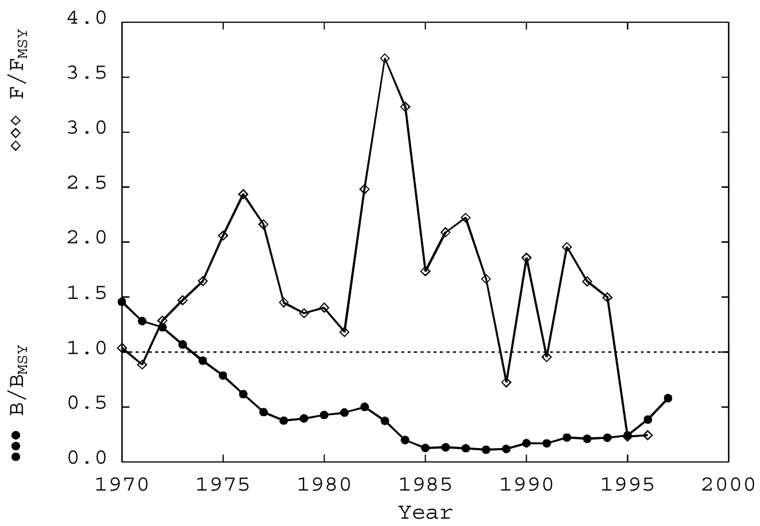
* Asterisk indicates missing value(s).

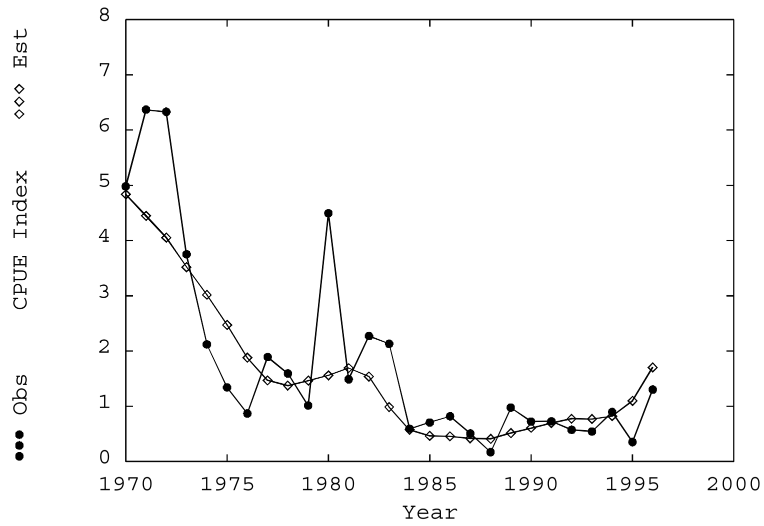
```
UNWEIGHTED LOG RESIDUAL PLOT FOR DATA SERIES # 1
                   -1       -0.75     -0.5     -0.25       0        0.25      0.5       0.75      1
                    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |    .    |
Year   Residual    ----------------------------------------------------------------------------------
1960     0.1876                                            |========
1961    -0.7214                 =============================|
1962    -0.0177                                           =|
1963     0.1435                                            |======
1964     0.2021                                            |========
1965     0.0919                                            |====
1966     0.3766                                            |===============
1967     0.4249                                            |=================
1968     0.2570                                            |==========
1969     0.0000                                            |
1970     0.0000                                            |
1971     0.0000                                            |
1972     0.0097                                            |
1973    -0.1553                                      ======|
1974     0.0420                                            |==
1975    -0.0714                                         ===|
1976    -0.5958                      ========================|
1977     0.0345                                            |=
1978    -0.2623                                  ==========|
1979    -0.1100                                        ====|
1980    -0.1154                                       =====|
1981     0.0361                                            |=
```

```
1982     0.0448                                             |==
1983     0.0797                                             |===
1984     0.0789                                             |===
1985     0.1013                                             |====
1986     0.0262                                             |=
1987    -0.0030                                             |
1988    -0.0161                                            =|
1989    -0.0684                                          ===|
                   -------------------------------------------------------------------------------------
ASPIC 3.6x Sample Input File (Table 2)                                                                  Page  4

                Observed (O) and Estimated (*) CPUE for Data Series # 1 -- Sample Effort & Catch, Table 2
           :
           :
    1400. -:
           :
           :
           :
           :
    1200. -:       O
           :
           :
           :
           :
    1000. -:   *
           :
           :
           :
           :   O
     800. -:
           :
           :
           :
           :
     600. -:
           :       *                                                 O
           :
           :          O
           :          *
     400. -:             *                                 O               O
           :             O   *  *                                O
           :                    O  *   *  *  *   *  *  2   *  2  *   *  *      O  O
           :                 O                                          O  *   *  *  2   *
           :                       O      O                                              O  2  2   *
     200. -:                           O                                                           O  2  2   O  O
           :                                                                                                 *  *
           :
           :
           :
```

```
  0. -:
      :........................................................................................................
       :         :         :         :         :         :         :         :         :         :         :
    1959.     1962.     1965.     1968.     1971.     1974.     1977.     1980.     1983.     1986.     1989.

                              Time Plot of Estimated F-Ratio and B-Ratio
      :
      :
10.5 -:
      :
      :
      :
      :
 9.0 -:
      :   B
      :
      :
      :
 7.5 -:
      :
      :
      :
      :
 6.0 -:
      :
      :
      :
      :
 4.5 -:
      :
      :
      :       B
      :
 3.0 -:
      :          B
      :
      :             B   B
      :                    B  B   B  B      B  B  B   B  B  B   B
 1.5 -:                                 B                          B  B   B  B  B   B  B
      :                                                                                   B   2  2  F   F
      :   -   -  -  -   -  -  -   -  -  -   -  -  -   -  -  -   -  -  -   -  -  -   -  2  2   -  -  2   2  3  2
      :                                                          F  F  F   F  F  F   F
      :       F  F  F   F  F  F   F  F  F   F  F  F   F  F  F
 0.0 -:   F
      :........................................................................................................
       :         :         :         :         :         :         :         :         :         :         :
    1959.     1962.     1965.     1968.     1971.     1974.     1977.     1980.     1983.     1986.     1989.
```

Example AGRAPH Figures





APPENDIX 4. SOURCE CODE

A copy of the entire source code has been filed with the Secretariat and the full source code is available from the author on request. The source code reproduced here contains several major non-proprietary sections of the ASPIC program. These are provided for the benefit of advanced users and neither the author nor the ICCAT Secretariat intends to provide any guidance on using or interpreting this computer code. Important: If any of the source code is used in any way, the author requests that Prager (1994) be cited and the source of the code be acknowledged.

```
! ============================================================
  MODULE MYKINDS
     integer, parameter   :: real4 = selected_real_kind(6,37)
     integer, parameter   :: r8 = selected_real_kind(15,307)
  END MODULE MYKINDS
! ============================================================

! ====================================================================
! File ASPICVAR.F90      Variables MODULE for ASPIC   rev. June 1998
! ====================================================================
!     INDEXES:    i is fishery (i = 1 ... nq, nq <= 5)
!                 When i=0 the amount is the total.
!                 j is year (j = 1 ... nyr, nyr < 90)
!
!     VARIABLES:
!
!     B1rgues     Starting guess, B1-ratio               (input)
!     B1rgues2    Starting guess, B1-ratio               (computed)
!     B1wt        Weight for min((B1 - K),0) in loss fn. (input)
!     bio(j)      Starting population biomass            (computed)
!     bbar(j)     Average population biomass             (computed)
!     corr(i,j)   Correlation between CPUE i,j,i<j       (computed)
!     cover(k)    Coverage index of B,F,combined         (computed)
!     cpue(i,j)   CPUE, fishery i, year j                (either)
!     cpuehat(i,j)Estimated CPUE, fishery i, year j      (either)
!     debug       Logical                                (derived)
!     eflag(i)    Flag: 1=estimate parm, 0=fix parm      (input)
!     emph(i)     Emphasis for fishery i                 (input)
!     emsy(i)     Current estimates of effort at MSY     (computed)
!     eps1        Relative conv. crit. within simplex    (input)
!     eps2        Relative conv. crit. for restarts      (input)
!     eps3        Relative conv. crit. for estimated F   (input)
!     etype       Type of error: CAT or EFF              (input)
!     f(i,j)      Observed fishing effort for year j     (input)
!     fhat(i,j)   Estimated fishing effort for year j    (computed)
!     ferr(i)     CV of added error in effort            (input, SIM)
!     fstart(j)   Starting guess for F(j) when error in f(computed)
!     yerr(i)     CV of added error in yield             (input,SIM)
!     fmort(i,j)  Instantaneous fishing mortality        (computed)
!     fmsy        Current estimate of F at MSY           (computed)
!     ib          Current bootstrap trial #              (internal)
!     ipage       Current page number for output         (internal)
!     ipctl       User percentile for CI's               (input)
!     ID(j)       ID #; i.e., year                       (input)
!     isearch     Flag for Monte Carlo Search 0...3      (input)
!     near        Nearness index of B, F, combined       (computed)
!     nsearch     Number of Monte Carlo trials to search (input)
!     kgues2      Starting guess, K (carrying cap.)      (computed)
!     kmin        Minimum allowed K                      (input or computed)
!     kmax        Maximum allowed K                      (input or computed)
!     like(i)     Individual loss function components    (computed)
!     maxf        Maximum allowed F                      (input)
!     msygues     Starting guess for MSY                 (input)
!     msymin      Lower limit on MSY for boot            (input or computed)
!     msymax      Upper limit on MSY for boot            (input or computed)
!     nboot       Number of bootstrap trials, < 1000     (input)
!     nobs(i,j)   Number of nonzero, nonmissing obs.     (computed)
```