Development and testing of a dynamic model for data from recreational fisheries

N. G. Hall

Project No. 2002/075

Fisheries Research and Development Corporation Report

FRDC project 2002/075

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FINAL REPORT

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January 2005

ISBN: 86905-871-1

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Table of Contents

2002/075	Development and testing of a dynamic model for data from recreational fisheries.

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Objectives

1. To develop a dynamic fishery model that uses those types of data, which are typically available for recreational fisheries.
2. To assess the suitability of the model in providing a tool that fisheries agencies might use to investigate the trade-off between the cost and the resultant benefit for stock assessment associated with different frequencies of such surveys.
3. To assess the suitability of the model in providing an approach that might be used by fisheries agencies to investigate the consequences for subsequent stock assessment of reducing the proportion of the catch that is allocated to the commercial fishing sector.

NON-TECHNICAL SUMMARY:

OUTCOMES ACHIEVED TO DATE

1. A dynamic fishery model is now available to assess the state of fish stocks which are fished by both commercial and recreational fishers and for which the available data are not amenable to fishery models traditionally applied to commercial fisheries data.

2. A method for determining the impact of changes to the frequency of recreational fishing surveys on the accuracy and precision of stock assessment has been developed. This provides a "tool" that enables fisheries agencies to consider more adequately the cost-effectiveness of the sampling regime they should adopt.

3. A tool has been developed to enable exploration of the impact of decisions related to the re-allocation of catch from the commercial to the recreational sector on the accuracy and precision of the subsequent stock assessments.

Dynamic fishery models are the basic “tools” used by fisheries scientists to assess the state of a fish stock and the current level of exploitation of that stock, and to determine whether the stock is able to sustain the current level of fishing mortality. They provide the typical methods used by scientists to assess the impacts on catches and on the spawning stock of alternative harvest strategies and fishery regulations. Traditionally, the single-species, single-area models that are employed by scientists require data on the time series of total catches that have been removed from the stock and on the time series of abundance indices (*e.g.* catch per unit of effort (cpue)) that result from those removals. Biological and fishery data such as growth curves, maturity-length relationships, net selectivity, results from tagging studies, and age-composition data are also employed where these data are available. Typically, these models use simple book-keeping approaches to keep track of the numbers of fish within each age class and attempt to match predictions of the abundance indices with those corresponding values that were observed for the fishery.

Despite their importance to the community, formal stock assessments using dynamic fishery models have not been undertaken for the majority of Western Australia's recreational finfish fisheries. Instead, fisheries scientists have relied on values of fishing mortality estimated from age composition data, which have been based on assumptions that fish stocks are in equilibrium. These assumptions are unlikely to be valid and models based on such assumptions must be used with appropriate caution. However, the lack of a time series of data on total catches has precluded the use of traditional fisheries models for recreational finfish fisheries. While data from the commercial fishing sector is readily available, the cost and difficulty of obtaining reliable fishery data from the recreational sector precludes the acquisition of such data on an annual basis and it is only in the last two decades that creel censuses have been conducted on a regular but infrequent basis in Western Australia. The data derived from these creel censuses have been invaluable in identifying the magnitude of the recreational catches, however, until now, the ability to use these data in appropriate dynamic fishery models has been lacking.

In this FRDC study, a dynamic fishery model that uses the types of data available for Western Australia's recreational finfish fisheries has been developed and tested. The input required for this model was a time series of catch and effort data for the commercial fishing sector, catch estimates for the recreational sector (for at least two years), and age compositions for several years. Such recreational and age-composition data might reflect the data arising from an occasional creel census of the recreational catch. Input was also required of parameter estimates for the growth equations, the weight-length relationships, the maturity and selection ogives, the sex ratio of recruits and the instantaneous rate of natural mortality, M.

The study has demonstrated that, with simulated test data, it is able to produce parameter estimates that are likely to be consistent with those used to generate the test data but that the accuracy and precision of the resulting parameter estimates will be sensitive to the frequency at which recreational data are collected, the accuracy of input data such as the value used as the estimate of the instantaneous rate of natural mortality, and the precision of the catch and cpue data from the commercial fishery. It has also demonstrated how the model can be used to investigate the impact on the accuracy and precision of parameter estimates of reduced frequency of data collection for the recreational fishing sector, thereby illustrating how this approach might be used to investigate the trade-off between the cost and the resultant benefit for stock assessment associated with different frequencies of such surveys. An important implication of the study is that continued availability of an appropriate time series of abundance indices, such as that provided by the commercial fishing sector, is essential if reliable stock assessments are to be developed using dynamic fishery models.

With the types of data that are currently available for Western Australia's finfish fisheries, the model that has been developed in this study is likely to prove invaluable in addressing current needs for stock assessment and the provision of the advice required for integrated fisheries management.

KEYWORDS: model, stock assessment, recreational fishery, creel census, integrated fishery management

ACKNOWLEDGEMENTS

We are most grateful to the FRDC and to Murdoch University for the financial support that has made this study possible, and to WAFIC, RecFishWest and the Department of Fisheries Western Australia for their support of the project.

BACKGROUND

The status of stocks of finfish, that are the target species for fisheries with a significant recreational fishing sector, are difficult to assess. This problem arises because appropriate time series of total catch and effort data, which form the basis for most dynamic fisheries models, are usually not available for such fisheries, thus hampering the ability to determine the magnitudes of the catches that might be sustainable. The determination of such catches relies on an assessment of the current state of the fish stocks and the likely response of those stocks to different management strategies. In many recreational fisheries, the lack of the types of data that are essential for fishery modelling is now exacerbated by the loss of adequate commercial catch and effort statistics as catches are re-allocated from the commercial to the recreational fishing sector. There is little doubt that, as such recreational fisheries are subjected to an increasing level of fishing pressure, fishery managers and recreational fishers will be demanding more accurate and timely stock assessments and more robust management strategies. Methods are urgently required that will overcome the deficiencies that exist within the data that are available.

Finfish stocks throughout Australia are being exposed to increasing levels of fishing effort. Recreational fishing effort has risen as the population has grown and participation rates have increased, while, despite tighter controls on commercial fishing, greater competition and demand have often led to increased fishing power and higher exploitation by commercial fishers. The growth in recreational fishing effort has also been a consequence of improved access to fishing locations and of developments in fishing gear and technology. Inevitably, these increases in fishing effort and efficiency have placed greater pressure on the stocks of finfish that are exploited. An increasing level of competition for the nearshore fish stocks has resulted in pressure being exerted by recreational fishers to reduce the level of commercial fishing on these stocks, thereby allowing the fish that might previously have been caught by commercial fishers to be exploited by the recreational anglers. Such allocation issues have been at the forefront of many of the planning decisions considered by fisheries managers, while concerns regarding stock status and the need to ensure sustainability of the fish stocks have been addressed by setting bag limits and appropriate legal sizes that, based on information regarding the biology of the various fish species, would be likely to ensure that the fish survive to reach maturity and would thus have the opportunity to breed before becoming exposed to fishing mortality.

The collection of catch and effort data from the recreational fishing sector is expensive. As a consequence, creel census surveys of the recreational fishing within a region are usually undertaken infrequently. In Western Australia, for example, the Department of Fisheries has adopted a five-year cycle of creel census surveys to provide coverage of the different regions along the Western Australian coastline. Even with this low frequency of survey, the cost of these annual surveys is considerable as they require a team of interviewers operating throughout the year.

Creel census surveys of recreational fishing, collection of catch and effort data from commercial fishers and research on the biology of the various target species have been invaluable in providing sufficient data to assist managers in determining both an appropriate allocation of catches between fishing sectors and appropriate size limits. However, because these recreational surveys are usually not conducted annually, considerable difficulty has been experienced by fisheries scientists in undertaking the assessments that are necessary for the provision of advice regarding the status of fish stocks and whether current fishing levels are sustainable, or in evaluating the effectiveness of alternative management strategies in achieving management objectives. With increasing exploitation, the provision of such advice becomes of greater importance.

Unfortunately, the conventional approaches used by fisheries scientists, when assessing commercial fisheries, break down when faced with the types of data that are typically available for fisheries within which the recreational sector takes a significant proportion of the total catch. For commercial fisheries, stock assessment and evaluation of alternative management strategies are undertaken using dynamic fisheries models, which conventionally require time series of catch and effort data from all sectors of the fishery. For recreational fisheries, such data are often not available, thereby precluding the use of these traditional approaches to fisheries modelling. However, in specific fisheries where there is a well-defined population of recreational fishers (such as the licensed recreational rock lobster fishers), mail and telephone surveys have proven to be cost-effective and are able to provide estimates of the annual catch and effort from the recreational sector. Similarly, in recreational fisheries such as that for Roe's abalone along the coastline in the Perth metropolitan region, the fishery is confined in both space and time, making it possible to undertake cost-effective annual surveys. Nevertheless, annual surveys of recreational catch and effort are prohibitively expensive for the typical recreational fishery.

As exploitation of nearshore finfish stocks continues to increase, the development of modelling approaches that will allow the assessment of the status of fisheries, which have a significant recreational component, is becoming increasingly urgent. Equally urgent is an evaluation of the adequacy of infrequent, expensive creel census surveys in providing the data that are essential if such assessments are to be undertaken. Are more frequent surveys required, or would a reduction in frequency result in a marked increase in the uncertainty of the resulting stock assessments? It is also becoming increasingly urgent that the value of the commercial fisheries statistics for the assessment of recreational fisheries should be examined. This is necessary so that management decisions regarding any re-allocation of catches from the commercial to the recreational fishing sector are made with an understanding of the potential value for subsequent fisheries stock assessment of the catch and effort statistics provided by the commercial fisheries sector.

NEED

Models are urgently required that will allow stock assessment for fisheries in which a significant component of the catch is taken by recreational fishers, where these models will rely on abundance indices from the commercial fishery, occasional length or age composition samples from the total catch and occasional estimates of total catch. Given the expense associated with recreational surveys, there is a need for the development of an approach that would allow determination of an appropriate frequency for such creel censuses in order that they might provide the data necessary to achieve a specified level of precision from the resulting stock assessment. A method is required that will allow an assessment of the value of data derived from commercial fisheries statistics for use in assessing the stocks that are shared by recreational and commercial fishers, prior to making final management decisions on catch re-allocation from the commercial to the recreational fishing sector.

OBJECTIVES

1. To develop a dynamic fishery model that uses those types of data, which are typically available for recreational fisheries.
2. To assess the suitability of the model in providing a tool that fisheries agencies might use to investigate the trade-off between the cost and the resultant benefit for stock assessment associated with different frequencies of such surveys.
3. To assess the suitability of the model in providing an approach that might be used by fisheries agencies to investigate the consequences for subsequent stock assessment of reducing the proportion of the catch that is allocated to the commercial fishing sector.

METHODS

THE MODEL

Time steps

Annual time steps, which were aligned with the birth date of the fish, were used in the model. Thus, the first event simulated in each time step within the model was the determination of the spawning biomass and the calculation of the number of new recruits to the fishery.

Growth in length and weight

The fish are assumed to grow in accordance with the von Bertalanffy growth equation, thus the length at age of the fish of gender *g* (1 = males, 2 = females) may be calculated as

$$L_{a,g} = L_{\infty,g}\left\{1-\exp\left[-K_g\left(a-t_{0,g}\right)\right]\right\}$$

where $L_{a,g}$ is the length at age *a* years, $L_{\infty,g}$ is the expected asymptotic length, K_g determines the rate at which expected length at age approaches the asymptotic length and $t_{0,g}$ is the theoretical age at which the expected length would be zero. As the start of the time step corresponds with the birth date, lengths determined for integral values of age using the above equation correspond to the lengths at age at the beginning of the time step. An estimate of the length at age midway through each time step, *i.e.* each biological year, may be obtained using the equation

$$L_{a+0.5,g} = L_{\infty,g}\left\{1-\exp\left[-K_g\left(a+0.5-t_{0,g}\right)\right]\right\},$$

A value calculated using this equation has been termed the length at "mid-age".

The weights of the individual fish of each gender at each age, $W_{a,g}$, and mid-age, $W_{a+0.5,g}$, may be calculated from these lengths at age using the weight-length relationship, $W = aL^b$.

Number of fish in the unexploited stock

The model tracks the numbers of fish, $N_{a,g,t}$, of each sex g from recruitment at age $a = 0$ to a maximum age of A years through each year, t. In the unexploited stock, fish are assumed to be exposed to an instantaneous rate of natural mortality, M. The number of fish of age a ($0 \le a \le A$) and gender g at year t is denoted by $N_{a,g,t}$, where, for the unexploited stock at year $t = 0$,

$$N_{a,g,0} = \begin{cases} R_g^* \exp(-aM) & 0 \le a < A \\ R_g^* \exp(-aM)/[1-\exp(-M)] & a = A \end{cases}$$

In this equation, R_g^* is the virgin recruitment (age 0 years) of fish of gender g.

Stock-recruitment relationship

Recruitment of age 0 fish to the stock was assumed to be related to the biomass of mature females at the beginning of the time step. This spawning stock, *i.e.* the biomass of mature females in year t, is denoted by S_t, where

$$S_t = \sum_{a=1}^{A} p_a N_{a,2,t} W_{a,2} ,$$

p_a is the proportion of females of age a that are mature and $W_{a,g}$ is the body weight of fish of age a and gender g at the start of the biological year (*i.e.* at the time of spawning).

The form of the Beverton and Holt stock-recruitment relationship used in the model is

$$\hat{R}_t = \frac{a_{SRR} S_t}{b_{SRR} + S_t}$$

where $\hat{R}_t$ is the expected number of age 0 recruits in year *t* and a_{SRR} and b_{SRR} are parameters of the equation. The actual parameters of the stock-recruitment relationship used in the model are the virgin recruitment (age 0 years), R^*, and steepness, z, from which a_{SRR} and b_{SRR} may be calculated as

$$a_{SRR} = \frac{S^*}{R^*}\left(1 - b_{SRR} R^*\right)$$

$$b_{SRR} = \frac{z - 0.2}{0.8 z R^*}$$

where S^* is the virgin spawning stock, *i.e.* S_0.

In the operating model that is used to generate synthetic data to test the model, the actual number of age 0 recruits in year *t*, R_t, is assumed to be a random variate drawn from a log-normal distribution with expected value, $\hat{R}_t$. However, for the model itself, no process error is assumed and, thus, in this case, $R_t = \hat{R}_t$.

Sex ratio

The proportion of age 0 recruits of gender *g* (1 = males, 2= females) is denoted by ψ_g, where

$\psi_1 + \psi_2 = 1$.

Thus, in the unexploited stock, the number of age 0 recruits of gender *g* is $R_g^* = \psi_g R^*$, while, in subsequent years, $N_{0,g,t} = \psi_g R_t$.

Proportion mature at each length

The proportions of male and female fish that are mature at each length were assumed to be equal and to follow a logistic relationship. The proportion of mature fish of each gender *g* at each age ($a > 0$) is calculated as

$$p_{a,g} = \frac{1}{1 + \exp\left[-\log_e(19) \frac{L_{a,g} - L_{50\%,g}}{L_{95\%,g} - L_{50\%,g}} \right]},$$

where the lengths at which 50 and 95% of fish of that gender were denoted by $L_{50\%,g}$ and $L_{95\%,g}$, respectively. The proportion of age 0 fish that are mature is set to zero.

Annual mortality

The total annual mortality experienced by fish of age *a* and gender *g* represents the sum of the instantaneous rates of natural mortality *M* and the age- and gender-dependent fishing mortality, $F_{a,g,t}$, where this latter term represents the fishing mortality of fish of age *a* and gender *g* in year *t*. Thus, the instantaneous total mortality of fish of age *a* and gender *g* in year *t*, $Z_{a,g,t}$, may be calculated as

$$Z_{a,g,t} = M + F_{a,g,t}.$$

The fishing mortality $F_{a,g,t}$ is assumed to be a separable function of the annual fishing mortality for year *t*, F_t, and an age- and gender-specific vulnerability, $V_{a,g}$, *i.e.* the vulnerability of fish of age *a* and gender *g* to capture. Thus,

$$F_{a,g,t} = V_{a,g} F_t .$$

Vulnerability at age

The proportions of male and female fish that are vulnerable to the fishing gear at each length is assumed to be equal and to follow a logistic relationship. The proportion of vulnerable fish of each sex *g* at each age *a* is calculated using

$$V_{a,g} = \frac{1}{1+\exp\left[-\log_e(19)\dfrac{L_{a+0.5,g} - L'_{50\%,g}}{L'_{95\%,g} - L'_{50\%,g}}\right]},$$

where the lengths at which 50 and 95% of fish of that gender are expected to be vulnerable are denoted by $L'_{50\%,g}$ and $L'_{95\%,g}$ mm, respectively. It has been assumed that the vulnerability to capture is independent of the fishing sector, *i.e.* the commercial or recreational fisheries that are exploiting the stock. Note that if vulnerability is expressed as a function of length rather than age, the proportion of vulnerable fish of each age class may be estimated from the length-dependent vulnerability and the distribution of the lengths of the individual fish in each age class.

Number and biomass of fish at each age

The number of fish of each gender and age that are available at the start of each time step may be calculated as

$$N_{a,g,t} = \begin{cases} N_{a-1,g,t-1} \exp\left[-Z_{a-1,g,t-1}\right] & \text{for } 1 \le a < A \\ N_{a-1,g,t-1} \exp\left[-Z_{a-1,g,t-1}\right] + N_{a,g,t-1} \exp\left[-Z_{a,g,t-1}\right] & \text{for } a = A \end{cases}$$

Note again that the number of age 0 recruits to the fishery in year t is calculated from the total number of recruits for the year using the proportion of age 0 fish that are of each gender, *i.e.* $N_{0,g,t} = \psi_g R_t$.

The biomass of fish of age a and gender g at the start of year t, $B_{a,g,t}$, may be calculated as

$$B_{a,g,t} = N_{a,g,t} W_{a,g}$$

and an estimate of the biomass of vulnerable fish of this age and gender, $B^*_{a,g,t}$, may be determined from the equation

$$B^*_{a,g,t} = V_{a,g} B_{a,g,t} \ .$$

Thus, the total vulnerable biomass of fish in year t, B^*_t , may be estimated as

$$B^*_t = \sum_{g=1}^{2} \sum_{a=0}^{A} B^*_{a,g,t} \ .$$

Catch per unit of effort

An estimate of the catch per unit of effort of fishing sector f in year t, $\hat{U}_{f,t}$, may be calculated from the vulnerable biomass as

$$\hat{U}_{f,t} = q_f B_t^*$$

where q_f denotes the catchability of fishing sector *f* (1=commercial, 2=recreational).

It is assumed that a time series of estimates of the catch per unit of effort is available for the commercial fishery, *i.e.* values of $U_{1,t}$ are available for n_1 years. Although not available for all years, it is assumed that estimates of the recreational catch per unit of effort are available for n_2 years. The sum of squared deviations of the natural logarithm of estimated commercial catch per unit of effort from the natural logarithm of the recorded catch per unit of effort is calculated for each fishing sector *f* as

$$SS_f = \sum_t \left\{ \log_e\left(U_{f,t}\right) - \log_e\left(\hat{U}_{f,t}\right) \right\}^2$$

where the sum includes only those years for which values of catch per unit of effort are available for the fishing sector.

An estimate of the log-likelihood associated with the catch per unit of effort from each fishing sector *f*, *i.e.* λ_f, is calculated as

$$\lambda_f = \frac{n_f}{2}\left\{1 + \log_e\left(2\pi\right) + \log_e\left(SS_f / n_f\right)\right\}.$$

Harvest rate

The harvest rate (fraction caught) of fish of age *a* and gender *g* in year *t*, $H_{a,g,t}$, may be determined from the Baranov catch equation as

$$H_{a,g,t} = \frac{F_{a,g,t}}{Z_{a,g,t}}\left(1-\exp\left[-Z_{a,g,t}\right]\right).$$

Catch

The catch, *i.e.* number caught, of fish of age *a* and gender *g* in year *t*, $C_{a,g,t}$, is estimated as

$$C_{a,g,t} = H_{a,g,t}N_{a,g,t},$$

the total number of fish of gender *g* caught in year *t*, $C_{g,t}$, as

$$C_{g,t} = \sum_{a=0}^{A} C_{a,g,t}$$

and the total number of fish caught in year *t*, C_t, as

$$C_t = \sum_{g=1}^{2}\sum_{a=0}^{A} C_{a,g,t}.$$

Yield

An estimate of the yield, *i.e.* mass caught, of fish of age *a* and gender *g* in year *t*, $Y_{a,g,t}$, may be obtained by multiplying the number of fish caught by the weight at mid-age, *i.e.*

$$Y_{a,g,t} = C_{a,g,t}W_{a+0.5,g}.$$

Thus, an estimate of the total yield for year *t*, $\hat{Y}_t$, may be calculated as

$$\hat{Y}_t = \sum_{g=1}^{2}\sum_{a=0}^{A} Y_{a,g,t} \; .$$

The term 'yield' has been used to distinguish the biomass of fish caught from the number of fish caught, where the latter has been termed the 'catch'. If a creel census has been undertaken for year *t*, such that an estimate of recreational yield is available, this estimate can be combined with the recorded commercial yield to derive an estimate of total yield for the year, Y_t. For such years, these estimates of total yield were used to derive an estimate of F_t by iteratively solving the equations above. The value of F_t was constrained to lie between 0.0001 and 3 $year^{-1}$ by imposing a large penalty on the estimate of log-likelihood if it should fall outside this range. It is assumed that estimates of the recreational yield, and hence the total yield, are available for at least two years.

Age composition of catch

The fraction of fish, which are of age *a* and gender *g*, in the catch of year *t*, $\varphi_{a,g,t}$, may be estimated as

$$\varphi_{a,g,t} = \frac{C_{a,g,t}}{C_{g,t}}$$

while the estimated proportion of fish, which are of age *a*, in the catch in year *t*, $\varphi_{a,t}$, is calculated as

$$\varphi_{a,t} = \frac{\sum_{g=1}^{2} C_{a,g,t}}{C_t} \; .$$

If the observed frequency of fish of age *a* in the sample of fish from the catch in year *t* is denoted as $f_{a,t}$ then the log-likelihood associated with the age composition of the samples from the annual catches may be estimated as λ_3, where

$$\lambda_3 = \sum_t \sum_a f_{a,t} \log_e(\varphi_{a,t}).$$

This sum is calculated over all years for which age composition data are available.

Log-likelihood of catch-per-unit-of-effort and age-composition data

An estimate of the overall log-likelihood may be calculated as the sum of the log-likelihoods associated with the commercial and recreational catch-per-unit-of-effort data and that associated with the age-composition data. Thus,

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3.$$

Fitting the model

The parameters R^*, z, q_1 and q_2 are estimated when fitting the model to the data. The values of the annual fishing mortalities, F_t, are also estimated but are treated as nuisance parameters as they essentially represent a direct conversion of the times series of commercial catch per unit of effort to an equivalent time series of fishing mortalities (conditional on the parameters R^* and z, and the biology of the fish as represented by growth and maturation). Parameter estimates for the growth equations, the weight-length relationships, the maturity and selection ogives and the sex ratio of the recruits are assumed to be available from other studies for input to the model. An estimate of *M* is also assumed to be available.

Penalty functions were used when fitting the model to the test data set to ensure that the following constraints were satisfied:

R^*: lies between 500 and 10,000 thousand fish (for the test data used in this study)

z: lies between 0.25 and 0.95

q_1 and q_2: lie between 0.0000001 and 1

F_t: lie between 0.0001 and 3.0

$\hat{Y}_t$ > yield recorded by commercial fishing sector

Initially, attempts were made to estimate simultaneously all of the parameters, *i.e.* R^*, z, q_1 and q_2, and the values of the annual fishing mortalities, F_t. A variety of alternative iterative, non-linear algorithms were applied in these initial trials. However, for the test data that had been generated, fitting using these algorithms proved difficult. Furthermore, the log-likelihood surface was not of a form that readily allowed estimation of the confidence limits of the parameters through use of the Hessian matrix, *i.e.* the negative of the Hessian was not positive-definite (see Gill and King, 2004). Thus, as described below, a nested approach to fitting the model was adopted, and confidence limits were estimated from estimates of values of the profile log-likelihood function.

The log-likelihood λ was maximized using the non-linear simplex method described by Nelder and Mead (1965), employing the subroutine, MINIM (StatLib, Applied Statistics algorithms, http://lib.stat.cmu.edu/apstat/, No. 47), which was developed by D. E. Shaw, CSIRO, and subsequently modified by R. W. M. Wedderburn, Rothamsted Experimental Station, and, later, by Alan Miller, CSIRO, to estimate the parameters R^*, z, q_1 and q_2. For each set of parameters, R^*, z, q_1 and q_2, the value of λ was calculated as the maximum value of the log-likelihood obtained by fitting F_t with the same non-linear optimization algorithm. That is, a nested approach was adopted, as this was found to overcome difficulties in fitting the full set of parameters using a non-nested technique and employing a wide range of alternative optimization algorithms. Note that the objective function used in this study was modified slightly as the study progressed; while the values presented in the results differ slightly among some segments of the study, they are consistent within each individual segment. Approximate $100(1-\alpha)\%$ confidence limits were determined from the profile likelihood functions for the parameters R^*, z, q_1 and q_2, by determining the values of each parameter on either side of the parameter estimate associated with the maximum likelihood such that, when the parameter was fixed and the likelihood maximized over the remaining parameters, log-likelihoods of $\lambda_{\max} - 0.5\chi^2_{1-\alpha,1}$ were obtained (Venzon and Moolgavkar, 1988).

The FORTRAN source code for the model is presented in the CD that accompanies this report.

GENERATION OF TEST DATA

An operating model was developed to generate synthetic data that could be used to develop and test the model. This operating model assumed a unit stock exploited by recreational and commercial fishing sectors. The goal of the simulation was to generate synthetic data of the type that might be likely to arise from a fishery exploited by both commercial and recreational fishing sectors, and for which catches by the recreational sector represented a large component of the annual catch. Such fisheries in Australia are characterized by the availability of a time series of catch and effort data from the commercial fishery stretching back over a number of years and, for more recent years, occasional records of recreational catch and effort and samples of the age composition. Often, these latter data are available only for years in which creel censuses have been undertaken. A further characteristic of these fisheries is that they are often well established before recreational data become available, such that the available data are likely to contain relatively little information relating to the initial trend in population sizes at low levels of exploitation. Thus, the data generated by the simulation have been set intentionally to reflect the relatively non-informative data likely to be collected from such fisheries.

Growth of male and female fish was assumed to be identical and represented by a von Bertalanffy growth curve with $L_\infty = 100$ mm, $K = 0.2$ year^{-1}, and $t_0 = 0$ years. Estimates of the lengths at age and at "mid-age" of fish from age 0 to a maximum age of 20 years were calculated from this curve. The weights of the individual fish at each age, W_a, and mid-age, $W_{a+0.5}$, were then calculated from the weight-length relationship, $W_a = 0.00001(L_a)^3$. A common weight-length relationship was assumed for male and female fish.

The lengths at which 50 and 95% of fish of each gender were expected to be mature were set as $L_{50\%} = 50$ and $L_{95\%} = 60$ mm, respectively, and the lengths at which 50 and 95% of fish were expected to be vulnerable were set as $L'_{50\%} = 40$ and $L'_{95\%} = 55$ mm, respectively.

The parameters of the Beverton and Holt stock-recruitment relationship were assumed to be virgin recruitment, $R^* = 1000$ thousand fish, and steepness, $z = 0.8$. The proportion of females in the age 0 recruits was set to 0.5. At each annual time step, the number of recruits estimated using the stock-recruitment relationship was taken as the expected number of recruits. The actual number of recruits at the time step was a random variate selected from the log-normal distribution around this expected level of recruitment, where the standard deviation of the normally-distributed error associated with the log-transformed recruitment was assumed to be 0.1, *i.e.*

$$R_t = \hat{R}_y \exp(\varepsilon_t) \text{ where } \varepsilon_t \sim N(0,0.01).$$

When generating the synthetic data that would be used to test the proposed model, it was assumed that the fishery was unexploited from 1940 to 1979 and that expected levels of commercial and recreational fishing mortalities then grew at annual rates of 0.005 and 0.004 year^{-1} between 1980 and 2001. The annual fishing effort for each fishing sector was calculated by dividing the commercial and recreational fishing mortality by the corresponding catchability, 0.01 and 0.001 (effort-unit^{-1}) for the commercial and recreational fishing sectors, respectively. The fishing mortality applied to each age class was then randomly selected from a log-normal distribution of fishing mortalities around each of the expected values of mortality, where the standard deviation of the log-transformed mortalities was set at 0.6. The commercial and recreational fishing mortalities were then used, in combination with the body weight at "mid-age" and the number of fish alive at the start of each year, to determine the annual recreational and commercial catches and combined to determine the total catch and survival from each age class.

Random samples of 500 fish were drawn from the calculated catch-at-age data for each year to represent the samples of age composition that might be collected from a fishery during a creel census or biological survey.

To replicate the types of data available for fisheries in which there is a significant recreational catch, but only limited data are available from the recreational fishery, it was assumed that recreational and age-composition data were available for only three fishing seasons. Three scenarios were considered, with data available for

1. 1997, 1998 and 1999;
2. 1995, 1997 and 1999; and
3. 1993, 1996 and 1999.

The impact on parameter estimates of alternative levels of precision of the estimates of the catches per unit of effort (cpue) recorded by commercial fishers was investigated. Such reduced precision might be expected if commercial fishing effort was to be reduced markedly by fisheries managers through increased allocation of catch to the recreational sector and gradual removal of commercial fishers from the fishery, e.g. the reduction of the number of commercial fishers from four to one. For this investigation, random values of commercial cpue were selected from an assumed log-normal distribution of values around the mean cpue, where this latter value was taken as the “recorded” value of cpue. Four values of the standard deviation (SD) of the log-tranformed cpue data were considered in the analysis, *i.e.* 0.05, 0.1, 0.15 and 0.2. The model was fitted to the resulting set of randomly-selected commercial cpue data and the parameter estimates were recorded. The process was then repeated until 20 different sets of parameter estimates were available for each value of SD. The average, standard deviation and coefficient of variation were calculated for each parameter. Accuracy was assessed by comparing the calculated means with the parameter values that had been used to generate the synthetic data used in the analysis while precision was evaluated by examining the CVs of the parameter estimates.

RESULTS/DISCUSSION

Simulated data used as input to the model

The synthetic data generated by the simulation were used to establish input data for the three scenarios with annual, biennial and triennial collection of recreational fishing data (see Appendix 3 for details of the contents of the various input files that were created from the simulated data). The trends in spawning stock and recruitment in the synthetic data set produced by the simulation, and that are reflected in the data sets that would subsequently be used as input to the model, represent a fishery in which, by 2001, spawning stock has been reduced to approximately 30% of the 1980 level while recruitment had decreased by approximately 7% from the 1980 level (Fig 1).

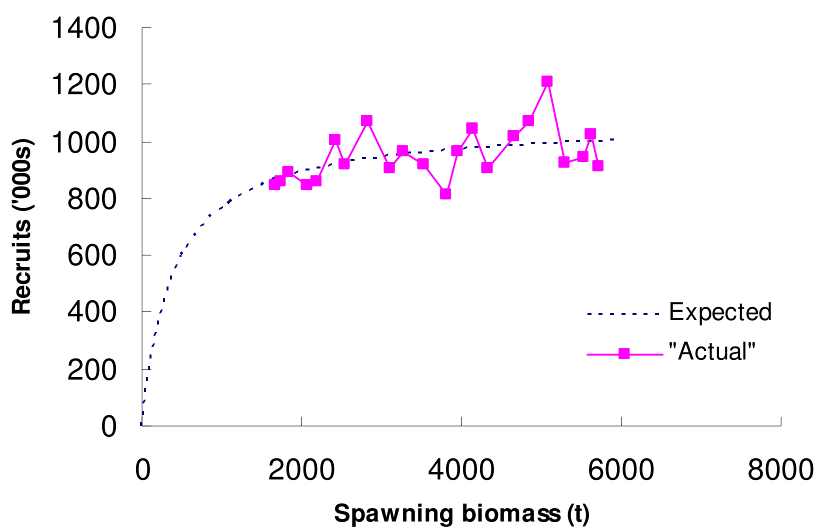

Figure 1. The trend in spawning stock biomass and recruitment resulting from the simulation and used when generating the synthetic data that would subsequently be input to the fishery model to represent the "actual" data collected from a fishery. The dashed line represents the underlying stock-recruitment relationship from which the simulated data were generated.

The commercial catch data generated by the simulator initially reflected the increasing trend in fishing mortality that had been simulated but, by the mid-1980s, commercial catches had reached an asymptote and, by 2000, appeared to be starting to decline (Fig. 2). To reflect the situation that exists for most of Western Australia's recreational finfish fisheries, recreational data for the simulated data set were only generated for the last decade.

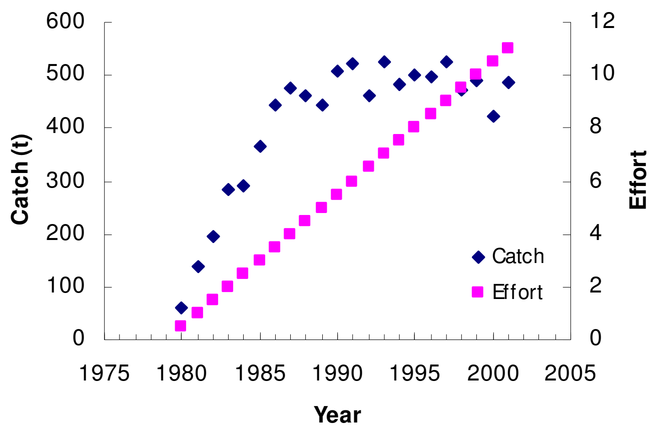

Figure 2. Synthetic annual catch and effort data generated for the commercial fishing sector.

Fitting the model to the simulated data

An initial version of the model to test the approach was implemented in Microsoft EXCEL, using macros developed with Visual Basic for Applications and employing SOLVER to maximise the log-likelihood. Subsequently, a second version of the model was implemented in AD Model Builder (ADMB) (Fournier, 2001). As a result of this exercise, the decision was made to estimate the annual fishing mortality in each of those years in which recreational catch data were available by solving for F the equation that relates annual total yield to the numbers of fish at each age in that year and the vulnerabilities and weights at the various ages. It was also noted that estimation of fishing mortality was not possible for the final year of data if no recreational catch data were available for that year. Age composition data for the final year reflected only the mortalities experienced in earlier years and no catch per unit of effort data were available for a subsequent year to provide information on the survival during that final year.

In the first ADMB implementation, bounded parameters were employed to ensure that estimates of parameters were in the range of values for each variable that were considered to be feasible, *e.g*. non-negative fishing mortalities. Subsequently, this constraint was replaced with the use of penalty functions as this approach appeared to provide improved performance.

Although, on a few occasions, AD Model Builder could be used to estimate the parameters from the test data, on most occasions the routine "converged" to a false minimum and the resulting Hessian matrix could not be used to determine the approximate variance-covariance matrix or profile log-likelihood distribution of the parameter estimates. Thus, it appeared that, with the model as it had been specified at that stage, ADMB was inappropriate for fitting the model to the available data. Accordingly, the ADMB code was modified such that, on setting an appropriate input option, the log-likelihood would be calculated for a set of input values of the various parameter estimates. The resulting ADMB code was linked to EXCEL macros that employed either the Amoeba or Powell algorithms (Press *et al*., 1992) to maximise the log-likelihood or to calculate the value of the profile log-likelihood function for any selected parameter. However, the process of estimating the parameters or the profile log-likelihood function was, at this stage, only semi-automatic as the fitting procedure had to be re-started when the procedure terminated prematurely.

The need for a more robust, automated fitting procedure became increasingly evident as the model was extended to allow exploration of the impacts on the parameter estimates of changes in the frequency of recreational creel surveys. While the application of a fitting procedure, such as the use of simulated annealing with a slow cooling schedule, would be likely to identify the location of the global minimum of the log-likelihood surface, it appeared more computationally efficient to continue to use a combination of iterative methods, each of which used the slope of the surface to identify the direction in which to continue to search for the minimum. To overcome the problem of premature termination and false minima, the routines were embedded within a loop that applied each fitting procedure in turn and terminated only when further improvement in the log-likelihood could be realised. However, even at the resulting set of estimates, the Hessian was found to be non-positive definite, suggesting that the minimum had still not been found or that some parameters were highly dependent on other parameters.

Recognising the very considerable correlation between the stock-recruitment and fishing mortality parameters that existed, a decision was made to nest the estimation of fishing mortalities within a two-stage fitting process, such that these fishing mortality estimates became conditional on current values of the parameters of the stock-recruitment relationship. The final version of the model fitting procedure was implemented in FORTRAN. The source code for the model is presented in the CD that accompanies this report. Only the code written for this project has been presented in the CD and details of routines written by other parties that are available on the Internet, which have been used in the model, are not presented. However, the URLs of the locations from which these routines may be obtained are listed in comments within the source code that has been presented.

As expected, given the number of parameters and the low number of degrees of freedom, relatively good fits for the catches per unit of effort and age composition data were obtained when the model was fitted using the annually-collected recreational data (Figs 3 and 4).

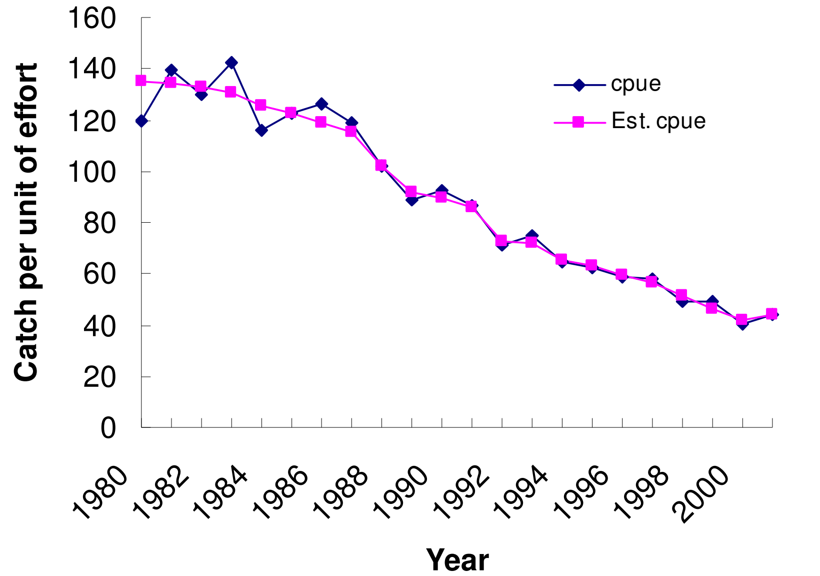

Figure 3. Time series of catches per unit of effort for the commercial fishery. The observed values were input to the model, while the estimated values were those predicted by the model.

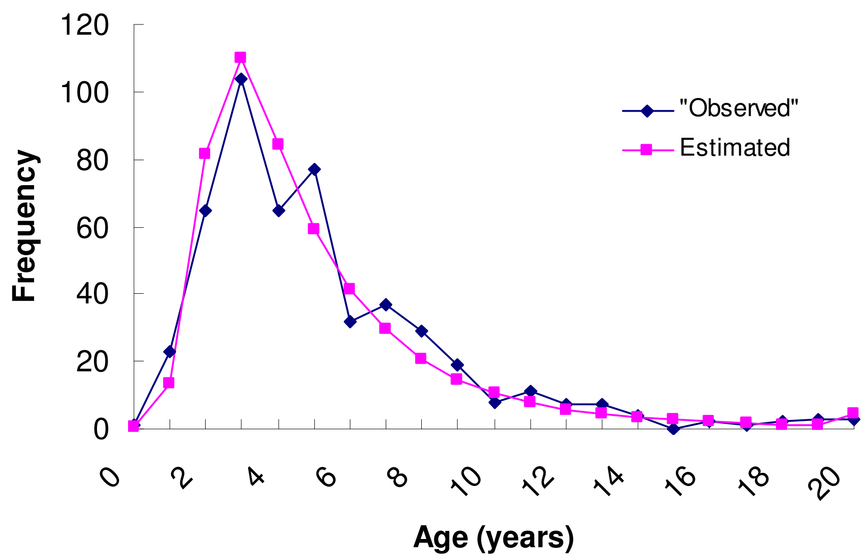

Figure 4. An example of the age-composition data that were input to the model and the age composition that was predicted by the model.

Precision and accuracy of parameter estimates

Although the total catch and fishing mortality data employed in the simulation procedure when generating the input data were not available to the model when it was fitted to the subset of annually-collected recreational data that was input, the model produced surprisingly good estimates of the trends in these unknown quantities given the paucity of the input data (Figs 5 and 6), although considerable inter-annual variability was present in the estimates for both variables.

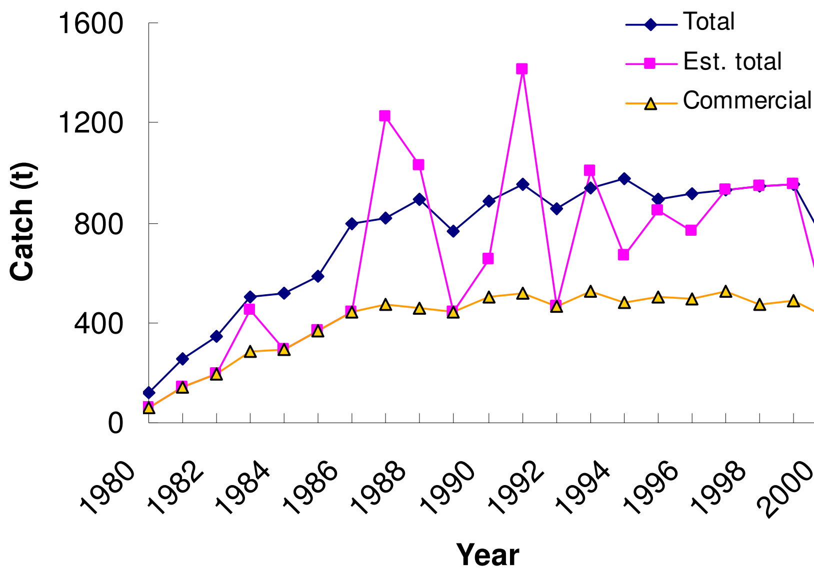

Figure 5. The commercial catches that were input to the model and the resulting values of total catch predicted by the model displayed against the original total catches from which the 1997, 1998 and 1999 total catches, which were used as the only input of total catch data to the model, were drawn.

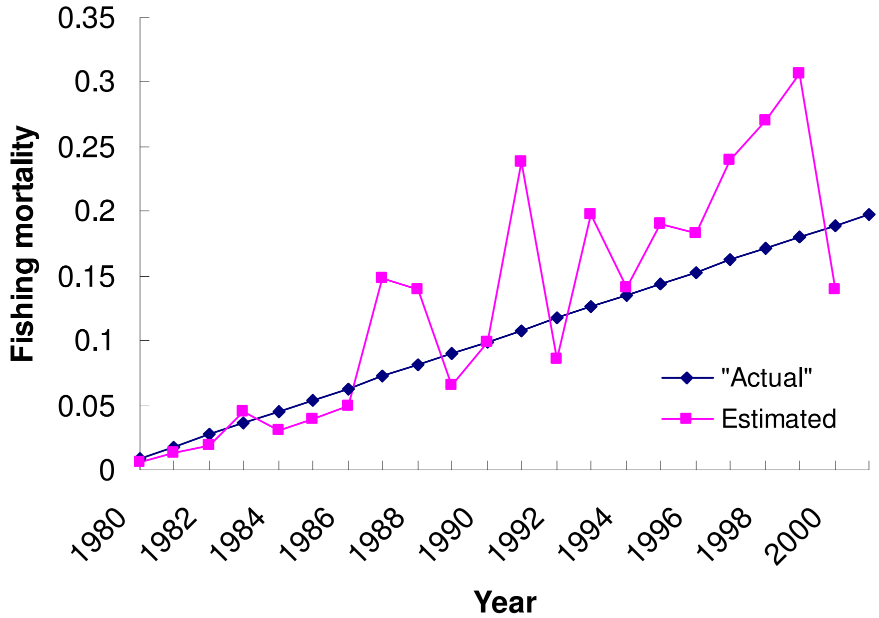

Figure 6. Estimated values of fishing mortality displayed against the 'actual" values used by the operating model when generating the synthetic data (noting that the fishing mortalities for each age class and each fishing sector were randomly sampled from a log-normal distribution).

Estimates of values of the profile log-likelihood function for virgin recruitment, steepness, commercial and recreational catchabilities and for the fishing mortality estimate for 1997 were calculated using the annually-collected recreational data (Fig. 7). The approximate 95% confidence limits for the first four of these parameters encompassed the values used by the simulator when generating the test data, but the "true" fishing mortality in 1997 fell below the estimated 95% confidence limit for that parameter (Table 1). It should be noted that the upper 95% confidence limit for steepness was 0.95, the bound that had been imposed on this parameter by imposing a high penalty when fitting the model to the data.

Table 1. Estimates of the approximate 95% confidence limits for virgin recruitment, steepness, commercial catchability, recreational catchability and fishing mortality for 1997, derived when fitting the model to the test data using annually-collected recreational data, and the "true" values used in the simulation when generating the test data.

Parameter	***Approximate 95% confidence interval***		***Value used to generate test data***
	Lower limit	***Upper limit***	
Virgin recruitment (thousand fish)	660	1240	1000
Steepness	0.76	0.95	0.8
Commercial catchability (per unit of effort)	0.008	0.014	0.01
Recreational catchability (per unit of effort)	0.00097	0.0016	0.001
Fishing mortality in 1997 ($year^{-1}$)	0.17	0.26	0.162

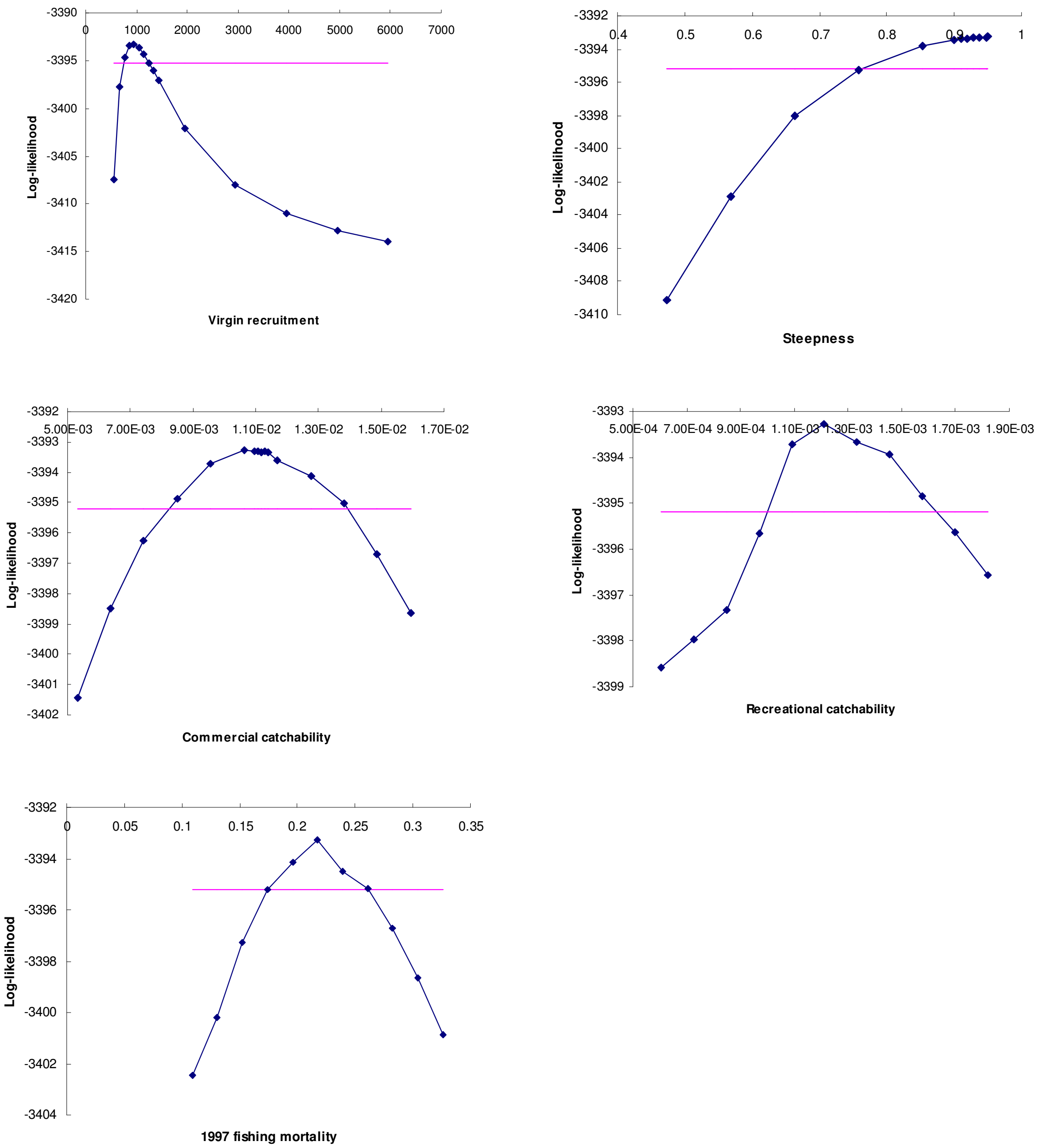

Figure 7. Estimates of the values of the profile log-likelihood function for virgin recruitment, steepness, commercial catchability, recreational catchability and fishing mortality for 1997, derived when fitting the model to the test data using annually-collected recreational data, and the 95% confidence limits derived from the intersection of the line calculated by subtracting 0.5 $\chi^2[1,1-\alpha]$ from the maximum log-likelihood obtained when fitting all parameters.

Sensitivity of parameter estimates

An analysis of the sensitivity of the estimates of the fishing mortality in 1997 and the ratio of the spawning biomass of females in 2000 relative to that in 1980 to alternative estimates of the instantaneous rate of natural mortality used when fitting the model to the data set with annually-collected recreational data indicated that the estimate of fishing mortality would be likely to decrease and that of the spawning biomass ratio to increase as the value of natural mortality was increased (Fig. 8).

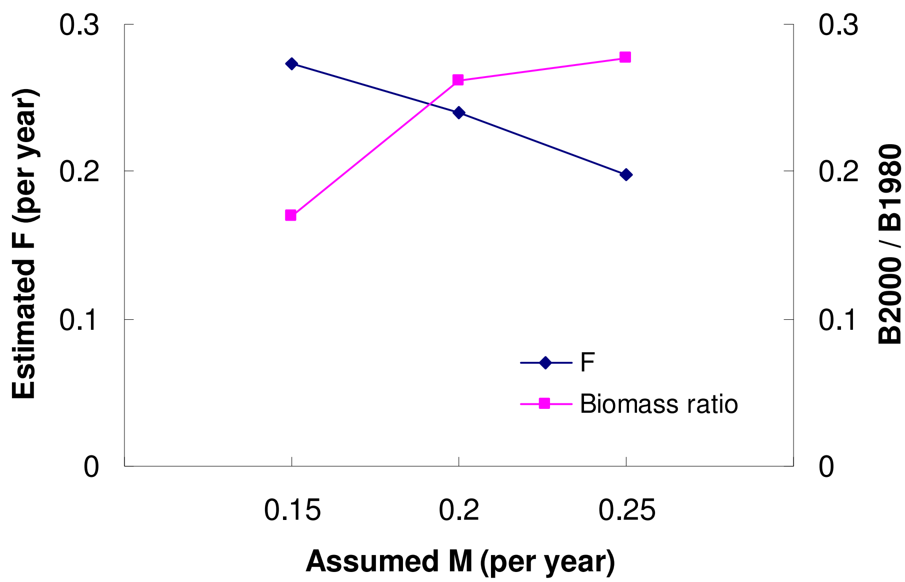

Figure 8. The sensitivity of the point estimates of the fishing mortality for 1997 and the ratio of the spawning biomass in 2000 to that in 1980, derived when fitting the model to the test data, using three different input values for the estimate of natural mortality.

The estimates of the ratio of the spawning female biomass in 1999 relative to that of the virgin stock were well defined in the cases of the data sets containing annual or biennial recreational data but not so well defined for the data set employing triennial data (Fig. 9). Note that the differences in the magnitudes of the negative log-likelihoods presented in Figure 9 represent the different data sets employed when fitting the model, whereas the minimum value represents the point estimate of the parameter and the precision of the estimate is indicated by the slopes of the curves on either side of the minimum. The trends in the negative of the log-likelihoods showed a clearly defined minimum. The biomass ratio was estimated to be approximately 0.29 when the model was fitted to the data sets employing annual and biennial recreational data and 0.26 when fitted to the set using triennial recreational data. The “true” ratio for the data used by the operating model to generate the synthetic data that were analysed was 0.32. Thus, while analyses of the datasets that used annual or biennial recreational data yielded relatively accurate estimates of the ratio, the (relatively imprecise) value obtained using the triennial recreational data appeared to underestimate the true value.

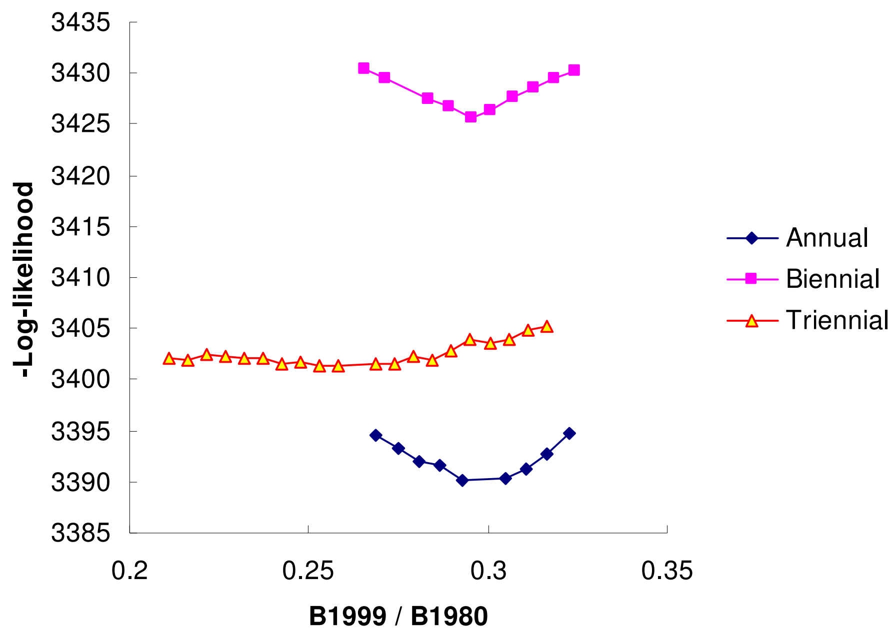

Figure 9. The impact of changes in the frequency at which creel censuses are undertaken on the estimate of spawning stock biomass, as represented by the negative of the three-point moving averages of profile log-likelihood estimates for the ratio of spawning female biomass in 1999 to the spawning female biomass of the virgin stock.

The sensitivity of estimates of stock status and level of exploitation derived from the use of a model such as that described in this study will be highly dependent on the information content of the data to which the model is fitted. Thus, although the sensitivity of the estimates derived by fitting the model to the data used in this study could have been explored in considerably greater detail, the conclusions drawn from such analysis might not be entirely applicable to other cases. Accordingly, it is essential that detailed sensitivity analyses are undertaken when this or a similar model is applied to other fishery data.

The impact of reduced precision of commercial fishery data

Increasingly accurate but less precise estimates of the level of virgin recruitment and the steepness of the stock-recruitment relationship were obtained when the model was fitted to artificial data containing commercial catch rate data of greater imprecision (Table 2). Although the estimates of commercial catchability were consistent with the value employed when generating the artificial data, those of the recreational catchability tended to exceed the value used in the simulation. As anticipated, the parameter estimates became increasingly imprecise as the precision of the commercial cpue data was reduced.

Table 2. Mean values of parameter estimates calculated from fitting the model to 20 sets of commercial catch per unit of effort data selected randomly from log-normally-distributed data where the standard deviation of the log-transformed catch per unit of effort ranges from 0.05 to 0.20.

Parameter	Value used to generate data	SD=0.05	SD=0.10	SD=0.15	SD=0.20
Virgin recruitment	1000	902 ± 123	928 ± 205	952 ± 331	974 ± 307
Steepness	0.8000	0.91 ± 0.10	0.92 ± 0.07	0.82 ± 0.24	0.82 ± 0.32
Comm. Catchability	0.0100	0.0114 ± 0.0015	0.0113 ± 0.0026	0.0119 ± 0.0039	0.0117 ± 0.0039
Rec. catchability	0.0010	0.0013 ± 0.0001	0.0013 ± 0.0003	0.0014 ± 0.0004	0.0013 ± 0.0004

Conclusions

A dynamic fishery model that uses data of the types that have typically been collected for recreational finfish fisheries in Western Australia has been developed. The model has been applied to simulated test data to demonstrate that it was able to produce reliable estimates of the parameters that were used to generate those data. However, the study has also demonstrated that the accuracy and precision of parameter estimates are dependent on the accuracy and precision of the input data and the frequency of collection of recreational data. The results obtained in this study have demonstrated that, for the simulated test data, it was possible to assess the impact on the accuracy and precision of parameter estimates of changes in the frequency of collection of recreational data. For these simulated data, the analysis demonstrated that the parameters considered were likely to become less precise and accurate as the frequency of collection of recreational data was reduced. While the results from the test data cannot be extrapolated to actual fisheries, the study has demonstrated that the modelling approach provides a tool that fishery agencies might apply to their own fisheries to investigate the trade-off between the cost and the resultant benefit for stock assessment associated with different frequencies of such surveys. Such investigation is likely to be of considerable value in determining the appropriate frequency of the expensive surveys required to collect recreational data.

Increasingly, the allocation of fish among the recreational and commercial sectors is becoming an issue that must be considered by fishery managers. In Western Australia, commercial fishing has been phased out of Leschenault Inlet, and has or is being considered in other estuarine fisheries. Increasing participation in recreational fishing is also likely to affect the commercial fishing sector. Through both direct intervention by fishery managers or through gradual erosion of catch share, it is highly likely that reduced commercial catches may lead to a decrease in the precision of the estimates of commercial catch per unit of effort. Of even greater concern is the possibility that the accuracy of the estimates of commercial catch per unit of effort as an index of stock abundance may be compromised by reduced allocation of catch share to the commercial fishery and resultant changes in fishing practices. There is thus a need, when considering the re-allocation of catch shares, to be aware of the impact on future stock assessments of any reduced precision or accuracy in commercial cpue. The results presented in this FRDC study demonstrate that, as the precision of commercial cpue data was decreased, parameter estimates produced by the model become increasingly imprecise. If the commercial fishery is completely eliminated, the model described in this report is no longer appropriate unless an alternative time series of reliable abundance indices can be obtained from either the recreational fishing sector and/or research surveys. For fishery managers, the implication of this is that phasing commercial fishers out of a fishery is likely to degrade the reliability of future stock assessments if there is no increase in the quantity and quality of recreational data, which are collected, that might compensate for the greater imprecision of the commercial fisheries data.

Much of the information used in the model is derived from the age composition data and it is essential that these data are collected appropriately and are representative of the catch.

Although the model developed in this study appears to offer the potential to undertake stock assessments using data of the types that are currently available for many of Australia's recreational finfish fisheries, it is stressed that far more reliable stock assessments would be possible if a time series of data of an appropriate quality was available from the recreational fishing sector or from a well-designed research survey conducted at appropriate intervals.

The study has demonstrated the potential of the model for the stock assessment of fisheries that are exploited by both recreational and commercial fishers. However, it is also likely to be of benefit in the assessment of commercial fisheries for which there is considerable discard mortality of the target species, and for which only occasional estimates of the mass of fish discarded annually are available.

BENEFITS AND ADOPTION

Fishery scientists now have a tool that may be used to assess the status of fisheries in which a large proportion of the catch is taken by recreational fishers and for which only occasional estimates of recreational catch are available. Although considerable investment in the collection of recreational data has been made by fishery agencies during the past two decades, the resulting data have frequently been used only to determine the magnitude of the catch taken by the recreational sector or to determine, through application of equilibrium-based approaches such as yield-per-recruit or catch-curve analysis, an estimate of current fishing mortality relative to yield-per-recruit-based reference points. The ability to use the data collected from creel census studies has been impeded by the lack of appropriate models. This study offers the opportunity to use such data to develop dynamic fishery models that can provide the essential advice that is required by fishery managers for integrated fishery management. The model also provides a tool that permits a quantitative cost-benefit evaluation of the frequency at which creel censuses should be undertaken. Perhaps most importantly, the study has demonstrated that the data provided by commercial fishers are valuable in assessing the status of fish stocks. Thus, consideration needs to be given to ensuring that similar time series of abundance data remain available for fishery stock assessment when decisions are made on the allocation of catch among the recreational and commercial fishing sectors. Similarly, if the commercial sector of a fishery is reduced, the resultant impact on the quality of future stock assessments needs to be considered.

After the final report on the project has been reviewed and accepted by the FRDC, copies of the software will be available from the Centre for Fish and Fisheries Research at Murdoch University, on request.

FURTHER DEVELOPMENT

The pattern of over and underestimation of total catches and of fishing mortality evident in Figures 5 & 6 was a consistent feature when fitting the model. Although recruitment variation could produce such changes in total catch, and fishing effort could respond to the changes in fish abundance, it appears likely that the changes in the estimates are artefacts of the model. It would therefore be useful to investigate whether it is appropriate to impose a constraint to the magnitude of the change that is permitted to occur when fitting the model.

A paper describing the model will be prepared for submission to a peer-reviewed, international journal to further disseminate the results of the project and encourage application of the model to the development of stock assessments for many of our currently unassessed fish stocks that are exploited heavily by recreational fishers.

PLANNED OUTCOMES

The outcome envisaged in the original project application was that improved and more cost-effective management of recreational fisheries would result from the following:

1. A dynamic fishery model will be available that can be applied to assess the state of fish stocks that are fished by both commercial and recreational fishers, for which the data that are available are not amenable to the application of those fishery models that are traditionally applied to data from commercial fisheries. Through such a model, it will be possible to assess the status of those recreational fisheries that are currently assessed using models based on equilibrium assumptions, *e.g.* those based on yield and egg per recruit analyses.
2. A method for determining the impact on the accuracy and precision of stock assessment of changes to the frequency of the recreational surveys that are undertaken will have been developed, thereby providing a "tool" that will allow fishery agencies to consider more adequately the cost-effectiveness of the sampling

regime that they should adopt. It is pertinent to note a considerable expense is associated with such surveys of recreational fishing.

3. Fisheries managers will be better informed when considering the re-allocation of catch from the commercial to the recreational sector, and the impact of such decisions on the accuracy and precision of the subsequent stock assessments of those recreational fisheries. It is likely that such stock assessments may benefit from the continued presence of a commercial fishing sector, to provide those data, which are necessary for assessment, as the cost of obtaining such data through independent research may be excessive.

Examining these proposed outcomes,

1. A dynamic fishery model is now available that can be applied to assess the state of fish stocks that are fished by both commercial and recreational fishers, for which the data that are available are not amenable to the application of those fishery models that are traditionally applied to data from commercial fisheries.
2. A method for determining the impact on the accuracy and precision of stock assessment of changes to the frequency of the recreational surveys that are undertaken has been developed, providing a "tool" that allows fishery agencies to consider more adequately the cost-effectiveness of the sampling regime that they should adopt.
3. A tool has been developed that allows exploration of the impact on the accuracy and precision of the subsequent stock assessments of recreational fisheries of decisions related to the re-allocation of catch from the commercial to the recreational sector. This tool allows fisheries scientists to provide better advice to fisheries managers when such resource re-allocation issues are considered. The extent to which fisheries managers become better informed will, however, be dependent on the

uptake by fisheries scientists of the modelling approaches described in this report, subsequent derivations and enhancements of this model or development of alternative assessment approaches.

The benefits of the study will flow to both the commercial and recreational fishers who exploit the recreational fisheries to which this model is applied, as the resulting stock assessments are likely to be more accurate. In particular, the outputs of the model are likely to be of considerable value to the implementation of integrated fisheries management.

CONCLUSION

The objectives of FRDC 2002/075 have been met. Thus, a dynamic fishery model that uses those types of data, which are typically available for recreational fisheries, has been developed and the study has demonstrated, with simulated test data, that it is able to produce parameter estimates that are likely to be consistent with those used to generate the synthetic data. However, the study has also demonstrated that the accuracy and precision of the resulting parameter estimates will be sensitive to the frequency at which recreational data are collected, the accuracy of input data such as the value used as the estimate of the instantaneous rate of natural mortality, and the precision of the catch and cpue data from the commercial fishery. Age composition data provide much of the information used by the model and thus it is important that these are obtained through an appropriate sampling regime that ensures that the age compositions of the samples are representative of those of the catches.

The study has demonstrated how the model can be used to investigate the impact on the accuracy and precision of parameter estimates of reduced frequency of data collection for the recreational fishing sector, thereby illustrating how this approach might be used to investigate the trade-off between the cost and the resultant benefit for stock assessment associated with different frequencies of such surveys.

The model has been used with the simulated test data to investigate the consequences for subsequent stock assessment of reducing the proportion of the catch that is allocated to the commercial fishing sector has been presented in this report. Thus, as expected, it has demonstrated that reduced precision of commercial cpue data will result in reduced precision of parameter estimates and greater uncertainty of the resulting stock assessment and management advice.

The development of dynamic models for fisheries in which a large proportion of the catch is taken by recreational fishers and for which only occasional estimates of recreational catch are available has been impeded in the past by the lack of time series of total catch data that are required by traditional fisheries models. Accordingly, for such fisheries, which are common in Western Australia and other Australian states, often the only recourse has been to use yield or egg per recruit analyses, despite the limitations of such equilibrium approaches (Hilborn and Walters, 1992). The approach developed in this FRDC project has demonstrated that, despite the limitations of the data, it may be possible to develop dynamic models for such fisheries provided that a time series of commercial catch and effort data exist, and fishery data for the recreational sector and the age composition of the catch are available for two or more years. This is a significant advance as such dynamic fishery models allow estimation of stock size and fishing mortality and determination of the levels of catches that must not be exceeded if the stock is to be sustained. Such estimates are essential if integrated fishery management is to succeed.

An important implication of the study is that continued availability of a reliable time series of abundance indices, such as that provided by the commercial fishing sector, is essential if reliable stock assessments are to be developed using dynamic fishery models. The impact of changes in allocation of catches between the recreational and commercial fishing sectors on the quality of future stock assessments needs to be recognised by fishery managers when proposals for re-allocation are considered. Although the model developed in this study provides an approach that overcomes deficiencies in the types of data that are typically available for recreational finfish fisheries, it should be recognised that the collection of appropriate and reliable data from the recreational fishing sector would allow far more reliable stock assessments to be undertaken. However, with the types of data that are currently available for Western Australia's finfish fisheries, the model that has been developed in this study is likely to prove invaluable in addressing current needs for stock assessment and the provision of the advice required for integrated fisheries management.

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APPENDIX 1 – INTELLECTUAL PROPERTY

The value of the intellectual property will be 75.51% based on PART C of the FRDC project proposals.

APPENDIX 2 – STAFF

Associate Professor Norman Hall

Dr David Fairclough

Dr Alex Hesp

Dr Simon de Lestang

Mr Peter Coulson

Mr Bryn Farmer

APPENDIX 3 – INPUT DATA

Content of the file, **RECMODEL.DAT**, which contains details of the parameters for growth, the weight-length and maturity-length relationships, the vulnerability-length relationship, natural mortality and the proportion of females that are present in the age 0 recruits.

```
# Maximum age
 20
# Growth
# Linf of males and females
 100   100
# K of males and females
 0.2   0.2
# Tzero for males and females
 0   0
# Weight-length relationship
# a of males and females
 0.00001   0.00001
# b of males and females
 3   3
# Maturity-length relationship
# L50 of males and females
 50   50
# L95 of males and females
 60   60
# Selectivity-length relationship
# L50 of males and females
 40   40
# L95 of males and females

 55   55
# Natural mortality
 0.2
# Proportion of females in recruitment
 0.5
```

Content of the file **COMCAT.DAT**, which contains details of the catch, effort and catch per unit of effort data for the commercial fishing sector.

```
# Commercial catch statistics generated by fishery simulator
# Year   Catch              Effort  CPUE
  1980   59.8087932264164   0.5     119.617586452833
  1981   139.398199611297   1       139.398199611297
  1982   195.376830449514   1.5     130.251220299676
  1983   284.263061973268   2       142.131530986634
  1984   290.208082270104   2.5     116.083232908042
  1985   366.61684653539    3       122.205615511797
  1986   442.714074793168   3.5     126.489735655191
  1987   475.673627181292   4       118.918406795323
  1988   459.969587335287   4.5     102.215463852286
  1989   445.523574874877   5       89.1047149749753
  1990   506.746979065555   5.5     92.1358143755554
  1991   520.882088058633   6       86.8136813431055
```

```
  1992   462.108392935993   6.5     71.0935989132297
  1993   525.881069179072   7       75.1258670255817
  1994   483.605371323706   7.5     64.4807161764941
  1995   501.499861255381   8       62.6874826569226
  1996   497.579921532824   8.5     58.5388142979793
  1997   524.385742945286   9       58.2650825494762
  1998   470.540530260832   9.5     49.5305821327191
  1999   488.56011502124    10      48.856011502124
  2000   421.26612819969    10.5    40.1205836380657

  2001   485.31432403569    11      44.1194840032445
```

Content of the file **RECCAT1.DAT**, which contains details of the recreational catch, effort and catch per unit of effort for annual collection of recreational data

```
# Recreational catch estimates
# Year   Catch             Effort CPUE
  1997   405.98139451646   72     5.63863047939528
  1998   476.69985299137   76     6.27236648672856
  1999   468.466225022657  80     5.85582781278321
```

Content of the file **RECCAT2.DAT**, which contains details of the recreational catch, effort and catch per unit of effort for biennial collection of recreational data

```
# Recreational catch estimates
# Year   Catch             Effort CPUE
 1995    390.651230575814  64     6.1039254777471
 1997    405.98139451646   72     5.63863047939528
 1999    468.466225022657  80     5.85582781278321
```

Content of the file **RECCAT3.DAT**, which contains details of the recreational catch, effort and catch per unit of effort for triennial collection of recreational data

```
# Recreational catch estimates
# Year   Catch             Effort CPUE
  1993   409.392952848115  56     7.31058844371634
  1996   419.600990044024  68     6.17060279476506
  1999   468.466225022657  80     5.85582781278321
```

Content of the file **AGECOMP1.DAT**, which contains details of the age composition of samples from the catch that were collected with recreational data during annual collection of such data.

```
# Age composition data
# Year  0   1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20
  1997  1   23  65  104 65  77  32  37  29  19  8    11   7    7    4    0    2    1    2    3    3
  1998  0   6   103 90  80  58  44  28  35  16  8    7    7    5    3    1    2    0    3    1    3
  1999  0   14  142 53  124 67  45  16  3   9   12   2    4    3    1    0    1    0    0    0    4
```

Content of the file **AGECOMP2.DAT**, which contains details of the age composition of samples from the catch that were collected with recreational data during biennial collection of such data.

```
# Age composition data
# Year  0   1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20
 1995   0   15  67  125 105 30  27  35  19  9   16   9    7    13   3    5    1    5    4    1    4
 1997   1   23  65  104 65  77  32  37  29  19  8    11   7    7    4    0    2    1    2    3    3
 1999   0   14  142 53  124 67  45  16  3   9   12   2    4    3    1    0    1    0    0    0    4
```

Content of the file **AGECOMP3.DAT**, which contains details of the age composition of samples from the catch that were collected with recreational data during triennial collection of such data.

```
# Age composition data
# Year  0   1   2   3   4   5   6   7   8   9   10   11   12   13   14   15   16   17   18   19   20
  1993  0   13  58  60  61  129 38  22  40  15  12   2    9    10   6    7    2    0    5    2    9
  1996  1   6   106 143 55  45  46  19  21  11  6    9    7    4    2    9    2    1    0    0    7
  1999  0   14  142 53  124 67  45  16  3   9   12   2    4    3    1    0    1    0    0    0    4
```

Content of the file, **RECMODEL.PIN**, which contains initial estimates for the parameters, *i.e.* in order, virgin recruitment, steepness, commercial catchability, recreational catchability, and the fishing mortalities for each year from 1980 to 2001. The fishing mortality for 2001 is actually a dummy entry, used to match the years of commercial catch data, but cannot be estimated if there are no recreational data for this final year in the time series of fishing data.

```
  864.846441504572
 0.937924942411440
 1.174582078486004E-002
 1.346912255009170E-003
 5.743550930311446E-003
 1.350967772905549E-002
 1.922519779002054E-002
 4.554022234302646E-002
 3.041004392161286E-002
 3.947909333945461E-002
 4.929831436804893E-002
 0.147777427415962
 0.139622495227572
 6.490531680429643E-002
 9.921062996273969E-002
 0.238114895642282
 8.577540954028054E-002
 0.197414438304118
 0.141045612235978
 0.189744921779226
```

```
0.183540382262315
0.200000000000000
0.126349678458684
0.334765019672165
0.140076270840744
0.2
```