



Australian Government



MURRAY-DARLING BASIN AUTHORITY

# Murray Cod Management Model: User Manual

MURRAY-DARLING BASIN AUTHORITY

# Murray Cod Management Model: User Manual



Charles Todd and John Koehn

Arthur Rylah Institute for Environmental Research  
123 Brown Street, Heidelberg, Victoria 3084

October 2009

## Acknowledgements

The authors wish to thank Jim Barrett, Matt Barwick and Janet Pritchard from the Murray-Darling Basin Authority for support, members of the Murray-Darling Basin Authority Murray cod Taskforce, members of the National Murray cod Recovery Team and the steering committee for this project: Mark Lintermans; Roger Pech; Andrew Sanger; Glenn Wilson and Ross Winstanley. This project has been greatly assisted by the workshop participants at the Murray cod modelling workshop: Gary Backhouse, Matt Barwick, Paul Brown, Travis Dowling, Robert Gibb, Jason Higham, Changhao Jin, Peter Kind, Mark Lintermans, Adrian Moorrees, Simon Nicol, Roger Pech, Bill Phillips, John Pursey, Anita Ramage, David Ramsey, Stuart Rowland, Andrew Sanger, Julia Smith, Terry Walker, Karen Weaver, Cameron Westaway, Glenn Wilson, Ross Winstanley, Qifeng Ye and Brenton Zampatti. Helpful comments on this document as well as model testing were provided by Steve Saddler and Adrian Kitchingman.

Manual produced by:

Arthur Rylah Institute for Environmental Research  
Department of Sustainability and Environment  
PO Box 137  
Heidelberg, Victoria 3084  
Phone (03) 9450 8600  
Website: [www.dse.vic.gov.au/ari](http://www.dse.vic.gov.au/ari)

© State of Victoria, Department of Sustainability and Environment 2009

This publication is copyright. Apart from fair dealing for the purposes of private study, research, criticism or review as permitted under the *Copyright Act 1968*, no part may be reproduced, copied, transmitted in any form or by any means (electronic, mechanical or graphic) without the prior written permission of the State of Victoria, Department of Sustainability and Environment. All requests and enquires should be directed to the Customer Service Centre, 136 186 or email [customer.service@dse.vic.gov.au](mailto:customer.service@dse.vic.gov.au)

Citation

User manual

Todd, C.R. and Koehn, J.D. (2009). Murray Cod Management Model: User manual. Arthur Rylah Institute for Environmental Research Report to the Murray Darling Basin Commission (now Murray-Darling Basin Authority). Arthur Rylah Institute for Environmental Research Report, Department of Sustainability and Environment.

Software

Todd, C.R. (2009) Murray Cod Management Model: an application of Essential. Arthur Rylah Institute for Environmental Research Report to the Murray Darling Basin Commission (now Murray-Darling Basin Authority). Arthur Rylah Institute for Environmental Research Report, Department of Sustainability and Environment. <http://www.dse.vic.gov.au/ari/software>.

Disclaimer

This publication may be of assistance to you but the State of Victoria and its employees do not guarantee that the publication is without flaw of any kind or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence which may arise from you relying on any information in this publication.

Front cover photo: Murray cod (Gunther Schmida courtesy of Murray-Darling Basin Commission).

Authorised by the Victorian Government, Melbourne.

# CONTENTS

<b>Acknowledgements</b> .....	<b>ii</b>
<b>List of tables and figures</b> .....	<b>iv</b>
<b>1 Murray Cod Management Model: An Application of Essential</b> .....	<b>1</b>
1.1 Installation of Essential.....	1
1.2 Background to the Murray Cod Management Model.....	1
1.2.1 Age-structured Murray cod population model.....	1
1.2.2 Overview of Essential.....	2
<b>2 How to run the Murray Cod Management Model</b> .....	<b>4</b>
2.1 Principles for use.....	4
2.2 How to load the Murray Cod Management Model.....	4
2.3 Murray Cod Management Model interface.....	5
2.4 User prompt dialog.....	5
2.5 Example scenarios.....	6
2.5.1 Default scenario.....	6
2.5.2 Comparing scenarios.....	9
2.5.2 Complex scenarios.....	11
<b>3 Scenario specification</b> .....	<b>18</b>
3.1 Common parameters tab.....	18
3.2 Fishing scenarios tab.....	20
3.3 Fish kills scenarios tab.....	22
3.4 Stocking scenarios tab.....	24
3.5 Early life history scenarios tab.....	25
3.6 Habitat change scenarios tab.....	27
<b>4 Parameters of interest</b> .....	<b>28</b>
<b>5 References</b> .....	<b>31</b>
<b>6 Further reading</b> .....	<b>32</b>

## LIST OF TABLES AND FIGURES

### List of tables

Table 1: Comparisons of the average minimum population size for each scenario.....	14
Table 2: Comparisons of the average minimum population size for the stocking scenarios.....	16

### List of figures

Figure 1: An example of a fecundity distribution (numbers of eggs) for five year old female Murray cod, randomly generated from a lognormal distribution with mean 6000 and sd 2800.....	3
Figure 2: Default graphs used for the Murray cod management model producing output from the default scenario settings. Note that <i>TLegalC</i> Trajectory and Stats and Minimum Population Distribution graphs are both zero as no fishing scenarios have been implemented. See default graph descriptions below.....	7
Figure 3: Final three graphs of the default variable set. Note that <i>IllegalOverSize</i> , <i>IllegalUnderSize</i> , and <i>IllegalTotal</i> are all zero due to no illegal fishing scenarios having been implemented. See default graph descriptions above.....	9
Figure 4: Minimum population distributions used to characterise risk (risk curves).....	10
Figure 5: Risk curve produce for the variable <i>TA20A25</i> .....	10
Figure 6: Risk curve comparison for different scenarios for the variable <i>TA20A25</i> .....	11
Figure 7: Output from the complex scenario with stocking of 50,000 fingerlings from year 10 to year 14 (five years).....	16

# 1 MURRAY COD MANAGEMENT MODEL: AN APPLICATION OF *ESSENTIAL*

This manual provides overall instruction on the use of the Murray Cod Management Model (Todd, 2009). The model will aid judgements and support decisions reached by managers but does not offer solutions to all of the management problems for Murray cod. Rather, the model should be used as a tool to assess management options and help prioritise them.

## 1.1 Installation of *Essential*

The Murray Cod Management Model was developed using the software package *Essential* (Todd and Lovelace, 2009), a platform for writing stochastic population models and is available as freeware (<http://www.dse.vic.gov.au/ari/software>). The model and the software are distributed together and are installed on to any PC by executing the install file *Murray Cod Management Model Install.exe*. The installation of this software does not access or modify the computer's registry and can be safely installed without concern on any PC. The software is installed in the computer's directory C:\Program Files\Essential and the folder *Essential* will be automatically created if it does not already exist. A sub-directory is also created, C:\Program Files\Essential\MC Management Model, to hold the Murray cod model file *Murray Cod Management Model.mdl* and a back up file *Copy of Murray Cod Management Model.mdl* which holds the default settings for the model and can be copied and renamed if the user accidentally modifies the original file or can be opened and saved as a new name. **Please ensure that the copy file is never renamed or copied over.** Also found in this folder is the Murray cod management model: User manual (this document) and the report by Todd and Koehn (2009) Murray Cod Modelling to Address Key Management Actions Final Report for Project MD745.

If the user installs *Essential* to a location other than the default setting under C:\Program Files, the user needs to modify the file *essential.ini* found in the directory where *Essential* has been installed before attempting to run the Murray Cod Management Model. The lines `LastOpenPath=C:\Program Files\Essential\MC Management Model\` and `LastSavePath=C:\Program Files\Essential\MC Management Model\` need to reflect the new location of the *Essential* directory and sub-directories. Similarly, the lines `ModelFn=C:\Program Files\Essential\MC Management Model\Murray Cod Management Model.mdl` and `H0=C:\Program Files\Essential\MC Management Model\Murray Cod Management Model.mdl` also need to be changed to reflect the location of the file *Murray Cod Management Model.mdl*.

## 1.2 Background to the Murray Cod Management Model

The user may go straight to section 2 as the rest of this section provides an overview of *Essential* and is not necessary to run the Murray Cod Management Model.

### 1.2.1 Age-structured Murray cod population model

There is a long history of age-structured models being used to facilitate the analysis of exploited fish populations (Megrey 1989), and in more recent years including length based age-structure (Fournier et al. 1998; Hampton and Fournier 2001). In developing the age-structured model for Murray cod, both the life history and management questions were used to guide the process. The model summarises the life history of Murray cod by explicitly representing 25 age classes where entry into the first age class combines spawning, egg, larval and early juvenile survival where juveniles are defined as fish less than 1 year old. Murray cod are assumed to become sexually mature at 5 years of age with fecundity increasing to the final age class 25+ years of age. The population dynamics modelled are for females only and with an assumed even sex ratio males are included in the final tally by simply doubling the female count. The model includes stochastic processes for modelling variation in fecundity rates in all adult age classes and variation in survival in all age and stage classes each year (see for example Todd et al., 2005). Age-specific survival was estimated from otolith data collected from the Murray River

and southern tributaries. No study has been undertaken to estimate egg and larval survival in the wild; however, in hatchery operations, egg and larval survival have been documented and are quite variable (cf. Cadwallader and Gooley, 1985). Incorporating variability into fecundity and survival rates simulates the process of natural variation in the environment. Also included are processes for modelling demographic variation, the effects of density-dependence, and variable growth across different age classes. The management issues that drove the development of the Murray Cod Management Model fall in to two different categories: fishery management and habitat and flow management. Specific fishery management scenarios were developed to examine changing the minimum legal length; changing/setting the maximum legal length; a range of fishing effort/rate; reducing illegal take; outlawing set lines; having 'no take' areas; stocking of fingerlings and one year old fish. Specific habitat scenarios were developed to examine an increase or decrease in habitat; reducing the impacts of cold water pollution; providing environmental flows at differing times, durations. In addition other scenarios were developed to look at fish kills/poaching, impacts to early life history and the ability to cast the Murray Cod Management Model for differing regions by selection of some common parameters. For the complete model description as well as the process for developing the management scenarios see Todd and Koehn (2009).

### 1.2.2 Overview of *Essential*

Managers are sometimes forced to make decisions on management actions that can directly affect the survival of natural populations of animals and plants.

*Essential* provides a quantitative, stochastic modelling framework for assessing and comparing risks to a population. *Essential* can assist decision-making:

- by providing a quantitative approach for systematically exploring outcomes of management actions;
- by specifically allowing data uncertainty and variability to be incorporated in model formulation;
- through developing models as an explicit statement on the current knowledge about a species or population;
- by enabling consideration of several, simultaneous management actions; and
- by identifying knowledge gaps and enabling the prioritisation of research.

Most management decisions are based on a range of options. Modelling can assist in decision-making by introducing a logical and systematic approach to comparing different management options. *Essential* uses modelling as a problem-solving tool, not as a realistic representation of nature. In the absence of data for a particular parameter, the program can still allow an exploration of the difference that the missing data may make (Starfield, 1997).

This approach can be particularly useful for endangered species management, an area where data are often scarce and of poor quality but where management decisions cannot be postponed or avoided. By using *Essential*, managers can assess the relative importance of different population parameters, set priorities in data collection and research requirements, and evaluate management options based on available data and current understanding of the dynamics of a given population, including perceived threats to the population.

*Essential* uses Monte Carlo simulations with discrete time steps in the construction of stochastic population models. Monte Carlo simulation generates random numbers from distributions describing variation in population parameters. The purpose is to determine how random variation, lack of knowledge, or error affects the sensitivity, performance, or reliability of the predictions (Wittwer, 2004). Monte Carlo simulation is categorised as a sampling method as the inputs are randomly generated from probability distributions to simulate the process of sampling from an actual population (Wittwer, 2004). Including mechanistic descriptions of demographic and environmental variation into the model produces a stochastic population model (see Todd and Koehn, 2009 for more details).

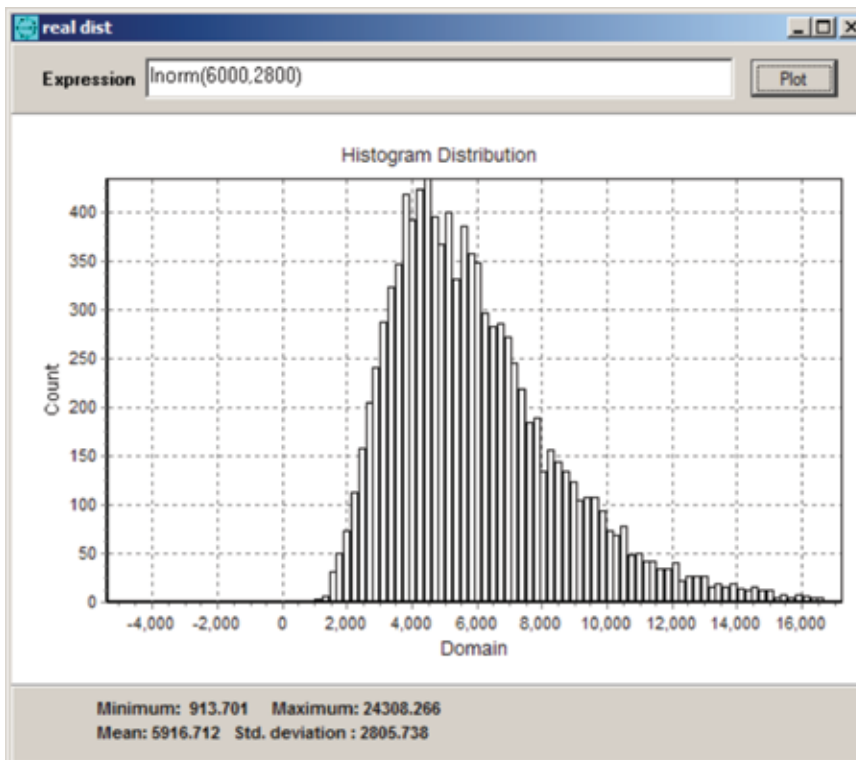
The output from *Essential* includes population trajectories and risk curves expressing the likelihood of population decline and increase. Probability boundaries can be estimated around particular outcomes to facilitate comparisons between different plausible management strategies. Sensitivity analysis can be used to assess the relative impacts of changing the starting values for particular parameters and environmental



conditions, allowing managers a quantitative approach to risk assessment of alternative management scenarios. Consequently, decisions can be made based upon an explicit process that includes uncertainty and is open to examination (Starfield and Bleloch, 1991; Burgman et al., 1993; Jackson et al., 2000).

*Essential* has two modes:

- Expert mode allows users to develop their own discrete-time population models. All model types relating to discrete time can be created: including unstructured and structured population models, for example, age- and stage-structured models and metapopulation models. A number of mathematical operators and functions are included in *Essential* allowing users to specify a wide array of mathematical relationships including a variety of stochastic functions (probability density functions returning random variates) to model environmental and demographic variation, as well as other random processes (see Fig. 1 for an example).
- General mode requires minimal modelling and mathematical expertise but does require models to be already developed or predefined for analysis and assessment. The structure of a predefined model is based on the knowledge of the life history of a given species as well as available data. Similarly, the form of the equations used for the models and parameter values are species-specific. Users are required to specify particular population and management parameters as requested in running the program. Users can easily change the input for several parameters that relate to the life history, biology and management of a species. The output can be used to assess the expected impact that a management scenario will have on a population and to compare the effects of different management scenarios. Furthermore, as several parameters can be manipulated in the same modelling run, the user can explore not just a single management action, but the consequences of several actions applied simultaneously.



**Figure 1: An example of a fecundity distribution (numbers of eggs) for five year old female Murray cod, randomly generated from a lognormal distribution with mean 6000 and sd 2800.**

The output from *Essential* allows the ranking of management options in terms of estimated probabilities of success (eg. probability of the population containing more than a given number of adults at the end of a specified time period) or failure.



## 2 HOW TO RUN THE MURRAY COD MANAGEMENT MODEL

### 2.1 Principles for use

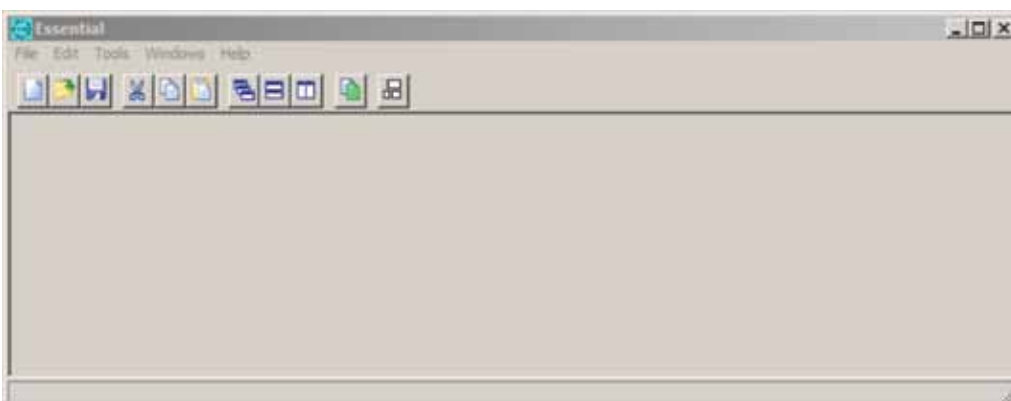
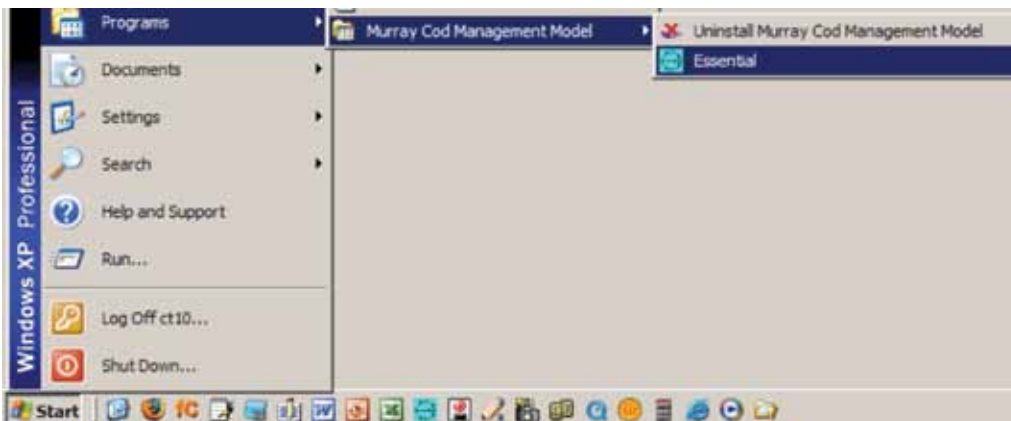
This section provides general instruction on the use of the Murray Cod Management Model. The Murray Cod Management Model will help judgements and decisions undertaken by managers but does not offer solutions to all management problems. Rather, the model should be used as a tool to assess management options and help prioritise them. Each parameter is fully explained in the following section with a rationale and the implications of its use explored. Suggestions are given as to how the parameters within the model should be applied under different circumstances. It is expected that the manual will be used in conjunction with the model, i.e. run the examples given in the following sections as the user works through the manual. Once the user has become familiar with the software it is useful to play with the software and the various parameters as much as possible to become comfortable with the features and confident in the program's use.

### 2.2 How to load the Murray cod management model


To run the Murray cod management model, locate and double click on the Essential icon you already have installed on your desktop,



alternatively you can click on the Start button on the bottom left your screen, select Programs and then select the folder Murray Cod Management Model, highlight the Essential icon and click.



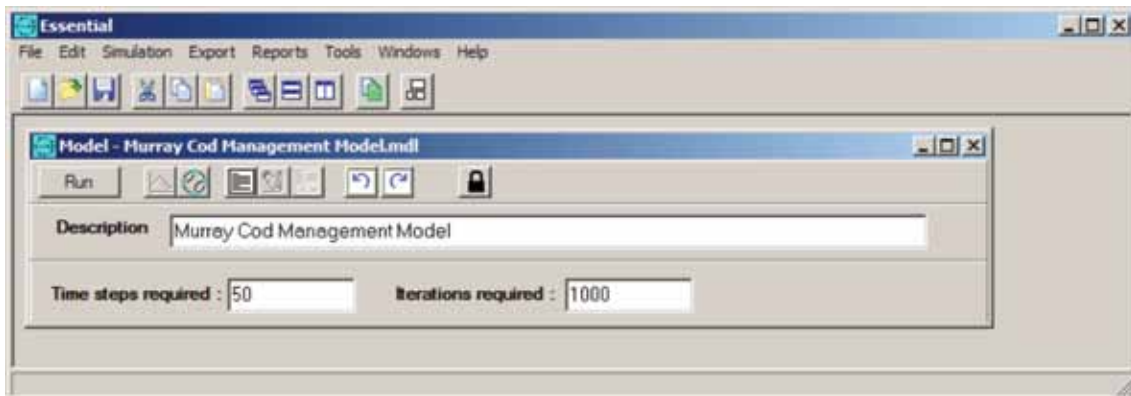
*Essential* starts with the Murray Cod Management Model file already loaded. However, if the interface starts without the model loaded or the user closes the model, then it is straightforward to open a file.


To open the Murray Cod Management Model select File → Open or click on the open file icon  to the open file *Murray Cod Management Model.mdl*. Do not open the file *Copy of Murray Cod Management Model.mdl* unless the user needs to reset the default values, if so, do this by saving the copy as *Murray Cod Management Model.mdl*.

### 2.3 Murray cod management model interface

The first time the Murray Cod Management Model is loaded the parameters are set in their default options. If the user is ever prompted to save the Murray Cod Management Model upon exiting *Essential* then it is advised to either save the model as some other file or exit without saving, unless the user has become proficient in the use of *Essential* and the Murray Cod Management Model and is aware of the impact of the changes they have made.

When the model is loaded the *Essential* interface look as follows:



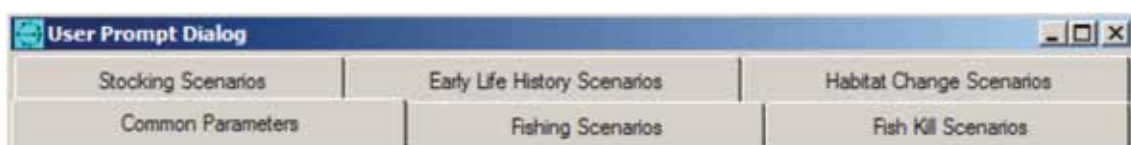
Selecting the Show/Hide Details button  will open this user manual as well as reveal a brief summary of the model.

The number of time steps should be selected at this point (in the case of the Murray cod management model time steps equate to years). It may be that the user is unsure of the number of time steps that they wish to implement - it is easy to try a value then run a scenario and then change the number of time steps if need. If the user is undertaking a number of scenario explorations it is sensible to decrease the number of iterations required to a lower number, for example 100. This means fewer trajectories are produced and therefore less possibilities are explored but it does allow the scenario calculations to be completed quicker, which makes for fast scenario exploration. When the user is satisfied that they have the right combination of parameters, they can reset the iterations required to 1000 so that a wide range of possibilities are explored.

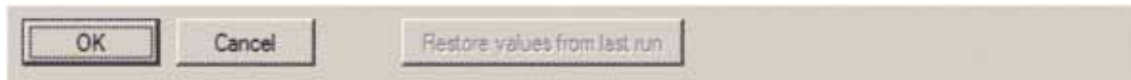
To chose from the variety of biological/ecological and management options click on the Run button .

### 2.4 User prompt dialog

Clicking the Run button opens the User Prompt Dialog window where the options to choose the variety of biological/ecological and management scenarios are displayed. There are six categories for scenario development which are expanded upon in section 3. Note that the view of the User Prompt Dialog window may change depending on the users settings.



Clicking on the various tabs reveals the parameters associated with the tab heading. Altering the available parameters allows the user to create alternate scenarios for exploration and analysis. Once the user's selection is made click on the OK button at the bottom of the User Prompt Dialog window. This will run the model under the specific parameter selection.



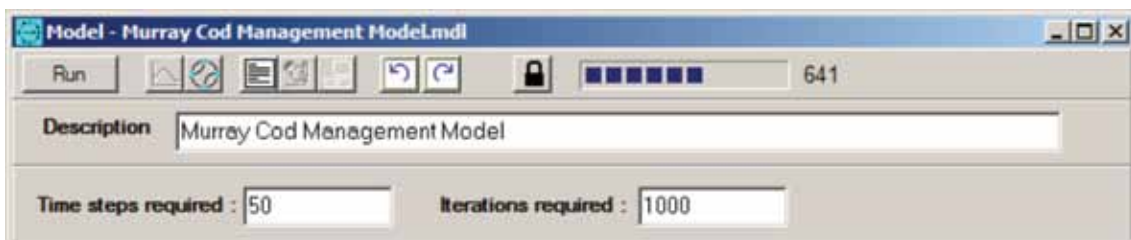
When running the model again, the User Prompt Dialog window opens with the last viewed scenario tab.

## 2.5 Example scenarios

### 2.5.1 Default scenario

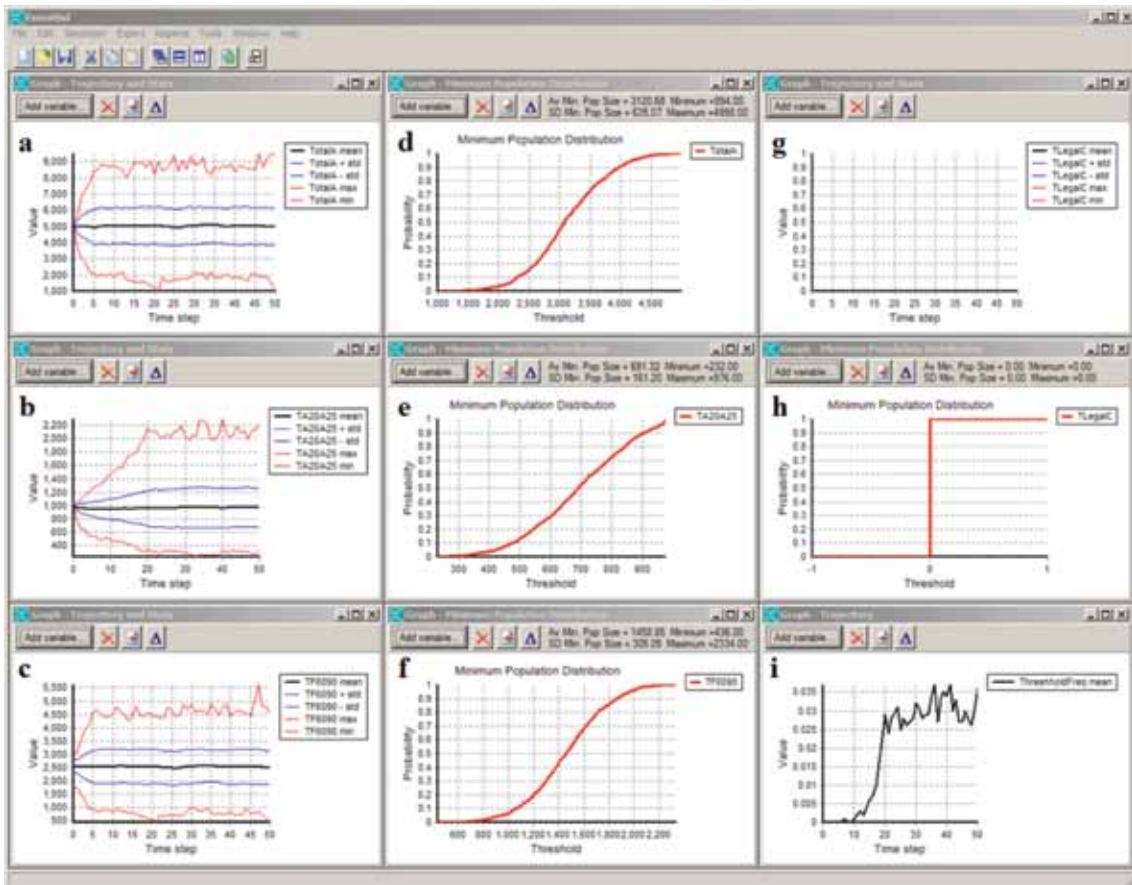
When the model is first loaded with 50 time steps and 1000 iterations selected, click run which brings up the User Prompt Dialog and without modifying any of the parameters, the parameter defaults are used, click the OK button.

The progress bar indicates that the simulation is running.



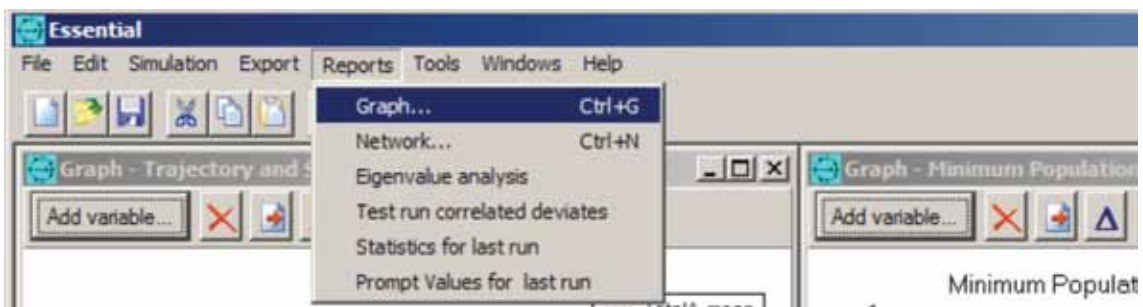
The default set of graphs are displayed when the model has completed the specified number of time steps and iterations. While there are six types of graphs available in the Murray cod management model (mean trajectory; mean trajectory and statistics; minimum population distribution; maximum population distribution; terminal minimum population distribution and terminal maximum population distribution), only three types are used in the default set: trajectory and statistics (Fig. 2 see graph title bar of graphs in the first column, graphs a, d, and g as well as the third column graphs c and f); minimum population distribution (Fig. 2 see graph title bar of graphs in the second column, graphs b, e, and h); and trajectory (Fig 2 see graph title bar of the bottom right graph, graph i). The other three available graph types can be used if desired for any parameter of interest.


The graph of the mean trajectory and statistics of a variable's trajectories plots the mean over the time period used in the simulation plus the statistics of  $\pm 1$  standard deviation, maximum and minimum values. The graph of the minimum population distribution of a variable is the normalised cumulative frequency of the minimum value from each trajectory (less iterations produce an irregular or rough graph as there are less minimum values). The mean trajectory is simply the mean of a variable over the simulation time period.



**Figure 2: Default graphs used for the Murray cod management model producing output from the default scenario settings. Note that *TLegalC* Trajectory and Stats and Minimum Population Distribution graphs are both zero as no fishing scenarios have been implemented. See default graph descriptions below.**

All variables can be graphed by selecting the Report option in the drop down menu list





or the graph icon  in the Murray cod management model window or Ctrl+G.

Only some of the available variables are graphed in the default set:

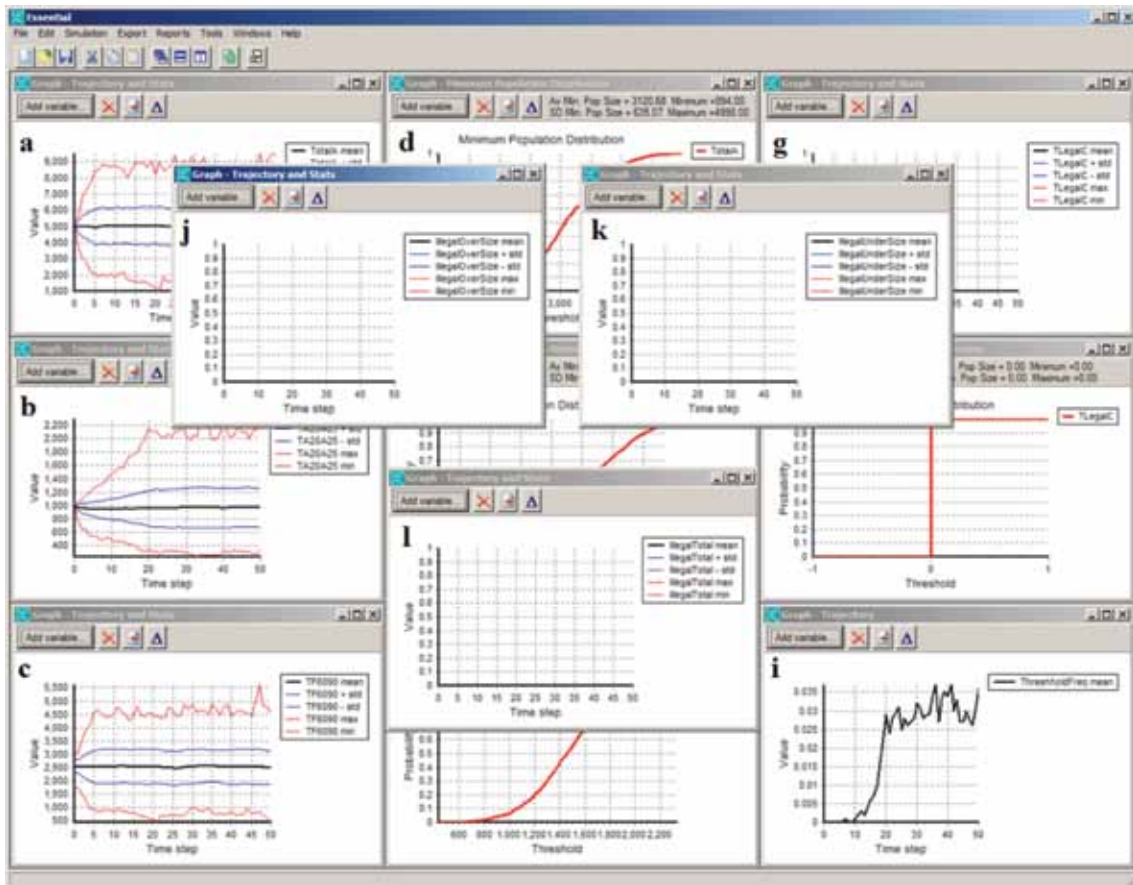
- a** *TotalA* – all adult fish or fish aged 5 and older;
- b** *TA20A25* – all fish aged 20 and older;
- c** *TF6090* – all fish in the size class 60cm to 90cm inclusive;
- d** *TotalA* – minimum population size distribution for all adult fish, adult fish risk analysis;
- e** *TA20A25* – all fish aged 20 and older risk analysis;
- f** *TF6090* – all fish in the size class 60cm to 90cm risk analysis
- g** *TLegalC* – the total legal catch;
- h** *TLegalC* – minimum population size distribution for all legally caught fish, provides the minimum catch distribution; and
- i** *ThresholdFreq* – the number of trajectories for *TA20A25* that fall below the specified critical threshold (see section 3.1) over time.
- j** *IllegalOverSize* – the number of fish removed by poaching over the maximum legal size
- k** *IllegalUnderSize* – the number of fish removed by poaching under the minimum legal size
- l** *IllegalTotal* – the total number of fish removed by poaching

This set of variables should be sufficient to analyse the impacts of all the available scenarios.


An analysis of the graphical output in Fig. 2 leads to the interpretation that this modelled population is stable. The variables *TotalA*, *TA20A25*, and *TF6090* have mean trajectories that are not in decline and the associated minimum population distributions are well above zero indicating low risk of the population being small. As fishing has not yet been initiated, *TLegalC* is always zero and a very small frequency of trajectories of *TA20A25* falling below the specified critical threshold of the default setting [500].

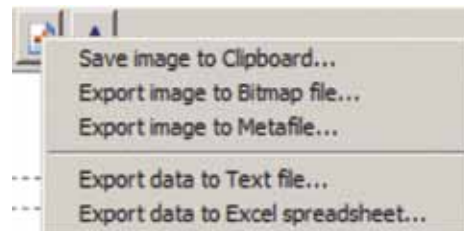
To access the final three graphs in the default variable set (*IllegalOverSize*; *IllegalUnderSize*; and *IllegalTotal*) click on the Bring model form to front icon , clicking on this icon allows the user to cycle through the graphs of the default variable set. Under the default scenario settings there is no illegal fishing and consequently the graphs for the three illegal fishing variables are always zero, see Fig. 3. The user can click on the Bring model form to front by clicking on the icon  at any time or by continuously clicking on the icon cycle through the graphs.





**Figure 3: Final three graphs of the default variable set. Note that *IllegalOverSize*, *IllegalUnderSize*, and *IllegalTotal* are all zero due to no illegal fishing scenarios having been implemented. See default graph descriptions above.**

A graph can be easily exported or saved or the data exported to a text file or Excel spreadsheet by clicking on the Export data button  and choose from the available options:

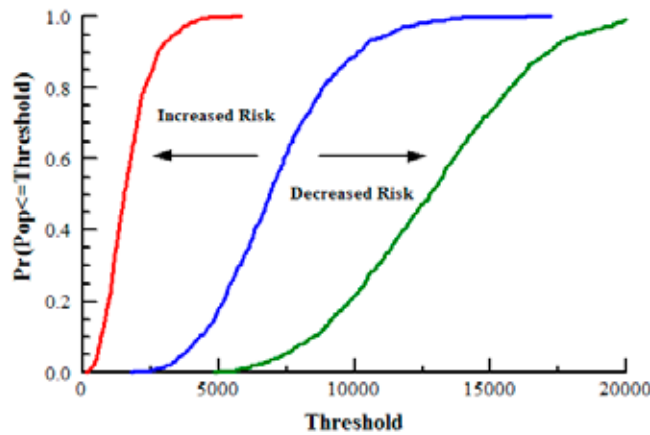


### 2.5.2 Comparing scenarios

There are a number of ways in which it is possible to compare scenarios. The methods for comparing scenarios presented here are the most general approaches.

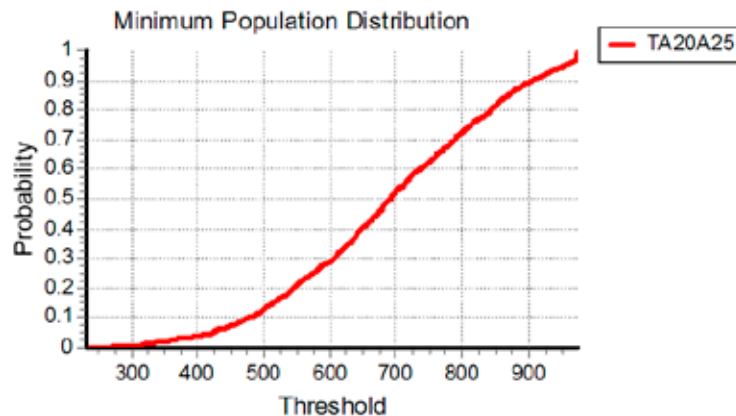
Each iteration produces a population trajectory and each trajectory will have an associated minimum population size. Each scenario is made up of the number of trajectories specified (iterations) and therefore each scenario will have a range of minimum population sizes. Generating a cumulative frequency distribution from the minimum population sizes for the scenario produces a minimum population size distribution. When the minimum population size distribution is graphed the resultant cumulative distribution curve represents risk (termed a risk curve, Fig. 4) and can be interpreted as the probability of the population falling to or below some

value or threshold. Increased risk shifts to the risk curve to the left or closer to zero with a higher likelihood of the modelled population being small and decreased risk shifts the risk curve to the right or further away from zero or a lower likelihood of the modelled population being small (Fig. 4).





**Figure 4: Minimum population distributions used to characterise risk (risk curves).**


For example, from the default parameter set, the minimum population distribution for *TA20A25* indicates that there is a 50% chance that the population of fish aged 20 and older was less than or equal to 692 at least once during the simulation period (see Fig 5.). Comparing risk curves of a variable under different scenarios demonstrates either increased risk or decreased risk (see Fig. 4), that is either the new risk curve has moved closer to zero indicating increased risk or further away from zero indicating decreased risk.

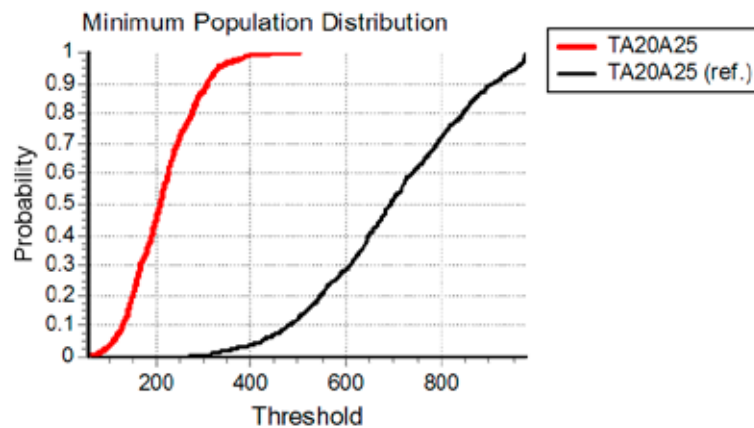


**Figure 5: Risk curve produce for the variable *TA20A25***

Comparing risk curves can be simply undertaken by clicking on the comparison icon  in the minimum population distribution graph for *TA20A25* (graph e in Fig. 2) and selecting Save as baseline. Clicking on the drop down menu item Simulation and selecting Run or pressing F9 will bring up the User Prompt Dialog window or click on the icon Bring model from to front  and then clicking on the Run button will also bring up the User Prompt Dialog window. Click on the tab for Fishing Scenarios and enter 1 in the item Enter 0 for no fishing or 1 for fishing (for binary choices do not use the slider simply type in the required value) and make no other changes, click Ok at the bottom of the Users Dialog Window. When the default graphs show click on the comparison icon in the minimum population distribution graph for *TA20A25* (graph e in Fig. 2) and select Show baseline. The original reference curve (minimum population distribution) is in black (as indicated, compare Fig. 6 to Fig. 5) and the red risk curve (minimum population distribution) is the curve associated with the current scenario (Fig. 6). The shift to the left demonstrates an increased risk that is associated with fishing.



All minimum population distribution risk curves can have similar comparisons undertaken and such comparisons represent a pictorial expression of changes in risk. If the user wishes to produce more than two risk curves on a graph then the data for each risk curve must be imported into the user's charting program. Graph data is saved by using the Export data button  and selecting either Export data to Text file or Export data to Excel spreadsheet and then copy and paste the data into the user's charting program.



**Figure 6: Risk curve comparison for different scenarios for the variable TA20A25**

Alternatively the user can document the average minimum population size for each scenario and rank these values as a tabular form of changes in risk. (Please note that the average minimum population size should not be confused with the 0.5 probability threshold population size, although they will be approximately the same when the distributions are not skewed) An example of how to use the average minimum population size: the average minimum population size for the variable TA20A25 under the default parameter set is 691.32, that is on average the minimum population size of fish aged 20 and older is 691.32 where as implementing the fishing scenario as described above produces an average minimum population size of 214.41. Subtracting the average minimum population size of the fishing scenario from the average minimum population size of the default scenario produces 476.91 and this is interpreted as an increased risk associated with fishing with an average loss of 476.91 20+ fish from the minimum population size and the risk curve has been effectively shifted to the left (or closer to zero) by an average of 476.91 20+ fish. When comparing multiple scenarios simply ranking the average minimum population size from highest to lowest provides a quantitative table of the expected changes in risk. When undertaking multiple scenario analysis it is important that the user keeps careful track of the various parameter values selected in the User Prompt Dialog and ensure that careful documentation is maintained to avoid confusion when recording data and/or charts.

### 2.5.3 Complex scenarios

The User Prompt Dialog window has five scenario categories: fishing; fish kill; stocking; early life history; and habitat change. The user can implement multiple management actions or include multiple threatening processes in one scenario. For example, consider a population where:

- moderate fishing occurs with some illegal fishing also occurring;
- there is an undershot weir and some irrigation off-take; and
- some likelihood of a fish kill occurring due to water quality issues.

To capture this scenario make the following changes in the:

Fishing scenario tab

- Enter 1 for fishing (recall for binary choices do not use the slider simply type in 1)
- Change the catch rate to 0.15 for fish <100cm

- Change the mortality due to catch and release to 0.05
- Enter 1 for illegal fishing and
- Change the illegal fishing rate to 0.05

Fish kill scenario tab

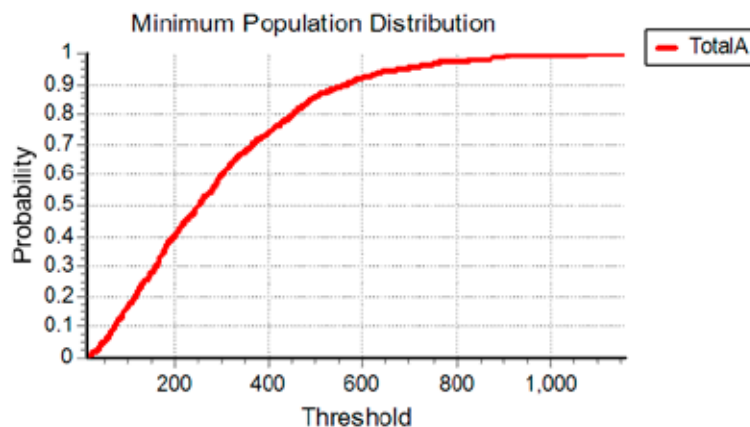
- Enter 1 for fish kill
- Enter 1 to impact on adults only
- Enter 1 for random occurrence and 0.1 for frequency
- Enter 30 for percentage loss


Early life history scenario tab


- Enter 1 for weir impacts
- Enter 50 in percentage loss due to weir
- Enter 1 for irrigation off-take impacts
- Enter 30 for percentage loss of larvae due to irrigation off-take.

Click OK.

The risk curve for the total adult population under this multiple impact scenario is




Click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Save as baseline.

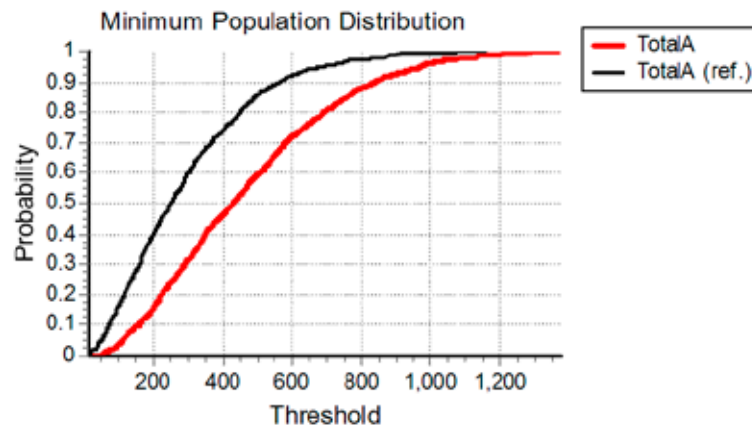
Let's assume a technique has become available that allows the irrigation off-take to be screened to stop larvae survival being impacted. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front  and then clicking on the Run button will bring up the User Prompt Dialog window. To capture this scenario make the following changes:


Early life history scenario tab

- Select 0 to remove the impacts of irrigation off-take (note: make sure that weir impacts have not turned off).
- Reset the percentage loss due to irrigation off-take impacts to 0 or it can be left unchanged, irrigation off-take impacts have been turned off by selecting 0.

Click OK.

When the simulation has completed, click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.




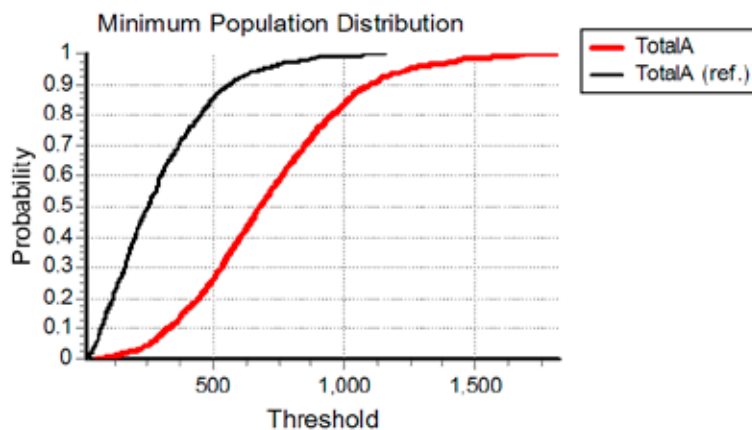
If the undershot weir has been modified into an overshoot weir. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front  and then clicking on the Run button will bring up the User Prompt Dialog window. To capture this scenario make the following changes:


Early life history scenario tab

- Change 50 to 15 in percentage loss due to weir.

Click OK.

When the simulation has completed, click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.




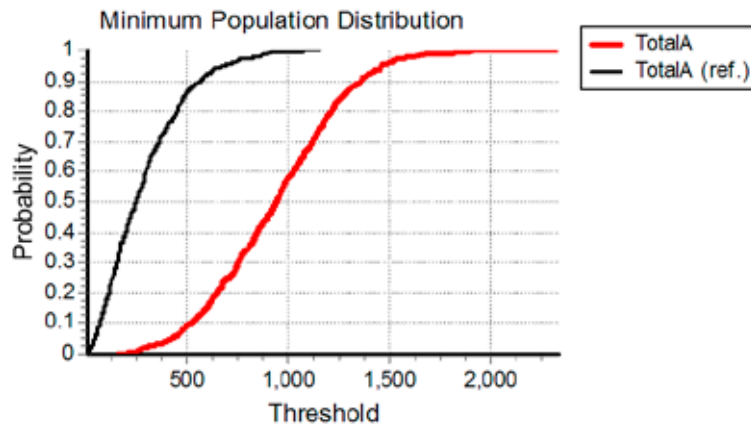
Improved water quality can remove the likelihood of a fish kill. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front  and then clicking on the Run button will bring up the User Prompt Dialog window. To capture this scenario make the following changes:

Fish kill scenario tab

- Enter 0 for no fish kill

Click OK.




When the simulation has completed, click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.



Changes the risk curve as well as changes to the average minimum population size of the *TotalA* parameter for each scenario (Table 1) indicate that risk is being reduced. The user can make further changes, by removing illegal fishing or by changing the fishing regulations, to see how this reduces risk even further. Alternate combinations can also be undertaken. Does the order in which management actions occur impact on the changing risk profile?

**Table 1: Comparisons of the average minimum population size for each scenario**

Scenario	Av. Min. Pop. Size
Complex	293.12
Remove irrigation off-take impacts	469.17
Convert undershot weir to overshot	708.31
Improved water quality	944.53

The user should take this opportunity to play with this complex scenario so that they become familiar with the analytic components as well as becoming used to the interface. Do not be afraid just to play with all the various options. The model can be easily reset if the user loses track of all the changes they have made by simply clicking on the Set to default button  for all parameters in each tab, to the left of the parameter slide . Or the user can load the copy of the Murray Cod Management Model by selecting File -> Open or click on the open file icon  and selecting the file *Copy of Murray Cod Management Model.mdl* and immediately saving the file as *Murray Cod Management Model.mdl*.

Another management option is to stock fish rather than ameliorating the threatening processes. Reinststate the initial complex scenario with the following changes:

Fishing scenario tab

- Enter 1 for fishing (recall for binary choices do not use the slider simply type in 1)
- Change the catch rate to 0.15 for fish <100cm
- The mortality due to catch and release is already set at 0.05
- Enter 1 for illegal fishing
- Change the illegal fishing rate to 0.05


Fish kill scenario tab


- Enter 1 for fish kill
- Enter 1 to impact on adults only
- Enter 1 for random occurrence and 0.1 for frequency
- Enter 30 for percentage loss

Early life history scenario tab

- Enter 1 for weir impacts
- Enter 50 in percentage loss due to weir
- Enter 1 for irrigation off-take impacts
- Enter 30 for percentage loss of larvae due to irrigation off-take.

Click OK.

Click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Save as baseline.


Now consider stocking 50,000 fingerlings for five years. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front  and then clicking on the Run button will bring up the User Prompt Dialog window.

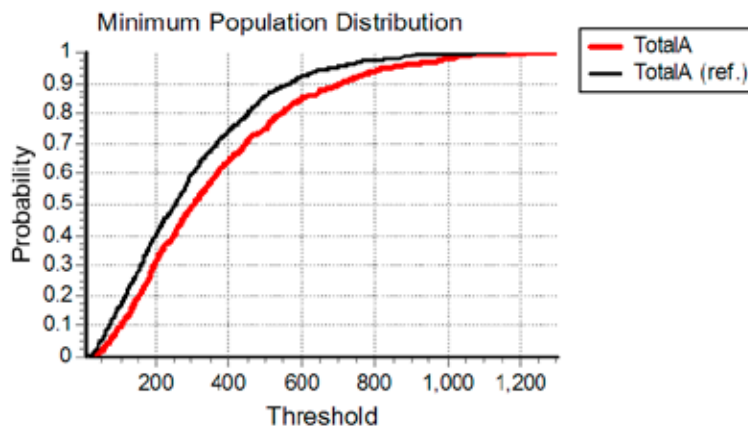
To capture this scenario make the following changes in the:

Stocking scenario tab

- Enter 1 for stocking
- Enter 0 for fingerlings (already set at 0)
- Enter 50,000 for the number of fish to be released
- Enter 10 for the year to begin releases
- Enter 5 in the number of years to stock for

Click OK.

When the simulation has completed click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.

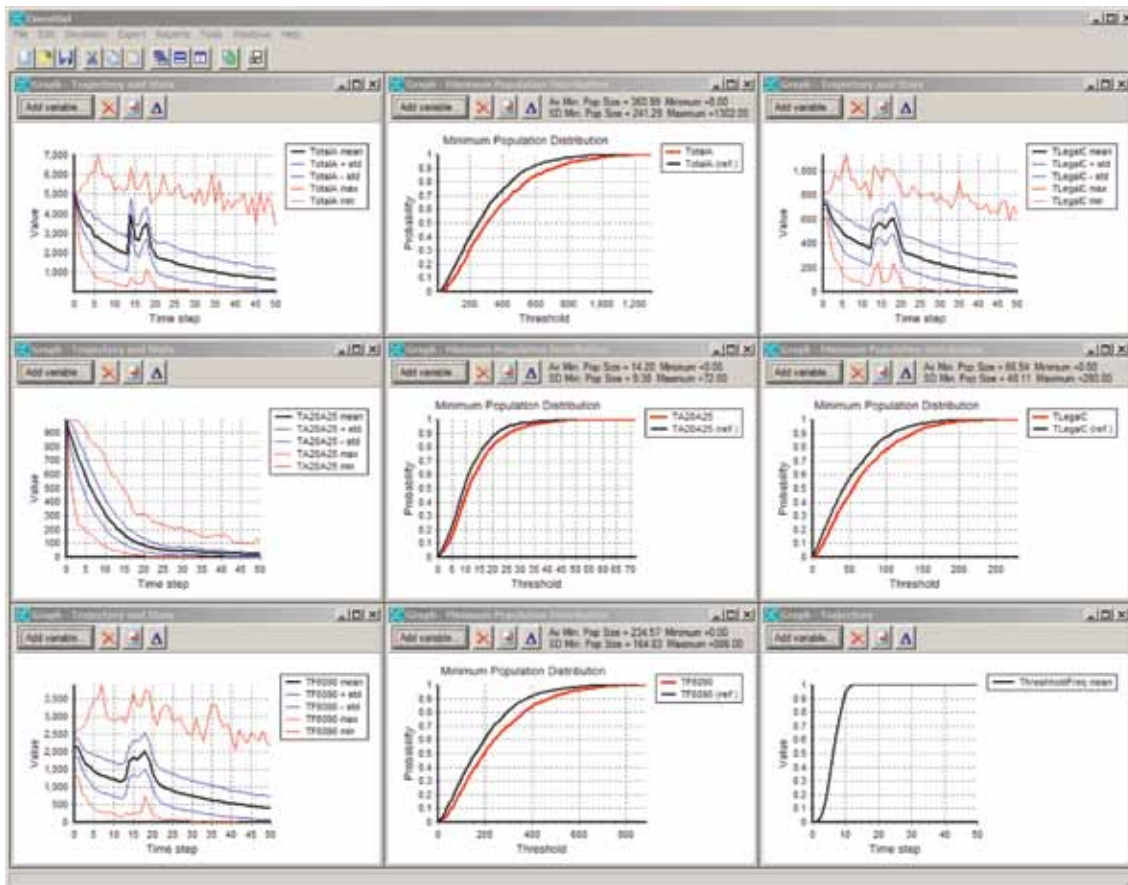


The user can clearly see that this stocking scenario has not greatly changed the risk curve and decreased risk associated with stocking with an average gain of approximately 40 adult fish to the minimum population size (see Table 2). This is not to say that stocking is not a valuable tool for managers as different objectives can be obtained with stocking. The angler catch is likely to increase when the fish reach legal angling size which can be seen in Fig. 7 (*TLegalC*), although little change to the distribution of minimum fish caught. It should be noted that while releases were only carried out for five years the increased catch persists over approximately eight years. Another feature of this scenario is the increase in fish sized 60 to 90cm (*TF6090*) in the third to fourth year after first stocking, however this increase only has a very small follow through to fish aged 20 plus (*TA20A25*).

**Table 2: Comparisons of the average minimum population size for the stocking scenarios**

Scenario	Av. Min. Pop. Size
Complex	293.12
Stocking 50k fingerlings for 5yrs	360.99
Stocking 200k fingerlings for 5yrs	375.17
Stocking 50k fingerlings for 40yrs	1364.74

To clear the baseline from a graph, just run the scenario again and do not use the Show baseline function.




**Figure 7: Output from the complex scenario with stocking of 50,000 fingerlings from year 10 to year 14 (five years).**

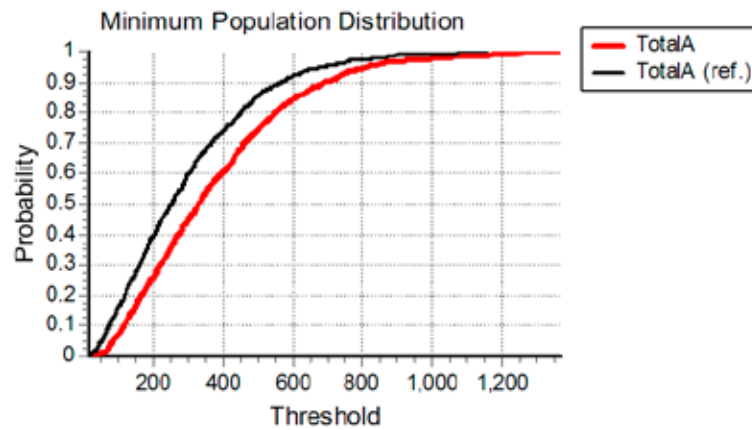
Now consider stocking 200,000 fingerlings for five years. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front and then clicking on the Run button will bring up the User Prompt Dialog window. To capture this scenario make the following changes:

Stocking scenario tab


- Change the number of fish to be released to 200,000.

Click OK.

When the simulation has completed, click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.




The extra effort of releasing more fingerlings does not translate into greatly improved conservation outcomes, although the angler catch increases again following the release of fish (see Table 2).

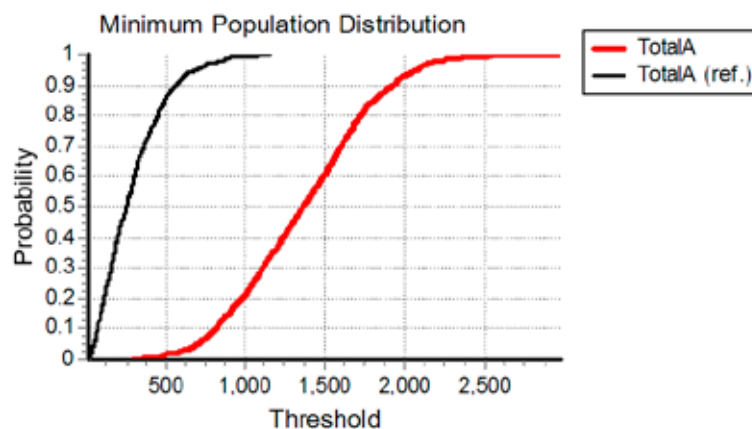
Now consider stocking 50,000 fingerlings for forty years. Run the model again by clicking on the drop down menu item Simulation and selecting Run or pressing F9 or click on the icon Bring model from to front  and then clicking on the Run button will bring up the User Prompt Dialog window. To capture this scenario make the following changes:

Stocking scenario tab

- Change the number of fish to be released to 50,000
- Change the number of years to stock for to 40

Click OK.

When the simulation has completed, click on the comparison icon  in the minimum population distribution graph for *TotalA* and select Show baseline.



When stocking continuously it is possible to achieve conservation outcomes as well as recreational fishery objectives but this does require a long term commitment to stocking when no other threats are abated (see average minimum population size comparisons in Table 2).



### 3 SCENARIO SPECIFICATION

A scenario is specified by selecting or changing a parameter to suit the desired construct.

In this section, and where appropriate, each parameter has:

- a brief description;
- specified default;
- a parameter range or choice;
- an explanation of the parameter; and
- a brief statement about the assumptions behind the parameter.

Parameters are grouped according to their relevance to the sections of the model and to the biological attributes of Murray cod.

#### 3.1 Common parameters tab

##### Average adult population size

*Parameter description:* Set the expected adult population size.

*Default option:* 5 000

*Parameter range:* 100 – 400 000

*Parameter explanation:* In the absence of any deleterious impacts it is expected that the value entered will be the average adult population size over time.

*Assumptions:* This parameter is likened to a carrying capacity, except that a carrying capacity is a fixed upper limit to a population which this parameter is not. However, this parameter is used in the density-dependent functions to limit population growth. This parameter does not fix an upper limit to the population but when the population rises above this parameter the strength of density dependent effects increases and causes the population to decline towards this parameter. When the population falls below this parameter density dependent effects decrease allowing the population to increase.

##### Enter 0 for automatic initialisation of population size; or 1 for user to choose

*Parameter description:* Choose to set the initial adult population size.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* The user can choose to have the initial population size set automatically set at the same level in the above Average adult population size selection or the user can choose to set the population at some other level by entering 1.

*Assumptions:* Automatically setting the initial population size always sets the adult population at the average population size in the absence of impacts and this may not always be appropriate for the scenario being examined. If impacts are being modelled and the automatic option is selected then the scenario will exhibit a decline in the adult population to some lower level. If automatic selected then the average adult population size value is distributed across the adult age classes 5-25 based upon the stable age distribution and extrapolated to the juvenile age classes 1-4.

Enter the initial adult population size

*Parameter description:* Set the initial adult population size.

*Default option:* 5 000

*Parameter range:* 0 – 100 000

*Parameter explanation:* Setting the initial adult population size initialises the model if the user has decided to set the initial population size above. In most circumstances the size of a population of interest will be unknown and will have to be estimated. This value can include zero for a reintroduction scenario, provided that the stocking parameter is suitably modified.

*Assumptions:* The value used is distributed across the adult age classes 5-25 based upon the stable age distribution and extrapolated to the juvenile age classes 1-4.

Choose Beverton-Holt density dependence or Combination dd or Top down dd; 1 or 2 or 3

*Parameter description:* Select the type of density dependence (dd) impacting on a population.

*Default option:* 2

*Parameter range:* 1, 2, or 3

*Parameter explanation:* All populations are constrained by their environment, whether it be through, but not limited to: limiting resources, predation or competition with other species. The choices are:

1. Density dependence impacting on larval survival;
2. Density dependence may simultaneously impact at different life stages; or
3. Density dependence impacting on fish aged 1 and older.

*Assumptions:* Density dependence is a difficult process to measure and much debate has occurred in the literature about the impacts of density dependence. The Beverton-Holt construct represents contest competition where resources are not shared evenly amongst individuals and it is this process that is applied to the survival of larvae, which are considered to be the most vulnerable life stage to heterogeneous resources. The Beverton-Holt function is constrained by the Average adult population size selection. The Top down construct proportionally decreases the survival rate of various age classes once the population rises above the Average adult population size selection, the further the population rises above this value the greater the decline in survival rates.

Choose Beverton-Holt shape

*Parameter description:* Choose the shape of the Beverton-Holt function.

*Default option:* 1

*Parameter range:* 1 – 15

*Parameter explanation:* The shape of the Beverton-Holt function governs the strength of the constraint. Choosing the value to be around 1 provides variable but continuous recruitment, much like the observed pattern in the middle reaches of the Murray River. Choosing a value around 10 provides highly variable recruitment with years of recruitment failure, much like the observed pattern in the lower Murray River. The choice of the parameter value can be made to reflect the regional character of recruitment. Changing this parameter from the default setting will change the automated initial population size. Also, the average population size will be lower than that specified for the parameter Average adult population size, as recruitment is constrained with the increasing value of the Beverton-Holt shape. If unsure about the appropriate value to choose, leave as default selection.

Enter a low threshold value for 20+ year old fish

*Parameter description:* Set a level for observing the frequency with which 20+ year old fish fall to or below over the simulation period.

*Default option:* 1000

*Parameter range:* 0 – 50000

*Parameter explanation:* This parameter is used for the graph *ThresholdFreq*. *ThresholdFreq* records the frequency with which the number of 20+ year old fish fall to or below the set threshold.

*Assumptions:* 20+ year old fish produce the most eggs (Todd and Koehn, 2009), have the highest natural survival rate and are the most important age classes both in a conservation sense as well as in maintaining a sustainable recreational fishery. The purpose of the parameter is to show the impacts of the scenario on the age classes where the user can set the level of sensitivity desired. If the frequency of trajectories that fall below the threshold rise too high it may be another indication of the level of threat depending on what the threshold is set at. Also this parameter is time based and indicates how risk changes over time, where as the minimum population distribution used to generate a risk curve has no time dependency other than being specific to the whole simulation period. The choice of the threshold value depends on the Average adult population size value, a rule of thumb selection is one tenth of this value.

#### Enter a time step to collect stats from

*Parameter description:* Select a time step to collect population statistics other than from the beginning of the simulation.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* Sometimes it is useful to collect population statistics other than from the beginning of the simulation, particularly if using the minimum population distribution or average minimum population size for comparing impacts. For some scenarios that change during the simulation period, such as changing the fishing regulations during a simulation, it may be useful to set this parameter to match the time step in which a scenario changes during a simulation. This is particularly so if the population is expected to increase after the change where the minimum population size distribution changes. It is not necessary to change this parameter in accordance with the time step change, but may help with scenario exploration. If unsure how to use this parameter leave it set at its default value, the default value starts collecting statistics immediately.

## 3.2 Fishing scenarios tab

#### Enter 0 for no fishing or 1 for fishing

*Parameter description:* Turn fishing scenarios off or on.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Turn the fishing scenarios off or on, selecting 0 will override any other fishing options so that no fishing occurs.

#### Min Size in cm – 0 for 30; 1 - 35; 2 - 40; 3 - 45; 4 - 50; 5 - 55; 6 - 60; 7 - 65; 8 - 70; 9 - 75; 10 - 80

*Parameter description:* Select the minimum legal length for fishing.

*Default option:* 4

*Parameter range:* 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10

*Parameter explanation:* No fish under the legal minimum length can be caught unless illegal fishing is also selected.

#### Max Size in cm – 0 for no max; 1 for 110; 2 - 100; 3 - 95; 4 - 90; 5 - 85; 6 - 80; 7 - 75; 8 - 70; 9 - 65; 10 - 60; 11 - 55; 12 - 50

*Parameter description:* Set the maximum legal length for fishing.

*Default option:* 0

*Parameter range:* 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, or 12

*Parameter explanation:* No fish over the legal maximum length can be caught unless illegal fishing is also selected.

Enter 1 to change regulations during simulation

*Parameter description:* Change the regulations during the simulation.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Selecting 1 will allow the user to change the regulations during a simulation.

New Min Size in cm – 0 for no change; 1 for 30; 2 - 35; 3 - 40; 4 - 45; 5 - 50; 6 - 55; 7 - 60; 8 - 65; 9 - 70; 10 - 75; 11 - 80

*Parameter description:* Enter the new minimum legal length.

*Default option:* 0

*Parameter range:* 0, 1, 2, 3, 4, 5, 7, 8, 9, 10, or 11

*Parameter explanation:* Change the minimum legal length of the fishing regulation, 0 for no change.

New Max Size in cm – 0 for no change; 1 for no max; 2 for 110; 3 - 100; 4 - 95; 5 - 90; 6 - 85; 7 - 80; 8 - 75; 9 - 70; 10 - 65; 11 - 60; 12 - 55; 13 - 50

*Parameter description:* Enter the new maximum legal length.

*Default option:* 0

*Parameter range:* 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, or 13

*Parameter explanation:* Change the maximum legal length of the fishing regulation, 0 for no change.

Enter an integer for year to change fishing regulations

*Parameter description:* Set the year in which the user wishes to change the regulations.

*Default option:* 0

*Parameter range:* 0–100

*Parameter explanation:* Set the year in which the regulations will change, to be entered as a number less than 100.

Enter an integer for closure before implementing new regulations

*Parameter description:* Select a number of years of fishing closure before implementing new regulations.

*Default option:* 0

*Parameter range:* 0–20

*Parameter explanation:* Allow a fishing closure for a selected number of years before implementing the new regulations, enter 0 for no closure.

Choose catch and remove rates for fish <100cm from; 0.0 – 0.5

*Parameter description:* Select the fishing rate for fish less than 100 cm where fish are removed from the population.

*Default option:* 0.05

*Parameter range:* 0.0–0.5

*Parameter explanation:* Choose the fishing rate to be applied to fish under 100 cm in length, this is applied to all age classes for fish less than 100 cm. The estimated fishing rate from mark-recapture data was up to 0.35 for some size classes, i.e. 60–75 cm (Todd and Koehn, 2009), with an average for legal fishing (>50cm) of approximately 0.17.

Choose catch rates for fish >100cm; 0.0 - 0.5

*Parameter description:* Select the fishing rate for fish greater than 100 cm where fish are removed from the population.

*Default option:* 0.05

*Parameter range:* 0.0 – 0.5

*Parameter explanation:* Choose the fishing rate to be applied to fish over 100 cm in length. The estimated fishing rate from mark-recapture data for fish over 90 cm was 0.03 (Todd and Koehn, 2009), albeit on limited tag returns for this size class so this is likely to be an underestimate.

Enter the mortality rate due to catch and release; 0 - 0.5

*Parameter description:* Enter the mortality rate for fish caught and released.

*Default option:* 0

*Parameter range:* 0 – 0.5

*Parameter explanation:* Fish caught and released can suffer from hook damage, or stress from being handled in correctly or some other impact from the process of being caught. Some studies indicate that this can produce average mortality effects of about 20%.

Enter 0 for no illegal fishing; 1 for illegal fishing

*Parameter description:* Turn illegal fishing on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no illegal fishing or 1 for illegal fishing to impact on the population.

*Assumptions:* Illegal fishing is implemented for fish below the legal minimum size and/or above the legal maximum size.

Choose illegal fishing rate; 0 - 0.25

*Parameter description:* Set the illegal fish rate.

*Default option:* 0

*Parameter range:* 0 – 0.25

*Parameter explanation:* To be used to examine the impact of illegal fishing. This rate is applied to all fish under the minimum legal size and over the maximum legal size. When the user changes the regulations this rate still applies to fish under and over the legal limits. If the user wishes to examine a scenario where set lines, drum nets or mesh nets or other illegal means are being used it is possible to use the Fish Kills scenario to model these illegal methods of removal.

### 3.3 Fish kills scenarios tab

Enter 0 for no fish kill; or 1 for fish kill

*Parameter description:* Turn fish kills on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no fish kills or 1 for fish kills to occur.

Enter 0 for the fish kill to act across whole population; or 1 for fish kill to only impact on adults

*Parameter description:* Select whether the fish kill impacts on both juvenile fish and adults or adults alone.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* The user may wish to target adults only when using this scenario to look at poaching events where a large number of fish are removed, which are fish kill scenarios as well as the more typical event from water quality issues etc. For example with set lines, drum nets or mesh nets or other illegal means that target larger fish. If a method of illegal removal or 'standard' fish kill targets all fish equally then use the *Default option*.

Enter 0 for percentage reduction; or 1 for number

*Parameter description:* Select whether to reduce the population by a proportion or a fixed amount.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* If the fish kill is to act across the whole population, juvenile fish and adults, then choosing percentage reduction to the population is the best option for when water quality issues may be the intended cause of the fish kill. The fixed number option can be used to model not just fish kills but a poaching event where all age classes are equally targeted such as with a net.

Enter 0 for fixed period of fish kills; or 1 for random occurrence

*Parameter description:* Select whether the fish kill occurs in a set time step or randomly through out the simulation period.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* It may be that water quality issues are repeated continuously until ameliorated, a fixed time period can be used to model such a case. It is not expected that poachers would operate over the whole simulation period, the choice of a fixed period would be appropriate when modelling repeated poaching events in a limited time period. When the fish kill is less predictable but is expected to occur with a particular frequency then choosing a random occurrence is the appropriate choice.

If fixed period enter a time step to begin fish kills

*Parameter description:* Enter the time step in which fish kills begin.

*Default option:* 0

*Parameter range:* 0 – 200

If fixed period enter the duration of a fish kill in time steps

*Parameter description:* Enter the number of time steps for which the fish kills continues to occur.

*Default option:* 0

*Parameter range:* 0 – 200

If random enter the frequency of occurrence of a fish kill as a probability

*Parameter description:* Enter the frequency of fish kills.

*Default option:* 0

*Parameter range:* 0 – 1

*Parameter explanation:* Selecting a value greater than 0 will determine the likelihood that a fish kill will occur in any time step. For example, choosing 0.1 means that there is a 10% chance of a fish kill occurring in each time step, or a fish kill occurring every ten time steps.

If percentage reduction enter the percentage loss

*Parameter description:* Enter the percentage loss to the population due to fish kills.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* If the user selected the fish kill to impact on the whole population then the percentage reduction reduces the whole population proportionally by the amount specified. If the user selected the fish kill to act on adults only then only the adult population is proportionally reduced by the amount specified.

If number reduction enter the number of fish

*Parameter description:* Enter the number of fish killed or removed.

*Default option:* 0

*Parameter range:* 0 – 100 000

*Parameter explanation:* If the user selected the fish kill to impact on the whole population then the number of fish removed is evenly distributed across the whole population by the amount specified. If the user selected the fish kill to act on adults only then only the adult population is reduced by the amount specified, evenly distributed across the adult population.

### 3.4 Stocking scenarios tab

Enter 0 for no stocking; 1 for stocking

*Parameter description:* Turn stocking on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no stocking of fish or 1 to stock fish.

Enter 0 for fingerlings or 1 for 1 year olds

*Parameter description:* Select whether to stock fingerlings or 1 year old fish.

*Default option:* 0

*Parameter range:* 0 or 1

Enter the number of fish to be stocked

*Parameter description:* Set the number of fish to be released in each time step.

*Default option:* 0

*Parameter range:* 0 – 200 000

Enter the time step to begin stocking

*Parameter description:* Select the time step in which to begin the stocking.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* The stocking of the number of fish to be released (set above) begins in the time step selected.

Enter the number of time steps to continue stocking for

*Parameter description:* Set the number of time steps for which stocking occurs.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* The stocking of the number of fish to be released (set above) begins in the time step selected (set above) and continues for the number of time steps specified.



### 3.5 Early life history scenarios tab

#### For thermal impacts below Hume Dam 0 - Off; 1 - On; 2 - Spawning Failure

*Parameter description:* Select whether to model the effects of Hume Dam, or whether to model complete spawning failure.

*Default option:* 0

*Parameter range:* 0, 1, or 2

*Parameter explanation:* This scenario is similar to the model described by Sherman et al. (2007) except that their model had 10 age classes and this model has 25 age classes. It is expected that the user will not run this scenario in conjunction with the subsequent larval loss scenarios. This scenario is intended as a stand alone example of specific thermal impacts.

#### Enter 0 for reference thermal regime or 1 for modelled increase thermal regime

*Parameter description:* Select whether to model the reference regime or the amelioration of the thermal impacts on the reference regime.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for the reference regime or 1 for modified thermal impacts.

*Assumptions:* The reference regime is the expected thermal regime released from Hume Dam (see Sherman et al. 2007) and the modelled increase is the expected changes if selective withdrawal were used at Hume Dam to modify the thermal regime.

#### Enter 0 for spawning in mid Oct; 1 for late Oct/early Nov; 2 for mid Nov

*Parameter description:* Select when spawning begins.

*Default option:* 0

*Parameter range:* 0, 1, or 2

*Parameter explanation:* Select 0 for spawning starting early in the season, 1 for starting in the middle of the season or 2 for starting later in the season.

*Assumptions:* This selection was considered to undertake sensitivity analysis of the impacts of thermal regime given different spawning starting times.

#### Enter 0 for early spawner or 1 for later spawner

*Parameter description:* Select the shape of the spawning distribution.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for the mass of spawning to occur at the beginning of the season or 1 for the mass of spawning to occur in the middle of the season.

*Assumptions:* Spawning generally occurs at different times each season, to overcome issues to do with timing two spawning distributions were considered for the assumed 60 day spawning period: a distribution where most of the spawning occurs early in the season; and a distribution where the spawning is spread out across the spawning period and most occurs in the middle (see Sherman et al. 2007).

#### Enter 0 for continued thermal impacts or 1 for return to unimpacted thermal regime

*Parameter description:* Select 0 for continued thermal impacts once the predicted thermal regime time series completes its cycle or 1 to return to a 'normal' thermal regime when the predicted thermal regime time series is complete.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* The predicted thermal regime time series runs for 24 time steps (years) and when the number of time steps exceeds this the thermal regime can either continue in the last thermal state by selecting 0 or can return to a 'normal' thermal state or unimpacted state by selecting 1.

Weir impacts on larval survival 0 - Off; 1- On

*Parameter description:* Turn weir impacts on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no weir impacts or 1 for weir impacts to effect larval survival.

Enter percentage loss due to weir

*Parameter description:* Set the percentage loss of larvae due to the effects of a weir.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* To be used to examine the impact of weirs.

*Assumptions:* Weirs can have a significant impact on the survival of larvae, Baumgartner et al. (2006) stated that a 52% loss can occur for undershot weirs and an 11% loss for overshot weirs. In further research up to a 90% loss can occur for undershot weirs (L. Baumgartner NSW DPI, unpubl. data).

Irrigation off-take impacts on larval survival 0 - Off; 1 - On

*Parameter description:* Turn irrigation off-take impacts on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no irrigation off-take impacts on larval survival or 1 for larval survival to be impacted by irrigation off-take.

Enter percentage loss of larvae due to irrigation off-take

*Parameter description:* Set the percentage loss of larvae due to irrigation off-take.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* To be used to examine the extent that irrigation off-take may impact.

*Assumptions:* It is unknown what percentage of larvae end up being diverted from natural riverine habitats to irrigation channels. O'Connor et al. (2008) considered a range of losses in conjunction with and without fishing impacts. The sensitivity to the loss of larvae increases as additional threatening processes are considered. The user can also treat this parameter as percentage loss due to general thermal impacts, that is thermal impacts occur but the specific temperature time series is unknown. If both irrigation off-take and general thermal impacts are modelled then simply add the respective percentage losses together.

### 3.6 Habitat change scenarios tab

#### Enter 1 to change the habitat 0 for no change

*Parameter description:* Turn the habitat change scenario on or off.

*Default option:* 0

*Parameter range:* 0 or 1

*Parameter explanation:* Select 0 for no habitat change or 1 to turn on habitat change.

#### Enter 1 to decrease or 2 to increase

*Parameter description:* Select 1 to decrease habitat or 2 to increase habitat.

*Default option:* 1

*Parameter range:* 1 or 2

*Parameter explanation:* Select 1 to decrease habitat or 2 to increase habitat. The change is implemented by making changes to the *average adult population size* (see section 3.1). Increasing habitat may occur through the reinstatement of wood, or the provision of appropriate flows into a river channel. Decreasing habitat may occur, for example, through habitat destruction, dewatering or with the instigation of a weir that decreases flow and flowing habitats.

#### Enter the proportional change as a percentage

*Parameter description:* Set the percentage change to the *average adult population size*.

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* To be used to examine the impacts of changing habitat availability. The *average adult population size* is either decreased or increased by the percentage selected.

#### Enter a time step to implement changes

*Parameter description:* Select the time step in which habitat change begins

*Default option:* 0

*Parameter range:* 0 – 100

*Parameter explanation:* Habitat change begins in the time step selected.

#### Enter duration for habitat change

*Parameter description:* Set the number of time steps in which habitat change occurs.

*Default option:* 0

*Parameter range:* 0 – 200

*Parameter explanation:* Habitat change begins in the time step selected (set above) and continues for the number of time steps specified. In most circumstances the value selected would extend the habitat change to the end of the simulation but there may be scenarios in which the user may wish to examine the habitat change returning to the original level.

## 4 PARAMETERS OF INTEREST

The user may wish to graph parameters other than the default set produced at the end of each simulation. The following are some parameters that may be useful.

Fish at age.

TA25 – Fish aged 25 and older

TA24 – Fish aged 24

...

TA2 – Fish aged 2

TA1 – Fish aged 1

TA20A25 – Fish aged 20+

TA15A19 – Fish aged 15 to 19

TA10A14 – Fish aged 10 to 14

TA5A9 – Fish aged 5 to 9

TA5A14 – Fish aged 5 to 14

TJ – Fish aged 1 to 4

Legal catch at age.

TC25 – Fish caught legally aged 25

TC24 – Fish caught legally aged 24

...

TC2 – Fish caught legally aged 2

TC1 – Fish caught legally aged 1

TCA – Adult fish caught legally, fish aged 5+

TCA25 – Fish caught legally aged 25+

TCA20A25 – Fish caught legally aged 20+

TCA15A19 – Fish caught legally aged 15 to 19

TCA10A14 – Fish caught legally aged 10 to 14

TCA5A9 – Fish caught legally aged 5 to 9

TCA5A14 – Fish caught legally aged 5 to 14

TCJ – Fish caught legally aged 1 to 4

Illegal catch at age

TP25 – Fish caught illegally aged 25

TP24 – Fish caught illegally aged 24

...

TP2 – Fish caught illegally aged 2

TP1 – Fish caught illegally aged 1

TPA – Adult fish caught illegally, fish aged 5+

TPA25 – Fish caught illegally aged 25+

TPA20A25 – Fish caught illegally aged 20+

TPA15A19 – Fish caught illegally aged 15 to 19

TPA10A14 – Fish caught illegally aged 10 to 14

TPA5A9 – Fish caught illegally aged 5 to 9

TPA5A14 – Fish caught illegally aged 5 to 14

TPJ – Fish caught illegally aged 1 to 4

## Fish at size

TF2025 – Fish in the size class 20cm to 25cm

TF2530 – Fish in the size class 25cm to 30cm

TF3035 – Fish in the size class 30cm to 35cm

TF3540 – Fish in the size class 35cm to 40cm

...

TF120125 – Fish in the size class 120cm to 125cm

TF125130 – Fish in the size class 125cm plus

TF2030 – Fish in the size class 20cm to 30cm

TF3040 – Fish in the size class 30cm to 40cm

TF4050 – Fish in the size class 40cm to 50cm

TF5060 – Fish in the size class 50cm to 60cm

TF6070 – Fish in the size class 60cm to 70cm

TF7080 – Fish in the size class 70cm to 80cm

TF8090 – Fish in the size class 80cm to 90cm

TF90100 – Fish in the size class 90cm to 100cm

TF100110 – Fish in the size class 100cm to 110cm

TF110120 – Fish in the size class 110cm to 120cm

TF120130 – Fish in the size class 120cm plus

TF110130 – Fish in the size class 110cm plus

TF100130 – Fish in the size class 100cm plus

TF2040 – Fish in the size class 20cm to 40cm

TF3050 – Fish in the size class 30cm to 50cm

TF4060 – Fish in the size class 40cm to 60cm

TF5070 – Fish in the size class 50cm to 70cm

TF6080 – Fish in the size class 60cm to 80cm

TF7090 – Fish in the size class 70cm to 90cm

TF80100 – Fish in the size class 80cm to 100cm

TF3060 – Fish in the size class 30cm to 60cm

TF4070 – Fish in the size class 40cm to 70cm

TF5080 – Fish in the size class 50cm to 80cm

TF6090 – Fish in the size class 60cm to 90cm

TF70100 – Fish in the size class 70cm to 100cm

## Legal catch at size

TCS3035 – Fish caught legally in the size class 30cm to 35cm

TCS3540 – Fish caught legally in the size class 35cm to 40cm

...

TCS120125 – Fish caught legally in the size class 120cm to 125cm

TCS125130 – Fish caught legally in the size class 125cm plus

TCS3040 – Fish caught legally in the size class 30cm to 40cm

TCS4050 – Fish caught legally in the size class 40cm to 50cm

TCS5060 – Fish caught legally in the size class 50cm to 60cm

TCS6070 – Fish caught legally in the size class 60cm to 70cm

TCS7080 – Fish caught legally in the size class 70cm to 80cm

TCS8090 – Fish caught legally in the size class 80cm to 90cm

TCS90100 – Fish caught legally in the size class 90cm to 100cm

TCS100110 – Fish caught legally in the size class 100cm to 110cm

TCS110120 – Fish caught legally in the size class 110cm to 120cm  
TCS120130 – Fish caught legally in the size class 120cm plus  
TCS110130 – Fish caught legally in the size class 110cm plus  
TCS100130 – Fish caught legally in the size class 100cm plus  
TCS3050 – Fish caught legally in the size class 30cm to 50cm  
TCS4060 – Fish caught legally in the size class 40cm to 60cm  
TCS5070 – Fish caught legally in the size class 50cm to 70cm  
TCS6080 – Fish caught legally in the size class 60cm to 80cm  
TCS7090 – Fish caught legally in the size class 70cm to 90cm  
TCS80100 – Fish caught legally in the size class 80cm to 100cm  
TCS3060 – Fish caught legally in the size class 30cm to 60cm  
TCS4070 – Fish caught legally in the size class 40cm to 70cm  
TCS5080 – Fish caught legally in the size class 50cm to 80cm  
TCS6090 – Fish caught legally in the size class 60cm to 90cm  
TCS70100 – Fish caught legally in the size class 70cm to 100cm

Illegal catch at size

TPS3035 – Fish caught illegally in the size class 30cm to 35cm  
TPS3540 – Fish caught illegally in the size class 35cm to 40cm  
...  
TPS120125 – Fish caught illegally in the size class 120cm to 125cm  
TPS125130 – Fish caught illegally in the size class 125cm plus  
TPS3040 – Fish caught illegally in the size class 30cm to 40cm  
TPS4050 – Fish caught illegally in the size class 40cm to 50cm  
TPS5060 – Fish caught illegally in the size class 50cm to 60cm  
TPS6070 – Fish caught illegally in the size class 60cm to 70cm  
TPS7080 – Fish caught illegally in the size class 70cm to 80cm  
TPS8090 – Fish caught illegally in the size class 80cm to 90cm  
TPS90100 – Fish caught illegally in the size class 90cm to 100cm  
TPS100110 – Fish caught illegally in the size class 100cm to 110cm  
TPS110120 – Fish caught illegally in the size class 110cm to 120cm  
TPS120130 – Fish caught illegally in the size class 120cm plus  
TPS110130 – Fish caught illegally in the size class 110cm plus  
TPS100130 – Fish caught illegally in the size class 100cm plus  
TPS3050 – Fish caught illegally in the size class 30cm to 50cm  
TPS4060 – Fish caught illegally in the size class 40cm to 60cm  
TPS5070 – Fish caught illegally in the size class 50cm to 70cm  
TPS6080 – Fish caught illegally in the size class 60cm to 80cm  
TPS7090 – Fish caught illegally in the size class 70cm to 90cm  
TPS80100 – Fish caught illegally in the size class 80cm to 100cm  
TPS3060 – Fish caught illegally in the size class 30cm to 60cm  
TPS4070 – Fish caught illegally in the size class 40cm to 70cm  
TPS5080 – Fish caught illegally in the size class 50cm to 80cm  
TPS6090 – Fish caught illegally in the size class 60cm to 90cm  
TPS70100 – Fish caught illegally in the size class 70cm to 100cm

## 5 REFERENCES

- Burgman, M.A., Ferson, S. and Akçakaya, H.R. 1993. *Risk Assessment in Conservation Biology*. Chapman and Hall: London.
- Baumgartner, L.J., Reynoldson, N. and Gilligan, D.M. 2006. Mortality of larval Murray cod (*Maccullochella peelii peelii*) and golden perch (*Macquaria ambigua*) associated with passage through two types of low-head weirs. *Marine and Freshwater Research* 57: 187-191.
- Cadwallader, P.L. and Gooley, G.J. 1985. *Propagation and rearing of Murray cod Maccullochella peelii at the Warmwater Fisheries Station Pilot Project Lake Charlegrark*. Government Printer, Melbourne.
- Fournier, D.A., Hampton, J. and Sibert, J.R. 1998. MULTIFAN-CL: a length-based, age-structured model for fisheries stock assessment, with application to South Pacific albacore, *Thunnus alalunga*. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 2105-2116.
- Hampton, J. and Fournier, D.A. 2001. A spatially disaggregated, length-based, age-structured population model of yellowfin tuna (*Thunnus alabacares*) in the western and central Pacific Ocean. *Marine and Freshwater Research* 52: 937-963.
- Jackson L. J., Trebitz A. S. & Cottingham K. L. 2000. An introduction to the practice of ecological modeling. *Bioscience* 50(8): 694-706.
- Megrey, B.A. 1989. Review and comparison of age-structured stock assessment models from theoretical and applied points of view. Pp. 8-48. In: Edwards, E.F., Megrey, B.A. (Eds.), *Mathematical Analysis of Fish Stock Dynamics*. American Fisheries Society Symposium 6.
- O'Connor, J., King A., Tonkin, Z., Morrongiello, J., and Todd, C.R. 2008. Fish in the Murray Valley and Torrumbarry Irrigation Areas. Arthur Rylah Institute for Environmental Research Technical Report Series No. 176. Department of Sustainability and Environment, Heidelberg, Victoria.
- Starfield A. M. 1997. A pragmatic approach to modelling for wildlife management. *Journal of Wildlife Management* 61(2): 261-270.
- Starfield A. M. & Bleloch A. L. 1991. *Building Models for Conservation and Wildlife Management*. Burgess International Group, Edina, MN.
- Sherman, B., Todd, C. R. Koehn, J. D. and Ryan, T. 2007. Modelling the impact of cold water pollution and its potential mitigation on Murray cod populations downstream of Hume Dam, Australia. *Rivers Research and Applications* 23: 377-389.
- Todd, C.R. 2009. Murray Cod Management Model: an application of Essential. Arthur Rylah Institute for Environmental Research Report to the Murray Darling Basin Commission (now Murray-Darling Basin Authority). Arthur Rylah Institute for Environmental Research Report, Department of Sustainability and Environment. <http://www.dse.vic.gov.au/ari/software>.
- Todd, C.R. and Koehn, J.D. 2009. Murray cod modelling to address key management actions: final report for project MD745. Arthur Rylah Institute for Environmental Research Report to the Murray-Darling Basin Authority (now Murray-Darling Basin Authority). Arthur Rylah Institute for Environmental Research Report, Department of Sustainability and Environment.
- Todd, C.R. and Lovelace P.R. 2009. Essential, version 2.12. Freeware: <http://dse.vic.gov.au/ari/software> 2 Oct 2009
- Todd, C.R., Ryan, T., Nicol, S.J. and Bearlin, A.R. 2005. The impact of cold water releases on the critical period of post-spawning survival and its implications for Murray cod (*Maccullochella peelii peelii*): A case study of the Mitta Mitta River southeastern Australia. *River Research Applications* 21: 1035-1052.



Wittwer, J.W. 2004. Monte Carlo Simulation Basics, Vertex42.com. <http://vertex42.com/ExcelArticles/mc/MonteCarloSimulation.html>: accessed April 2008.

## 6 FURTHER READING

- Anderson, J.R., Morison, A.K. and Ray, D.J. 1992. Age and growth of Murray Cod, *Maccullochella peelii* (Perciformes: Percichthyidae), in the Lower Murray-Darling Basin, Australia, from thin-section otoliths. *Australian Journal of Marine and Freshwater Research* 43: 983–1013.
- Bearlin, A.R.; Schreiber, E.S.G.; Nicol, S.J.; Starfield, A.M.; Todd, C.R. 2002. Identifying the weakest link: Simulating adaptive management of the reintroduction of a threatened fish Canadian Journal of Fisheries and Aquatic Sciences 59: 1709-1716.
- Cadwallader, P.L. and Gooley, G.J. 1984. Past and present distributions and translocations of Murray Cod *Maccullochella peelii* and Trout Cod *M. macquariensis* (Pisces: Percichthyidae) in Victoria. *Proceedings of the Royal Society of Victoria* 96(1): 33–43.
- Caswell, H. 2001. *Matrix Population Models, Second Edition*. Sinauer Associates: Sunderland, Massachusetts.
- Douglas, J.W., Gooley, G.J. and Ingram, B.A. 1994. Trout cod *Maccullochella macquariensis* (Cuvier) (Pisces: Percichthyidae) resource handbook and research and recovery plan. Department of Conservation and Environment, Victoria.
- Evans, M., Hastings, N. and Peacock, B. 1993. *Statistical Distributions, Second Edition*. John Wiley and Sons: New York.
- Ferson S, Ginzburg, L.R. and Silvers, A. 1989. Extreme event risk analysis for age-structured populations. *Ecological Modelling* 47: 175–187.
- Ferson, S. and Ginzburg, L.R. 1996. Different methods are needed to propagate ignorance and variability. *Reliability Engineering and Systems Safety* 54: 133–144.
- Gooley, G.J. 1992. Validation of the use of otoliths to determine the age and growth of Murray Cod, *Maccullochella peelii* (Mitchell) (Percichthyidae), in Lake Charlegrark, Western Victoria. *Australian Journal of Marine and Freshwater Research* 43: 1091–102.
- Hassell, M.P. 1986. Detecting density-dependence. *Trends in Ecology and Evolution* 1: 90–93.
- Hilborn, R. and Walters, C.J. 1992. *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York.
- Hilborn, R. and Mangel, M. 1997. *The Ecological Detective: Confronting Models with Data*. Princeton University Press, Princeton.
- Holling, C.S. (ed.) 1978. *Adaptive Environmental Assessment and Management*. International series on Applied Systems Management (3). Wiley and sons, Chichester.
- Koehn, J.D. 1997. Habitats and movements of freshwater fish in the Murray-Darling Basin. Pp. 27-32. In: Banens, R. J. and Lehane, R. (eds). *1995 Riverine Environment Research Forum. Proceedings of the inaugural Riverine Environment Research Forum of MDBC Natural Resource Management Strategy funded projects, held 4-6 October 1995 in Attwood, Victoria*. Murray-Darling Basin Commission, Canberra.
- Koehn, J.D. 2001. Impacts of weirs on fish. In: Blanch, S (ed) *The Way Forward on Weirs*. Inland.
- Koehn, J.D. 2005. Threats to Murray Cod. Pp. 30–37. In: *Management of Murray cod in the Murray-Darling Basin: Statement, Recommendations and Supporting Papers*, M. Lintermans, and B. Phillips (eds). Proceedings of a workshop held in Canberra ACT, 3-4 June 2004. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra:

- Koehn, J.D. 2005. The loss of valuable Murray cod in fish kills: a science and management perspective. Pp. 73-82. In: Lintermans, M. and Phillips, B. (eds.). *Management of Murray cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra.
- Koehn, J.D. and Nicol, S.J. 1998. Habitat and movement requirements of fish. Pp 1-6. In: Banens, R.J. and Lehane, R. (eds) *Proceedings of the Riverine Environment Forum, October 1996, Brisbane*. Murray-Darling Basin Commission, Canberra.
- Koehn, J.D. and O'Connor, W.G. 1990. *Biological Information for Management of Native Freshwater Fish in Victoria*. Department of Conservation and Environment: Government Printer, Melbourne.
- Levins, R. 1966. The Strategy of Model Building in Population Biology. *American Scientist* 54: 421-431.
- Levins, R. 1974. The qualitative analysis of partially specified systems. *Annals of the New York Academy of Science*. 231: 123-138.
- Lintermans, M. and Phillips, B. (eds) 2004. *Downstream movement of fish in the Murray-Darling Basin. Statement, recommendations and supporting papers from a workshop held in Canberra 3-4 June 2003*. Murray-Darling Basin Commission, Canberra.
- Manly, B.F.J. 1990. *Stage-Structured Populations: Sampling, Analysis and Simulation*. Chapman and Hall, London.
- Marttunen, M. and Vehanen, T. 2004. Toward adaptive management: The impacts of different management strategies on fish stocks and fisheries in a large regulated lake. *Environmental Management* 33: 840-854.
- Maunder, M.N. 1997. Investigation of density dependence in salmon spawner-egg relationships using queueing theory. *Ecological Modelling* 104: 189-197.
- McCarthy, M.A., and Thompson, C. 2001. Expected minimum population size as a measure of threat. *Animal Conservation* 4: 351-355.
- Murray-Darling Basin Commission 2004. *Native Fish Strategy for the Murray-Darling Basin 2003-2013*. Canberra, Murray-Darling Basin Commission. [www.mdbc.gov.au](http://www.mdbc.gov.au)
- Murray-Darling Basin Commission 2004. *Conceptual model to guide investments for improving the status of native fish populations in the Murray-Darling Basin*. Report of the expert panel convened by the Murray-Darling Basin Commission, December 2001. Canberra, Murray-Darling Basin Commission. [www.mdbc.gov.au](http://www.mdbc.gov.au)
- National Murray Cod Recovery Team. 2007. *National Murray Cod Recovery Plan. Draft for Public Comment*. Freshwater Ecology, Arthur Rylah Institute for Environmental Research, Melbourne.
- Odenbaugh, J. 2005. The "structure" of population ecology: Philosophical reflections on unstructured and structured models. In: B.E. Beisner and K. Cuddington (eds.) *Ecological paradigms lost. Routes of theory change*. Elsevier, Burlington: 63-80.
- Punt, A.E. and Smith, A.D.M. 1999. Harvest strategy evaluation for the eastern stock of gemfish (*Rexea solandri*). *Ices Journal of Marine Science* 56: 860-875.
- Punt, A.E., Smith, D.C., Thomson, R.B., Haddon, M., Xe, H. and Lyle, J.M. 2001. Stock assessment of the blue grenadier *Macruronus novaezelandiae* resource off south-eastern Australia. *Marine and Freshwater Research* 52: 701-717.
- Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board of Canada, Ottawa.
- Rose, K.A. and Cowan, J.H. 2000. Predicting fish population dynamics: compensation and the importance of site-specific considerations. *Environmental Science and Policy* 3: S433-S443.

- Rowland, S.J. 1983. Spawning of the Australian freshwater fish Murray cod *Maccullochella peelii* (Mitchell), in earthen ponds. *Journal of Fish Biology* 23: 525–34.
- Rowland, S.J. 1988. Hormone-induced spawning of the Australian freshwater fish Murray cod, *Maccullochella peelii* (Mitchell) (Percichthyidae). *Aquaculture* 70: 371–89.
- Rowland S.J. 1989. Aspects of the history and fishery of the Murray Cod, *Maccullochella peelii* (Mitchell) (Percichthyidae). *Proceedings of the Linnean Society of New South Wales* 111(3): 201–213.
- Rowland, S.J. 1992. Diet and feeding of Murray cod (*Maccullochella peelii*) larvae. *Proceedings of the Linnean Society of New South Wales* 113(4): 193–201.
- Rowland, S.J. 1998. Aspects of the reproductive biology of Murray cod, *Maccullochella peelii peelii*. *Proceedings of the Linnean Society of New South Wales* 120:147–162.
- Rowland, S.J. 1998. Age and growth of the Australian Freshwater fish Murray cod, *Maccullochella peelii peelii*. *Proceedings of the Linnean Society of New South Wales* 120: 163–180.
- Rowland, S.J. 2005. Overview of the history, fishery, biology and aquaculture of Murray cod (*Maccullochella peelii peelii*). Pp. 38–61. In: Lintermans, M. and Phillips, B. (eds). *Management of Murray Cod in the Murray-Darling Basin: Statement, recommendations and supporting papers. Proceedings of a workshop held in Canberra, 3-4 June 2004*. Murray-Darling Basin Commission and Cooperative Research Centre for Freshwater Ecology, Canberra. Canberra.
- Smith, A.D.M. 1994. Management Strategy Evaluation – The light on the hill. Pp. 249–253 In: Hancock, D.A. (Ed). *Population dynamics for fisheries management. Australian Society for Fish Biology workshop proceedings, Perth 24-25 August, 1993*. Australian Society for Fish Biology, Sydney.
- Smith, A.D.M., Sainsbury, K.J. and Stevens, R.A. 1999. Implementing effective fisheries-management systems – management strategy evaluation and the Australian partnership approach. *ICES Journal of Marine Science* 56: 967–979.
- Smith, D.C., Smith, A.D.M. and Punt A.E. 2001. Approach and process for stock assessment in the South East Fishery, Australia: a perspective. *Marine and Freshwater Research* 52: 671–81.
- Stuart, I. and Koehn, J. 2007. Big cod do breed. *Freshwater Fishing* July/August 85: 62–64.
- Todd, C.R., Nicol, S.J. and Koehn, J.D. 2004. Density-dependence uncertainty in population models for the conservation management of trout cod, *Maccullochella macquariensis*. *Ecological Modelling* 171: 359–380.
- Walters, C.J. 1986. *Adaptive management of renewable resources*. Macmillan publishing Co., New York.







Australian Government



**MURRAY—  
DARLING**  
BASIN AUTHORITY