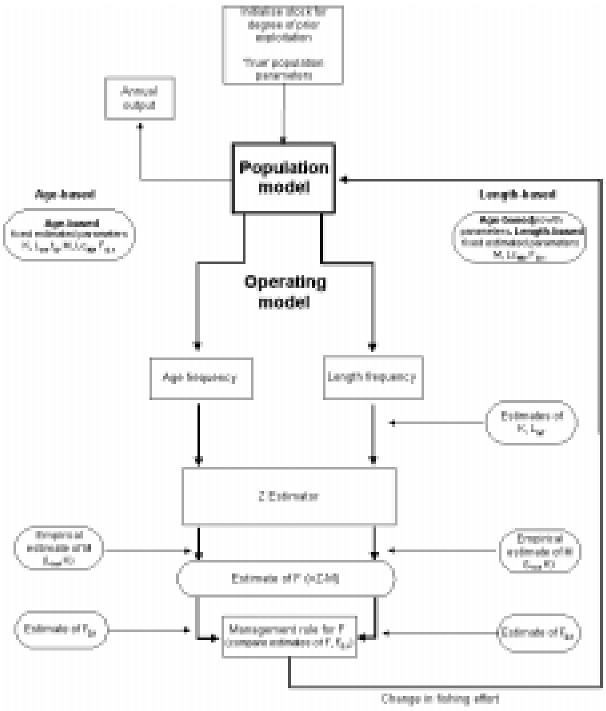
# The potential for improved management performance with increased age-based stock assessment components

## Final Technical Report

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# Final report - Administrative Details

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# Final Technical Report

## 1 Executive Summary

The purpose of this project was to address the constraints to management and development arising from the use of uncertain estimates of total mortality in stock assessments incorporating analytical fishery models such as yield per recruit. Through management strategy simulations, the project demonstrated that the use of age-based methods of total mortality estimation (using catch-curves based on age frequency distributions) in the estimation of current fishing mortality led to improved management performance. Guidelines for the management of demersal tropical fisheries were developed. These fisheries are important in tropical countries as sources of both employment and protein. The project purpose is therefore directly relevant to the FMSP goal of improving the livelihoods of poor people through sustainably enhanced production of land/water interface systems.

Species of the families Lutjanidae (snappers) and Lethrinidae (emperors) are long-lived and slow growing, and exhibit low rates of natural mortality. These life history characteristics render them vulnerable to over-fishing. To achieve sustainable exploitation of these vulnerable species, appropriate management is required. Historically, management has been based on the outputs of length-based methods of parameter assessment, which are highly uncertain for these species. This has a knock-on effect on the certainty of management based on stock assessments derived using these parameters.

Project R6465 noted that improvements to management performance could be gained through the use of age-based methods of growth parameter estimation (rather than length-based methods of assessment). However, it was noted that the improvements resulting from the use of age-based growth estimates in stock assessments were diluted by the need to use length-based methods later in the stock assessment process. It was suggested that a greater use of age-based approaches in the stock assessment process could improve management performance further. In particular, the use of an age frequency distribution to assess total mortality (using catch curves) avoids the need to use uncertain growth parameter estimates in the calculation. Using this method as part of stock assessments should result in improved estimates of current fishing mortality, and hence management of exploited fisheries.

During the project, management strategy simulations were used to examine whether the use of age-based methods of total mortality estimation led to improvements in the sustainable management of long-lived, slow growing fish species through analytical methods. To do this, the performance of management based on age-based total mortality estimates was compared to that of management based on length-based methods of assessment (specifically, using length-converted catch curves).

Results of the management strategy simulations indicated that the use of age-based total mortality estimation methods in stock assessments resulted in improved management performance. When combined with the results from FMSP Project R6465, it was concluded that age-based methods of growth (R6465) and total mortality estimation (this project) should be used to assess the stock status of long-lived, slow growing species.

Cost-benefit analyses performed during Project R7521 examined the cost-effectiveness of age-based approaches to total mortality assessment. Net present worth analysis indicated that the

use of otolith weight-age relationships to estimate an age frequency distribution (and hence total mortality) was the most cost-effective approach. The slightly greater costs of this method, when compared to the use of length-based approaches, was outweighed by benefits resulting from stock assessments incorporating age-based total mortality estimates. The use of length-based methods of assessment was the second most cost-effective approach, due to the relative cheapness of the method. The derivation of age frequencies through otolith increment counts (and hence total mortality through age-based catch curves) was very expensive. This cost outweighed the benefits of using age-based total mortality estimates in stock assessments. As a result, this approach was the least cost-effective. Where an age-otolith weight relationship exists, therefore, this should be used in the derivation of age-based total mortality estimates. In contrast, where such a relationship does not exist, length-based total mortality estimates should be used, in combination with age-based growth parameter estimates.

Despite improvements resulting from the use of age-based methods of growth and total mortality estimation, a notable degree of variability remained in the performance of management. This is likely to have resulted from the need to use empirical formulae to estimate natural mortality. It was concluded that management could be improved further if independent estimates of natural mortality could be obtained. Efforts to obtain estimates of this parameter were recommended.

A number of guidelines for the management of long-lived, slow growing tropical fish species were developed. These project outputs were presented to target institutions during national workshops. The adoption of these guidelines will contribute directly to the project goal of generating benefits to poor people through the application of new knowledge to fisheries management systems.

## 2 Background

Species of the Lutjanidae (snappers) and Lethrinidae (emperors) are widespread throughout warm waters of the world. They are highly valued food fish in many tropical countries; for example Seychelles (Mees, 1989), Mauritius (Ardil, 1986), Australia (Kailola, 1993), the Caribbean (Thompson and Munro, 1974), Hawaii (Okamoto, 1982; Parrish et al., 1997), and the Pacific (Dalzell et al., 1992). They represent both a cheap source of protein, and where they form the basis of an export trade, an important component of the national economy of many developing countries. Fisheries based on these species are therefore important to the livelihoods of both artisanal and semi-industrial fishers. In 1998, over 168,000t of Lutjanidae and Lethrinidae were caught from reef fisheries, with approximately 37% of this total taken from the Indian Ocean region (FAO, 1998).

Lutjanids and lethrinids can be characterised as bottom dwelling carnivores. Species of these families are commonly long-lived and slow growing (Manooch, 1987), with highly variable individual growth trajectories (Pauly et al., 1996) and protracted spawning periods (e.g. Thompson and Munro, 1983; Mees, 1993). Their slow growth, low reproductive capacity and low rates of natural mortality makes them vulnerable to overfishing (Haight et al., 1993; Russ, 1991). Since these species are favoured for consumption or sale, they are commonly targeted by fishermen (Koslow et al., 1988; Munro and Thompson, 1983), while their aggressive nature and relatively large size also make them particularly vulnerable to fishing gears (Munro and Williams, 1985). Sound management advice is therefore important to achieve long term sustainability of fisheries targeting these species.

Many tropical fisheries, including those targeting snappers and emperors, are managed based on the outputs of length-based methods. These methods are used as a result of the perceived difficulties in ageing tropical fish, the practical problems of funding studies to validate the periodicity of otolith increments, and the subsequent time and expense involved in the use of otoliths for age assessment. The results of length-based methods of growth estimation, however, are only as good as the data to which they are applied (e.g. Majkowski et al., 1987; Shepherd et al., 1987). Length-based methods are generally reported as unsuitable for tropical species such as snappers and emperors (Langi, 1990; Mathews, 1974; Mees and Rousseau, 1997; Morales-Nin, 1989; Morgan, 1983). For example, their life-history characteristics result in the superimposition of successive modal classes, affecting the information through which length-based methods estimate growth. Out of necessity, however, length-based methods continue to be used in tropical countries. As a result, one source of uncertainty in tropical fish stock assessments is the use of potentially biased growth parameter estimates in further calculations; for example, in the estimation of mortality and yield-per-recruit (Mees and Rousseau, 1997; Rowling and Reid, 1992).

A previous FMSP Project, R6465, ‘Growth parameter estimates and the effect of fishing on size-composition and growth of snappers and emperors: implications for management’ simulated the use of length-based methods to estimate growth parameters for long-lived, slow growing fish species. Simulation outputs indicated that resulting growth estimates were both inaccurate and imprecise, when compared to the mean growth parameter estimates used to simulate the exploited population. In contrast, age-based methods (using length-at-age data estimated through otolith increment counts) tended to result in more accurate growth parameter estimates.

In order to evaluate the performance of management based on stock assessments derived using uncertain (length-based) growth parameter estimates, a technique known as ‘management strategy simulation’ was used. These simulations investigated the effect of uncertainty in growth parameter estimation on management performance (assessed on the basis of measures including the level of exploitable biomass, spawning stock biomass, final year effort and average catch relative to management targets). Simulation results indicated that the use of length-based growth parameter estimates in the stock assessment process resulted in very poor management performance. By comparison, the use of age-based growth parameter estimates in stock assessments led to improved management performance.

During the management strategy simulations, it was also noted that the use of length-based methods of estimation at any stage of the assessment process (for example, during the estimation of total mortality) seriously affected management performance. As a result, improvements resulting from the use of age-based growth parameter estimates in stock assessments were diluted, and considerable uncertainty in management remained. It was suggested that an increased age-based component in the stock assessment process might eliminate uncertainty resulting from the use of length-based methods of parameter assessment, and hence lead to further improvements in the management of snapper and emperor fisheries. This was examined in the current project.

## 3 Project Purpose

Snappers and emperors form the basis of valuable fisheries important to the livelihoods of many small scale artisanal fishers in developing countries. As these fish are high level predators, with slow growth and low reproductive capacity, they are easily overfished. Appropriate management is required to sustainably manage and develop these fisheries.

Project R6465 examined the constraint to management arising from the use of length-based methods of growth parameter assessment in these fisheries. Where these estimates were used in stock assessments, management performance was poor. The use of age-based growth parameter estimates in stock assessments improved management performance. This approach was recommended when managing long-lived, slow growing species. However, Project R6465 noted that further improvements in management performance could be obtained by using further age-based approaches at later stages of the stock assessment process.

The current study aims to build on the outputs of Project R6465. It will assess whether the use of age-based methods of total mortality estimation (the estimation of total mortality levels using catch curves based on age frequency distributions) improve the ability of a fisheries manager to manage a fish stock appropriately using analytical methods such as yield-per-recruit. The use of an age frequency distribution to assess total mortality avoids the need to use uncertain growth parameter estimates in the calculation. Therefore, this method should decrease the level of uncertainty in management assessments.

Specifically, management strategy simulations will be performed to examine:

- the effect of uncertainty in total mortality estimation on management performance;
- the differences in management performance between age- and length-based methods of total mortality assessment.

Guidelines for management will be developed.

This project purpose is directly relevant to the goal of developing improved strategies and plans for the management of capture fisheries important to poor people.

## 4 Research Activities

This project was a desk-based study. A technique known as management strategy simulations was used to mimic the fisheries management process for artisanal demersal fisheries. Management strategy simulations analyse the behaviour of complex systems, such as the fisheries management process, using a simpler model of the system. This model was developed by modifying the ‘YIELD’ software developed during FMSP Project 7041, ‘Software for estimation of the potential yield of fisheries under uncertainty’. The effect on management performance of employing alternative total mortality estimation methods were investigated for an $F_{0.1}$ management strategy ($F_{0.1}$ is a biological reference point on which management targets can be based). The performance of management derived using stock assessments incorporating age- and length-based total mortality estimation methods in the estimation of current fishing mortality were compared. Management performance was assessed against conservation measures and fleet performance. Guidelines for management were developed based on the outputs of the simulation studies.

## 5 Outputs

The outputs from the management strategy simulations were used to develop stock assessment and management guidelines for fisheries in developing countries targeting long-lived, slow-growing species. In addition to the use of age-based growth parameter estimation methods for long-lived, slow growing species, as recommended by FMSP Project R6465, the current project recommended:

- **Use age-based methods of total mortality estimation when performing stock assessments for long-lived, slow growing species.**
  The use of age-based methods total mortality estimates in stock assessments resulted in improved management performance, when compared to that derived using length-

based total mortality estimates.[1] However, it was noted that care must be taken in using this approach where fishing mortality and/or recruitment variability is high.

- **Derive an independent estimate of natural mortality.**
  Despite improvements in management performance gained by using age-based methods of growth and total mortality estimation, considerable uncertainty in management remained. A possible cause was the need to use empirical estimates of natural mortality (derived using Pauly's or Ralston's formulae) in stock assessments. Bias in the estimate of this parameter biases the values of fishing mortality and $F_{0.1}$, the two parameters used to derive management decisions. Therefore, to improve management performance further there is a need to derive independent estimates of natural mortality.

## 6 Contribution of Outputs

### 6.1 Towards DFID developmental goals

The work performed during the current project is directly relevant to the DFID developmental goal of elimination of poverty in poorer countries, based on improved livelihoods for poor people and sustainably enhanced production and productivity of renewable natural resource systems, through the application of new knowledge to renewable natural resource systems.

The project directly related to the aim of improved strategies and plans developed for the management of capture fisheries important to poor people. The project directly addressed the FMSP output OVI 1.1 'development of new and improved biomathematical and bioeconomic methods and models for stock assessment and fisheries livelihoods management, and appropriate data management systems'. Benefits will be delivered to the target poor by application of the knowledge generated from this project to develop improved fisheries management guidelines.

The target beneficiaries of this project were national and regional fisheries departments, and both small scale and semi-industrial fishing communities. Small-scale fisheries based on demersal stocks represent an important source of nutrition and income for fishers and dependant communities throughout tropical areas including Africa, the Caribbean, Indian Ocean, and Pacific. The potential for rapidly overfishing demersal fish stocks of snappers and emperors requires that these important resources be managed effectively to safeguard the livelihoods of rural communities who are dependent upon them. This project presented stock assessment and management guidelines based on analytical stock assessment models. Adoption by target organisations will contribute directly to the project goal described above.

### 6.2 Promotion of outputs

The guidelines developed will be of relevance to fisheries management institutions in developing countries where local artisanal and industrial fisheries target long-lived, slow growing species. The scientific community will also benefit from the information.

[1] Cost-benefit analyses performed during Project R7521 indicated that age-based total mortality estimation methods should only be used where an age-otolith weight relationship has been estimated. Where a relationship cannot be derived, length-based methods of total mortality are the most cost-effective. See the Final Technical Report from that project for more information.

Implementation of the management guidelines arising from this project is required in order to achieve DFID goals. In order to reach both a national (in collaborating countries) and international audience of target organisations, a number of means for promoting project outputs were pursued, and will continue to be pursued beyond the life of the project. National workshops were held during the project to disseminate outputs, and to develop and promote management guidelines. A number of scientific papers are to be produced after the completion of the project.

On the basis of the outputs from Project R6465, the Seychelles and British Indian Ocean Territory have already moved towards age-based assessment methodologies. The results of the current project support that move, refine the methodologies used, and indicate important areas for continued research. In Mauritius, financial constraints have prevented a move towards age-based methodologies. The results of the current study add further impetus to the move towards using otoliths in routine stock assessments.

Through the circulation of the LFDA software package (developed in FMSP projects R4517 and R5050CB) MRAG has developed an extensive network of contacts with fisheries institutions around the world. The outputs of the current project, as well as those from Project R6465 have obvious relevance to institutions which currently employ the length-based methods available in LFDA to estimate growth parameters. Results of the studies will be circulated to these organisations as part of the dissemination process.

### 6.2.1 Publications

Pilling, G.M., Kirkwood, G.P. and Walker, S.G. (2001). An improved method for estimating individual growth variability in fish, and the correlation between von Bertalanffy growth parameters. Submitted to the Canadian Journal of Fisheries and Aquatic Sciences.

### 6.2.2 Internal reports

None

### 6.2.3 Other dissemination of the results

The findings of the study were disseminated during workshops undertaken at Albion Fisheries Research Centre (AFRC) in Mauritius and at the Seychelles Fishing Authority (SFA) 28$^{th}$ to 29$^{th}$ November 2000.

# 1. Introduction

Many tropical fisheries, including those targeting snappers and emperors, are managed based on the outputs of length-based methods. These methods are used as a result of the perceived difficulties in ageing tropical fish, the practical problems of funding studies to validate the periodicity of otolith increments, and the subsequent time and expense involved in the use of otoliths for age assessment. The results of length-based methods of growth estimation, however, are only as good as the data to which they are applied (e.g. Majkowski et al., 1987; Shepherd et al., 1987). Length-based methods are generally reported as unsuitable for tropical species such as snappers and emperors (Langi, 1990; Mathews, 1974; Mees and Rousseau, 1997; Morales-Nin, 1989; Morgan, 1983). For example, their life-history characteristics result in the superimposition of successive modal classes, affecting the information through which length-based methods estimate growth. Out of necessity, however, length-based methods continue to be used in tropical countries. As a result, one source of uncertainty in tropical fish stock assessments is the use of potentially biased growth parameter estimates in further calculations; for example, in the estimation of mortality and yield-per-recruit (Mees and Rousseau, 1997; Rowling and Reid, 1992).

A previous FMSP Project, R6465, 'Growth parameter estimates and the effect of fishing on size-composition and growth of snappers and emperors: implications for management' simulated the use of length-based methods to estimate growth parameters for long-lived, slow growing fish species. Simulation outputs indicated that resulting growth estimates were both inaccurate and imprecise, when compared to the mean growth parameter estimates used to simulate the exploited population. In contrast, age-based methods (using length-at-age data estimated through otolith increment counts) tended to result in more accurate growth parameter estimates.

In order to evaluate the performance of management based on stock assessments derived using uncertain (length-based) growth parameter estimates, a technique known as 'management strategy simulation' was used. This technique was used to investigate:

- the effect of uncertainty in growth parameter estimation on management performance;
- the difference in management performance between age- and length-based methods of growth assessment.

Results of the simulations indicated that the use of length-based growth parameter estimates in the stock assessment process resulted in very poor management performance. By comparison, the use of age-based growth parameter estimates in stock assessments led to improved management performance.

During the management strategy simulations, it was also noted that the use of length-based methods of estimation at any stage of the assessment process (for example, during the estimation of total mortality) seriously affected management performance. As a result, improvements resulting from the use of age-based growth parameter estimates in stock assessments were diluted, and considerable uncertainty in management remained. It was suggested that an increased age-based component in the stock assessment process might eliminate uncertainty resulting from the use of length-based methods of parameter assessment, and hence lead to further improvements in the management of snapper and emperor fisheries.

The current study aims to build on the outputs of Project R6465. It will assess whether the use of age-based methods of total mortality estimation improve the ability of a fisheries manager to appropriately manage a fish stock using analytical methods such as yield-per-recruit. The use of an age frequency distribution to assess total mortality avoids the need to use uncertain growth parameter estimates in the calculation. Therefore, this method should increase the certainty of management assessments.

Management strategy simulations will be performed to examine:

- the effect of uncertainty in total mortality estimation on management performance;
- the differences in management performance between age- and length-based methods of total mortality assessment.

Guidelines for management will be developed.

# 2. Methods

## 2.1 Management strategy simulation

Management strategy simulation is a technique which utilises intensive computer simulation studies to model and analyse the behaviour of complex systems by using a simpler model of that system. In the current study, we use management strategy simulation to simulate all the processes that occur in fisheries management. The basic simulation process was described in the Final Technical Report for FMSP project R6465. A summary of the methodology will be provided in this report. The differences between the two studies will be highlighted.

An example of a typical simulation model for fisheries management is indicated in Figure 1. This figure outlines the processes that occur and hence which need to be simulated in the model. The model encompasses those processes which occur both under the water, i.e. the fish stock and the impact of fishing on that stock ('operating model' in Figure 1); and above the water, i.e. catching the fish and management of the fishery. Each process from fishing, data collection, annual stock assessment, management advice and the effects of management actions on resources needs to be modelled in some way.

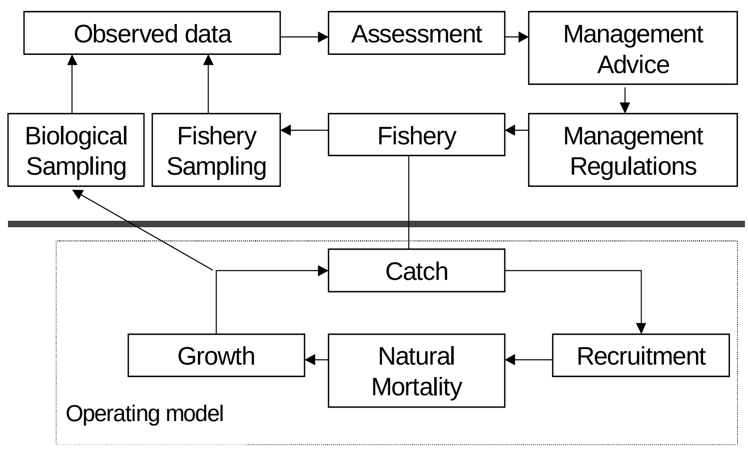


Figure 1 The processes that must be modelled in management strategy simulations for fisheries.

As this is a computer simulation, the true state of the fish stock is known at all times in a simulation model. This knowledge would not, however, be available to either the scientist doing the assessment, or the manager. In practice, the entire management process has to rely on imperfect information. Further, things can go wrong in every one of the processes simulated. To properly assess the impacts of changes in the system on management performance, possible imperfections at each stage of the system must be taken into account.

## 2.2 Management strategy simulation model developed for the current project

Management strategy simulations performed during Project R6465 examined the impact of uncertainty in growth parameter estimates on the accuracy of stock assessments, and hence management performance. The use of age-based methods to assess growth, and the use of these parameters in stock assessments, resulted in improved management performance. However, the use of length-based methods later in the stock assessment process diluted the gains made through the use of age-based growth parameter estimates. For example, growth parameter estimates were used in the estimation of total mortality using length-based methods (length-converted catch curve or Beverton and Holt Z estimator). The aim of the current project is to assess whether the use of age-based methods to estimate total mortality results in improved stock assessments, and hence management performance. Using age-based methods of total mortality estimation avoids the need to use uncertain growth parameter estimates in the estimation of this parameter, thereby eliminating one source of bias in stock assessments, upon which management is based.

Figure 2 details the stock assessment approach simulated in the current project, and compares this with the approach simulated in project R6465. Age-based growth parameters are used in each simulation to estimate subsequent biological and fishery parameters, since these resulted in the best management performance in Project R6465. The difference between the approaches is the use of length- or age-based methods to estimate total mortality. For the length-based approach (right hand limb of Figure 2), Project R6465 indicated that when using age-based growth parameter estimates, the use of the length-converted catch curve resulted in the best management performance. The resulting outputs of this approach will be used to compare to the performance of the age-based approach simulated in the current study.

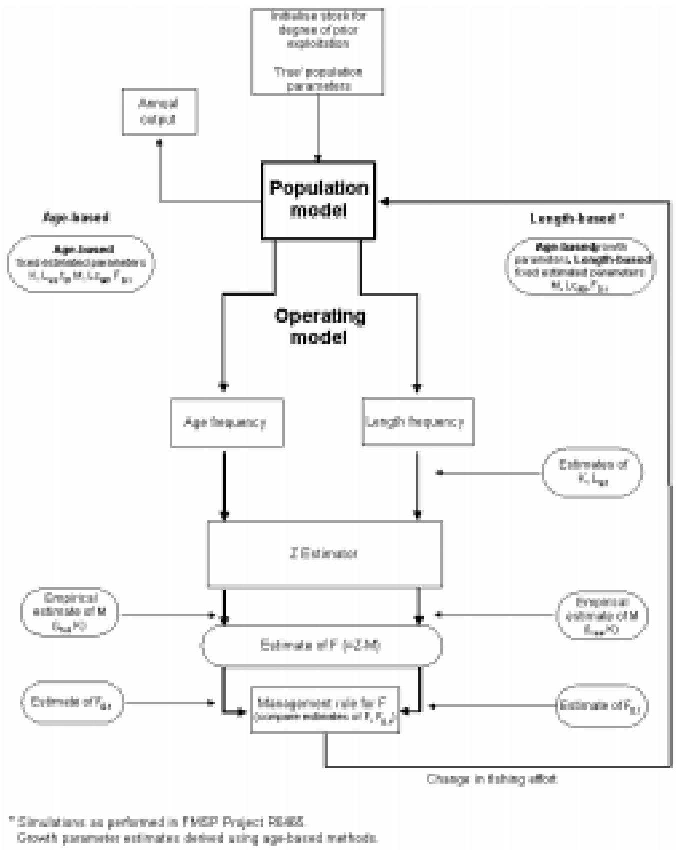


Figure 2. Flow diagram comparing the management process simulated in the current project ('age-based') and in project R6465 ('length-based').

To perform the age-based simulations required for the current project, modifications to the existing simulation software were required. These allowed age frequency distributions to be output from the population model (simulating the sampling of otoliths from the catch), enabling total mortality to be estimated using catch curves.

During Project R6465, 'MIDAS', the Multi-species Interactive Dynamics Age-structured Simulation model (see Pilling et al., 1999) was used to perform the management strategy simulations. However, the modifications required to that software to achieve the aims of the current project were complex. As a result, and with an eye to the future development of software, the 'YIELD' software developed during Project R7041, 'Software for estimation of the potential yield of fisheries under uncertainty' was modified to allow comparable management strategy simulations to be performed.

The simulation strategy employed used yield-per-recruit analyses to derive target effort levels upon which management advice was based. These assessments have been performed in the case study countries (MRAG, 1996; Seychelles, Mees and Rousseau, 1997; British Indian Ocean Territory, Mees et al., 1999). Effort control determined by $F_{0.1}$ was the management strategy selected for examination in the current study. Note that, due to the lack of information on stock recruitment relationships for *L. mahsena*, the species selected for this study, it was not possible to determine $F_{MSY}$. $F_{opt}$ from yield-per-recruit analyses was unrealistically high. Hence $F_{0.1}$ was selected (see also Pilling et al., 1999).

To model the *L. mahsena* stock under exploitation('true population parameters' in Figure 2), the parameters used to simulate populations of *Lethrinus mahsena* during Project R6465 were used in the current study. This allowed a direct comparison to be made between the results of the current study (age-based approach) and that of Project R6465 (length-based approach).

The management strategy simulations performed also require parameter sets (estimates of growth parameters, natural mortality, $F_{0.1}$ etc.) to initiate the simulation. Data sets representing the estimation of population and fishery parameters by the fisheries manager in the first year of management (year zero) were simulated during FMSP Project R6465. Those modelling age-based growth parameter estimates were used in the current study. These represent the 'age-based fixed estimate parameters' indicated in Figure 2. From this starting point, simulations were then run with management rules applied over a 20 year period. The output from management simulation was a set of management performance indices.

To take into account the uncertainty in parameter estimation, the 20 year management simulation was repeated 100 times, using 100 different sets of fixed (year zero) parameters estimated using age-based growth parameters during project R6465. These inputs encapsulate not only the uncertainty in total mortality estimation, but also uncertainty in biological reference points (e.g. $F_{0.1}$) derived using the growth parameter estimates (which are the same in the length- and age-based runs of the current study).

Variability in the true final year effort results from inaccuracies in the estimates of both current effort and $F_{0.1}$. This results from inaccuracies and variability in the growth parameter estimates (both parameters) and total mortality estimate (current effort). As both estimates of current effort and $F_{target}$ are used each year in the management rule to determine whether to increase or decrease effort in the subsequent year, the inaccuracies and variability in parameter estimates result in a failure to achieve $F_{0.1}$. The effect of uncertainty on management is interpreted through the examination of management performance. Greater uncertainty and variability is expected to lead to poorer management performance, i.e. more optimistic and pessimistic results might be expected. Given that identical fixed input parameters were available, it is possible to compare the resultant management performance of the approach simulated in the current project with the length-based approach taken in project R6465.

The steps undertaken in the management strategy simulations are now described in more detail:

The stock simulated within the YIELD software was initialised for a certain degree of prior exploitation until the stock reaches an equilibrium state at that level of exploitation. Simulations were run for a range of fishing mortalities, to represent states from lightly fished to over-exploited. Analyses performed in Project R6465 indicated that for management of *L. mahsena* based on $F_{0.1}$, the optimum fishing mortality was $F_{0.1}$=0.41yr$^{-1}$. Simulations were run at a range of $F_{start}$ values about 0.4 (0.05, 0.25, 0.7 and 1.2yr$^{-1}$), chosen to represent the range of estimates of current fishing mortality across the study fisheries (Seychelles, Mauritius and the British Indian Ocean Territory; BIOT).

Following initialisation, management simulations were run over a period of 20 years. The software generated a number of annual outputs of the true population parameters (see Table 1). These are details that would not be known to the fisheries manager. The YIELD software also simulated the catch age frequency distribution, an output which would be obtained by the fisheries manager through an otolith sampling and assessment programme. The management strategy simulation model uses the output age frequency to estimate current fishing mortality as a stock assessment specialist would do: by subtracting an estimate of natural mortality (here estimated using empirical formulae based on growth parameter estimates) from an estimate of total mortality (here derived through a catch curve applied to the age frequency distribution).

Table 1. A list of the relevant outputs from the YIELD software used in assessment of the performance of fisheries management. These are the 'true' population parameters, including fishing mortality (unknown to the stock assessment specialist), and the catch per annum.

Before initialisation: Unexploited equilibrium states

- The unexploited biomass ($ExB_0$)
- The unexploited spawning stock biomass ($SSB_0$)

Time 0-20: Exploited equilibrium state for $F_{start}$

- The exploited biomass each year, ExB
- The spawning stock biomass each year, SSB

- Total catch per annum
- Fishing mortality, F
- Age frequency distribution

To derive estimates of fishing mortality and $F_{0.1}$, fixed estimate input parameters for each $F_{start}$ value (i.e. at year zero) are required. These were derived in Project R6465. Simulations were run using age-based growth parameter estimates, and their corresponding estimates of $Lc_{50}$ and $F_{0.1}$ (derived using length-based methods). As noted in Project R6465, the Ralston estimate of M and resulting $F_{0.1}$ resulted in the best management performance where age-based growth parameters were used. These values were used in the current simulation studies.

To take account of uncertainty in the estimation of parameters, each 20 year simulation run used a different set of fixed input parameters (in these simulations, those estimates derived using age-based growth parameter estimates during Project R6465). In total, 100 runs were performed for each 20 year simulation.

Management is based on estimates of current fishing effort ($F_{curr}$; the fishing mortality level estimated by the fishery manager). Fishing mortality was increased or decreased by a preset percentage each year, moving the current effort towards the target effort (i.e. $F_{0.1}$). Management rules were set in the simulation model which determined the new fishing mortality applied to the stock (i.e. to be fed back into the YIELD software). These rules adjust the *true* underlying F within the YIELD software by the appropriate amount. The rule used in the current study was the fixed percentage change rule used in Project R6465. For this rule, it was considered to be more appropriate to increase by Y% if below the target, and to decrease by Z% if above the target, where:

$$Z = 100.\left[\frac{Y}{100 + Y}\right]$$

For example, the opposite of doubling effort (F x 2) is halving it (F / 2). In the simulations, the following percentages were used; if the estimated current effort was below the target ($F_{0.1}$=0.4), effort was increased by 20%. If current effort was above target, effort was decreased by 16.7%.

Simulations were performed for various scenarios (the range of starting efforts) to:

- examine the effect of uncertainty in total mortality estimation (and growth parameter estimation) on management performance
  Management performance was examined at a range of $F_{start}$ values, using the sets of 100 input parameters. Uncertainty in age-based total mortality estimates was then simulated using the age frequency distributions output from the YIELD software. Conclusions were drawn on the effect of uncertainty in total mortality and growth parameter estimation on management performance by comparing outputs with those from simulations where length-based total mortality estimation methods were used, and where perfect information was available (Project R6465 outputs). In the last of these runs, the management rule was applied directly to the true underlying F in the YIELD software, i.e. the value of the current F was taken to be the true F, and the management rule was applied to this value to determine the management action.

- compare the performance of length- and age-based methods of total mortality estimation
  The results obtained in the current study were compared with outputs from the management strategy simulations performed during project R6465, where length-based total mortality estimation methods were used. Comparisons were made at a range of $F_{start}$ values.

  During the management strategy simulations performed in Project R6465, it was noted that a direct comparison of the relative performance of input parameters could not be carried out. Age-based growth parameter inputs resulted in the under-exploitation of resources at all starting effort levels, whereas length-based inputs resulted in under-exploitation at low starting efforts, and over-exploitation at higher effort levels. Direct comparison required ‘tuning’, to ensure that the use of either set of input parameters resulted in optimum performance for a given initial fishing mortality level.

Histograms of the target effort levels ($F_{0.1}$) input into the model were plotted. For all starting efforts, estimates of $F_{0.1}$ were too low where age-based growth parameter estimates were used. Where length-based growth parameter estimates were used, $F_{0.1}$ estimates were closer to being correct. Tuning involved applying a multiplying factor to raise the estimates of target effort ($F_{0.1}$) such that after 20 years management resulted in exploitation at that target level (i.e. on average, F=0.4).

A range of multiplying factor values were investigated during Project R6465, using a starting effort of F=0.4 (the optimum effort level, to minimise computer time). Iterative methods were then used to achieve an average final year effort close to 0.4. Different multiplying factors were required for length- and age-based growth parameters, due to the more substantial under-exploitation resulting from the use of age-based growth parameters. For length-based growth parameters this equalled 1.07, while for age-based growth parameters the tuning factor was 1.4.

To ensure outputs from the current study could be compared directly with those from Project R6465, stock assessments were tuned using the approach described above. Again, an initial effort level of F=0.4 was selected. Given the non-linear relationship between the raising factor and average final year effort, as found during Project R6465, a range of likely values was first investigated. Iterative methods were then used to achieve an average final year effort close to 0.4. These multiplying factors were then applied to the estimated fixed input $F_{target}$ parameter (estimate of $F_{0.1}$).

### 2.3 Assessing management success

The study evaluated management performance by analysing four chosen performance measures. Two of these related to stock conservation measures, while the second two evaluated fleet performance measures. Histograms of these outputs were produced for each performance measure.

Conservation measures:

- Final year $ExB/ExB_0$: the ratio of the final year (year 20) exploitable biomass (ExB) to unexploited biomass ($ExB_0$). This measure indicates the probability of stock collapse. The optimum ratio for *L. mahsena* is 0.422 (Pilling et al., 1999). Values greater than this indicate that the fishery was under exploited, while values less than this indicated over exploitation.

- The frequency over the 20 year period with which the spawning stock biomass (SSB) dropped below 20% of unexploited levels ($SSB_0$)[2]. Indications that SSB frequently fell below 20% of $SSB_0$ would suggest that there was a danger of recruitment overfishing. If SSB rarely fell below 20% $SSB_0$ during the 20 years, the population was likely to remain within sustainable levels for the majority of the simulated period and the probability of recruitment overfishing was low.

[2] Mace and Sissenwine (1993) and Mace (1994) suggested that spawning stock biomass should not be allowed to fall below 20% and 30% of the initial biomass for stocks with average resilience to overfishing, and for little known stocks respectively. The former value is used here.

Fleet performance

- Final year effort: the frequency with which the simulation model reached the optimum final year F (in year 20) of 0.4 (true value of $F_{0.1}$ is 0.41; Pilling et al., 1999). Values greater than 0.4 suggested the final effort applied was too high, that overcapitalisation had occurred, and that over exploitation was likely. Below that level, effort was too low, and the resource was under exploited.

- Average catch: in order to compare the success of different scenarios, histograms of the average catch removed each year were plotted. This can be compared to the MSY value of 75 (units) (Pilling et al., 1999).

Using these performance measures, the success of management was determined.

# 3. Results

As stated, the objectives of the management strategy simulations were to investigate:

- the effect of uncertainty in total mortality estimation on management performance;
- the differences in management performance between age- and length-based methods of total mortality estimation.

Conclusions were drawn on management performance based on information derived from stocks fished at a range of fishing intensities. These represented lightly exploited stocks, such as those at Chagos, through to heavily fished stocks, such as those at the Mauritian banks.

## 3.1 Effect of uncertainty in total mortality on management performance

The effect of uncertainty in total mortality estimates was interpreted through a comparison of the management performance based on total mortality estimates derived using age and length frequency distributions with that resulting where perfect information was available. Management performance was evaluated using the four measures described in Section 2.3:

- final year exploitable biomass (ExB) as a ratio of unexploited biomass ($ExB_0$);
- number of years that spawning stock biomass (SSB) fell below 20% of unexploited levels ($SSB_0$);
- final year F; and
- average catch over the 20 year simulation period.

Each performance measure had an optimum value (Section 2.3). The effect of uncertainty in estimates was determined by investigating the performance of each measure relative to this optimum, i.e. the frequency of achieving the optimum, and the range of variability in each measure.

In a situation with perfect information and no variability in growth or recruitment, the optimum value for each performance measure would be achieved in every simulation. However, as a result of variability in these factors, even where perfect information on mortality and growth is available, variability in management performance around the optimum results. This was examined by running simulations using the true values of current fishing mortality in each year, and the true value of $F_{0.1}$. Comparison of the results of these simulations with those using estimates of current fishing mortality therefore show the degree to which management performance worsens due to the effect of uncertainty in the estimates of total mortality and growth parameter estimates on the estimates of current fishing mortality and $F_{0.1}$. The reader is reminded that age-based growth parameter estimates were used in each of the simulations where current fishing mortality was estimated, minimising uncertainty in the estimates of these parameters (see Pilling et al., 1999).

In the following sections, each performance measure is considered in turn. For each, histograms of the frequency distributions of that measure were produced, for different values of $F_{start}$.

### 3.1.1 Final year exploitable biomass

The optimum value of this ratio is the value at equilibrium maximum sustainable yield, 0.4. Ideally, there would be a narrow range of outcomes distributed closely around this value.

For age-based total mortality estimates (Figure 3) there was generally a high level of variability about the value of 0.4 for all starting efforts. This ranged from 0.1-0.8 for starting effort of F=0.25, to 0.1-1.2 for a starting F=0.7. With increasing effort, the proportion of instances in which the stock was under-exploited increased. With a starting F of F=1.2, management performed well, with a mode of the frequency distribution at $ExB/ExB_0$ = 0.4, and a further strong mode at 0.5. In contrast, at low F levels the population appeared over-exploited, with a mode at $ExB/ExB_0$ = 0.3. The distribution also had a notable tail toward $ExB/ExB_0$ levels indicating over-exploitation. Modes of the distributions tended to remain closer to the optimum of 0.4 across the range of starting efforts when compared to the distributions resulting from the use of length-based inputs (Figure 4).

When using length-based estimates of total mortality in stock assessments, there was a similarly high level of variability in outcomes (Figure 4). These ranged from 0.2-1.1 for $F_{start}$=0.05, to 0.5-1.2 for $F_{start}$=1.2. For the lowest starting effort of F=0.05, the results showed slight under-exploitation, with the mode of the distribution of $ExB/ExB_0$ at 0.5. As the starting effort increased, the degree of under-exploitation increased, with the mode of the distribution at 0.8 for $F_{start}$=1.2.

The runs performed using the true values of current effort and $F_{0.1}$ (Figure 5) also showed a degree of variability in outcomes. However, the range of $ExB/ExB_0$ values covered was slightly narrower than that resulting from the use of either the age- or length-based inputs. For example, with an $F_{start}$=0.05, final year $ExB/ExB_0$ ranged from 0.3-1.0, compared to 0.2-1.0 for age- and length-based inputs. Also, the modes of the distributions tended to remain closer to the optimum of 0.4 across the range of starting efforts. The proportion of times that the optimum was achieved was greater than for either age- or length-based inputs, again across the range of starting efforts. For these runs, the optimum of 0.4 was achieved for a minimum of 21% of runs ($F_{start}$=0.7), and up to 29% of runs for $F_{start}$=1.2. In comparison, the optimum was achieved for a maximum of 35% of runs for age-based inputs ($F_{start}$=1.2), but only 5% of runs for $F_{start}$=0.7. For length-based, the optimum was achieved between 0% of runs ($F_{start}$=1.2) and 23% of runs ($F_{start}$=0.05).

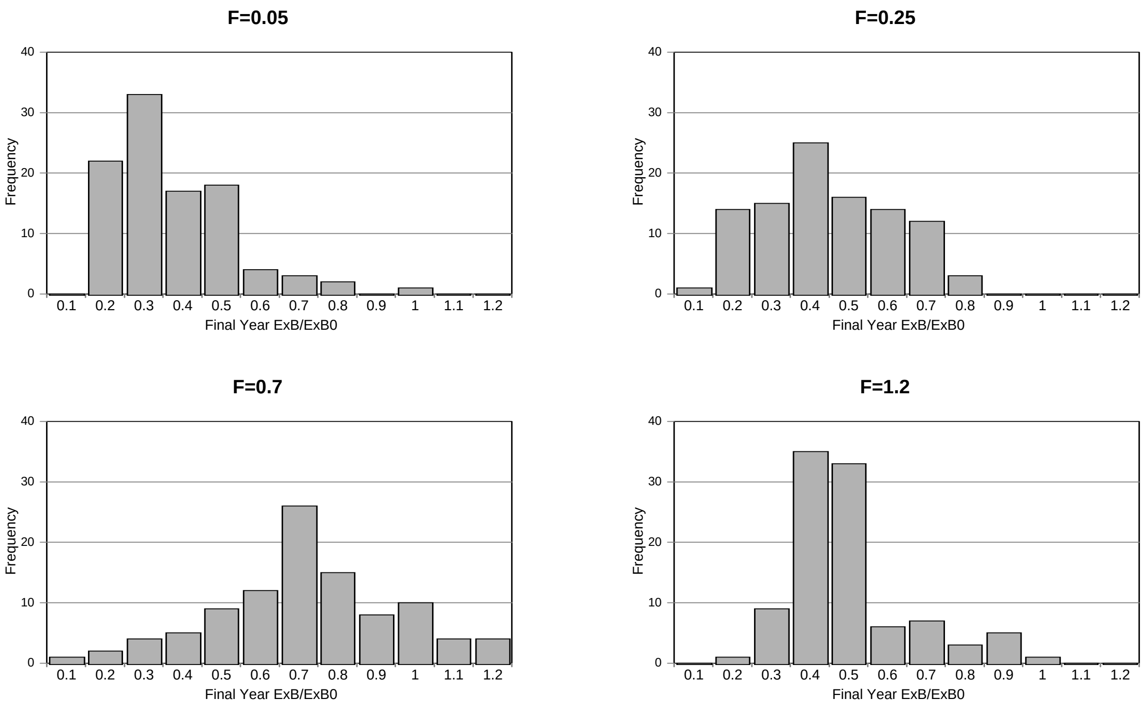


Figure 3 Histograms of final year $ExB/ExB_0$ for age-based total mortality estimates, for all $F_{starts}$.

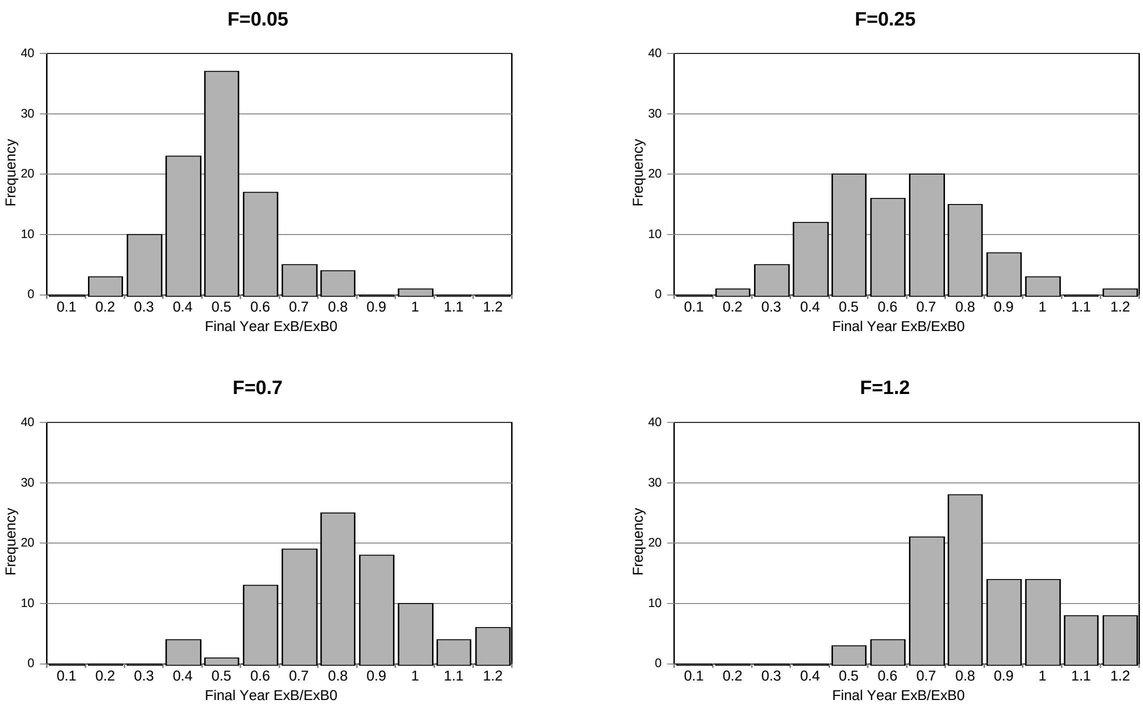


Figure 4 Histograms of final year $ExB/ExB_0$ for length-based total mortality estimates, for all $F_{starts}$.

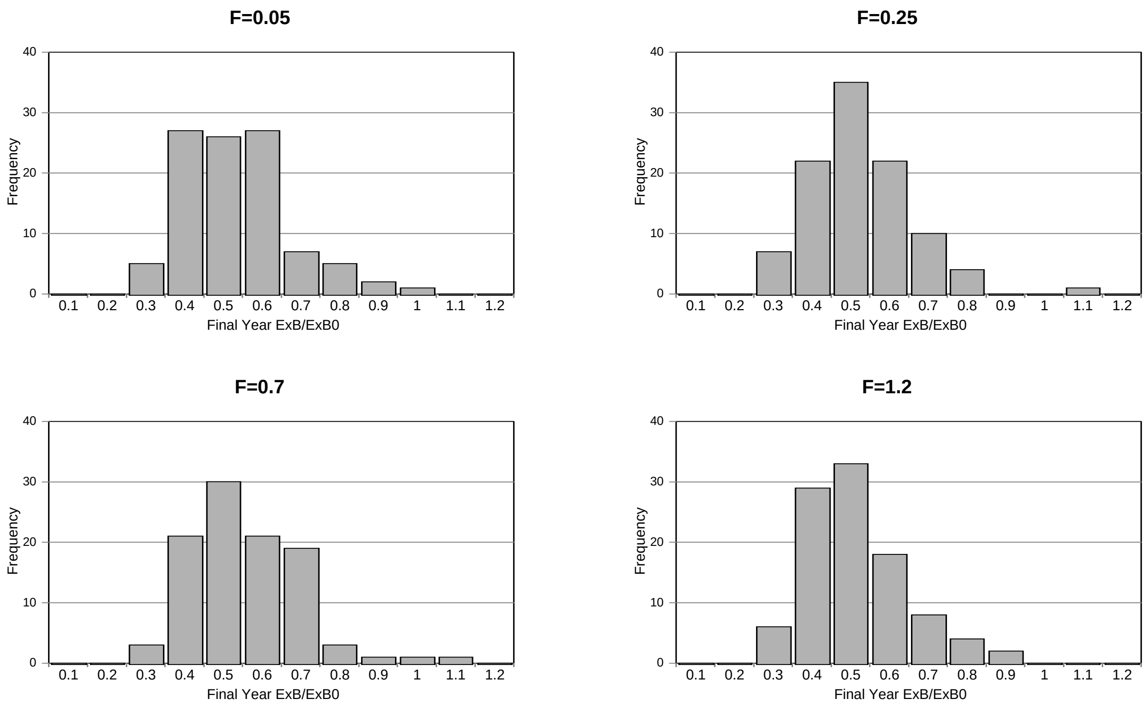


Figure 5. Histograms of final year $ExB/ExB_0$ for true current F and $F_{0.1}$, for all $F_{starts}$.

### 3.1.2 Spawning stock biomass

Optimally, spawning stock biomass should not be reduced to a level below 20% of the unexploited level for any of the twenty years of the simulation period.

At lower $F_{start}$ levels, the use of age-based total mortality estimates (Figure 6) resulted in good management performance, with SSB remaining above 20% of unexploited levels in 42% and 36% of the runs for $F_{starts}$ of 0.05 and 0.25 respectively. Distributions were skewed toward a low number of years in which $SSB/SSB_0$ <20%. However, as the level of $F_{start}$ increased, performance deteriorated notably. SSB was reduced to below 20% in all years of the simulation period for 3% and 22% of runs for $F_{starts}$ = 0.7 and 1.2 respectively.

Where length-based total mortality estimates were used in stock assessments (Figure 7), management was poor at $F_{start}$=0.05, with SSB being reduced to below 20% of unexploited levels for 6 years of the simulation period in 47% of the runs. Increasing starting effort led to a slight deterioration in performance, despite improvements at $F_{start}$=0.25. For a starting effort of 1.2, 10 years of the simulation period had SSB less than 20% of unexploited levels for 56% of the runs.

Runs using true effort and $F_{0.1}$ (Figure 8) did not perform as well as those using age-based total mortality estimates, but better than those using length-based total mortality estimates at lower $F_{start}$ levels. For example, at $F_{start}$=0.05, the true effort runs had 23% of runs where SSB never fell below the threshold value, compared to 42% for age-based total mortality estimates, and 12% for length-based total mortality estimates. At the highest starting effort levels, the true effort runs performed slightly worse than those based on age-based total mortality estimates, and notably worse than those derived using length-based estimates.

The reader should note that at the equilibrium target effort level $F_{0.1}$, $SSB/SSB_0$ is 21.3%. Where tested starting efforts are greater than F=0.4, therefore, SSB is already below the threshold level of 20% of $SSB_0$ at the start of the simulation. There will therefore be no cases in which the ratio never falls below the threshold 20% level. In this case, minimising the number of years in which $SSB/SSB_0$<20% will indicate good management performance. The difficulties imposed by the choice of the 20% $SSB/SSB_0$ reference level are discussed further in Section 4.1.

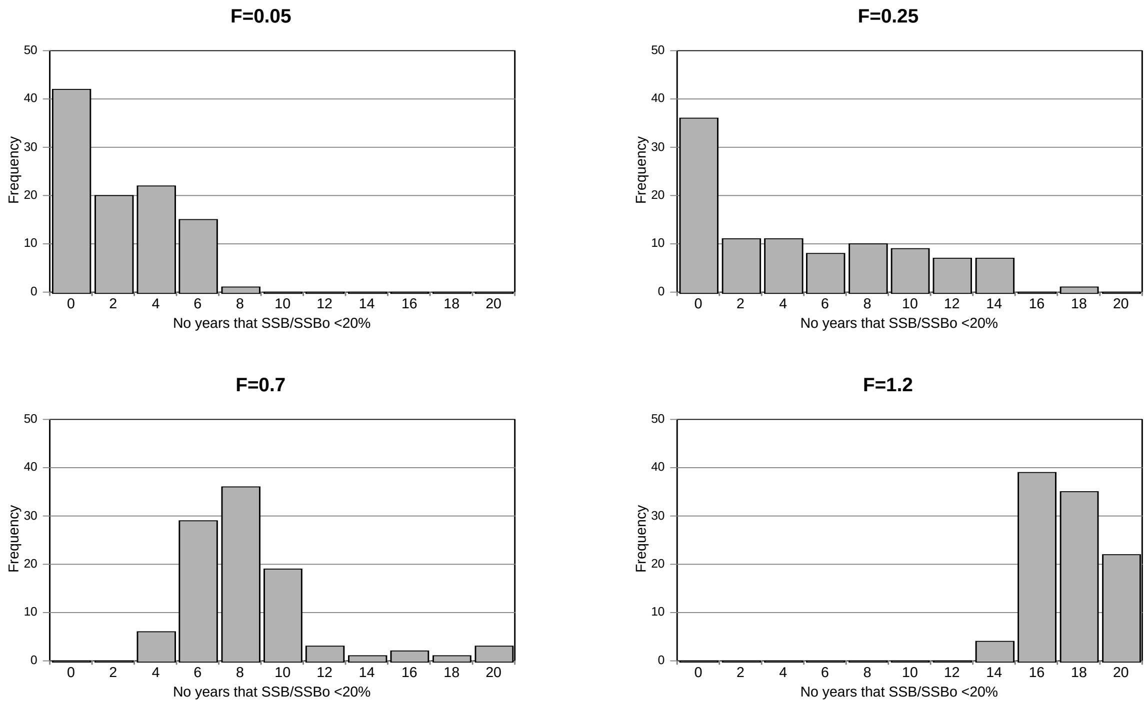


Figure 6. Histograms of the number of years that $SSB/SSB_0$ <20%, for age-based total mortality estimates, for all $F_{starts}$.

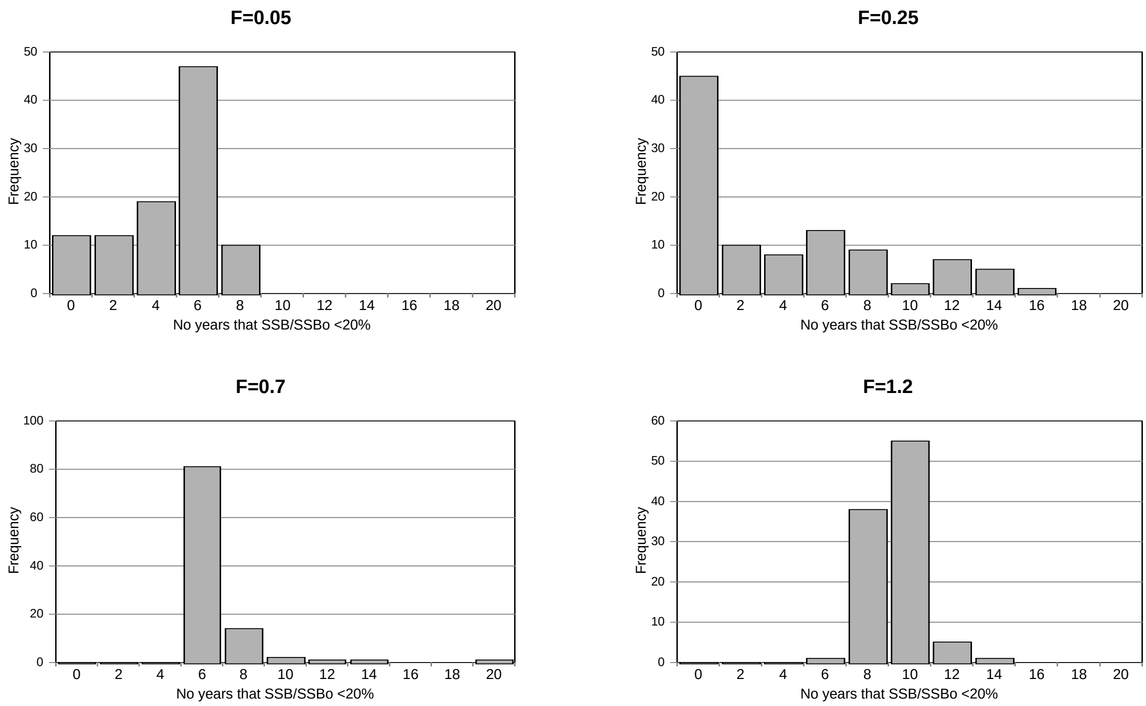


Figure 7. Histograms of the number of years that $SSB/SSB_0$ <20%, for length-based total mortality estimates, for all $F_{starts}$.

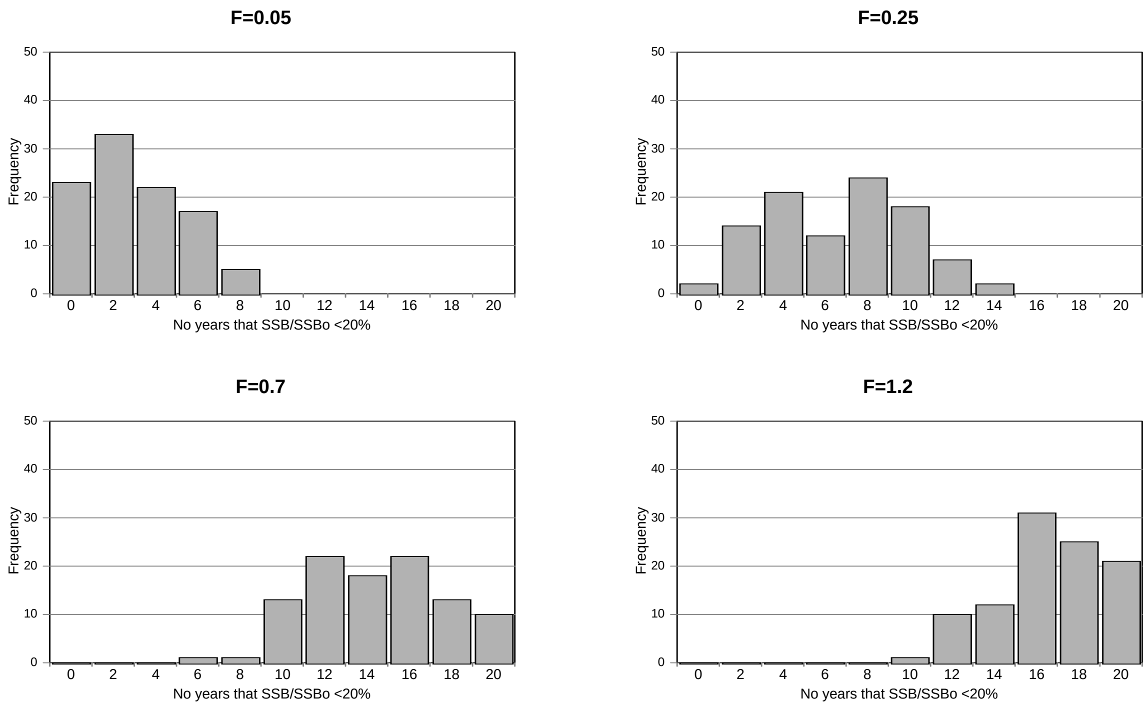


Figure 8. Histograms of the number of years that $SSB/SSB_0$ <20%, for true current F and $F_{0.1}$, for all $F_{starts}$.

### 3.1.3 Final year effort

The optimum value of the final year fishing effort is the target effort level $F_{0.1}$, for which the value estimated using the population parameters is F=0.4 (0.41). Where management is performing well, current fishing effort should be close to this value after 20 years of simulated management.

For age-based total mortality estimates (Figure 9), the largest spread of final year fishing mortality levels was found at the lower $F_{start}$ levels. For example, at $F_{start}$=0.05, the range covered F=0.1 - 1.2. The optimum was achieved for 20% of runs at $F_{start}$=0.05, and 13% of runs at $F_{start}$=0.25. For the two higher starting efforts, the range of outcomes was notably smaller, but in both cases the mode of the distribution was at 0.1 (67% of runs for $F_{start}$=0.7, and 91% of runs for $F_{start}$=1.2), indicating that the stock was under-exploited.

For length-based total mortality estimates (Figure 10), the pattern in the outcomes was comparable to those that resulted from the use of age-based total mortality estimates in stock assessments. However, where length-based estimates were used, the skew toward under-exploitation was greater. The optimum of 0.4 is achieved in 25% of runs for $F_{start}$=0.05, and 9% of runs for $F_{start}$=0.25. For the two higher starting efforts, the range of final year fishing mortality levels was reduced. As seen for the outputs of the age-based runs, the mode of the distributions was at 0.1 (in 79% of runs for $F_{start}$=0.7, and 97% of runs for $F_{start}$=1.2), again indicating under-exploitation.

For the simulation runs using the true values of current effort each year, and the true value of $F_{0.1}$, the target effort level is obviously reached by the final year of simulation in each run. These histograms are not shown. In fact, the greatest number of years taken to reach $F_{0.1}$ is 13 years, for a starting effort of 0.05.

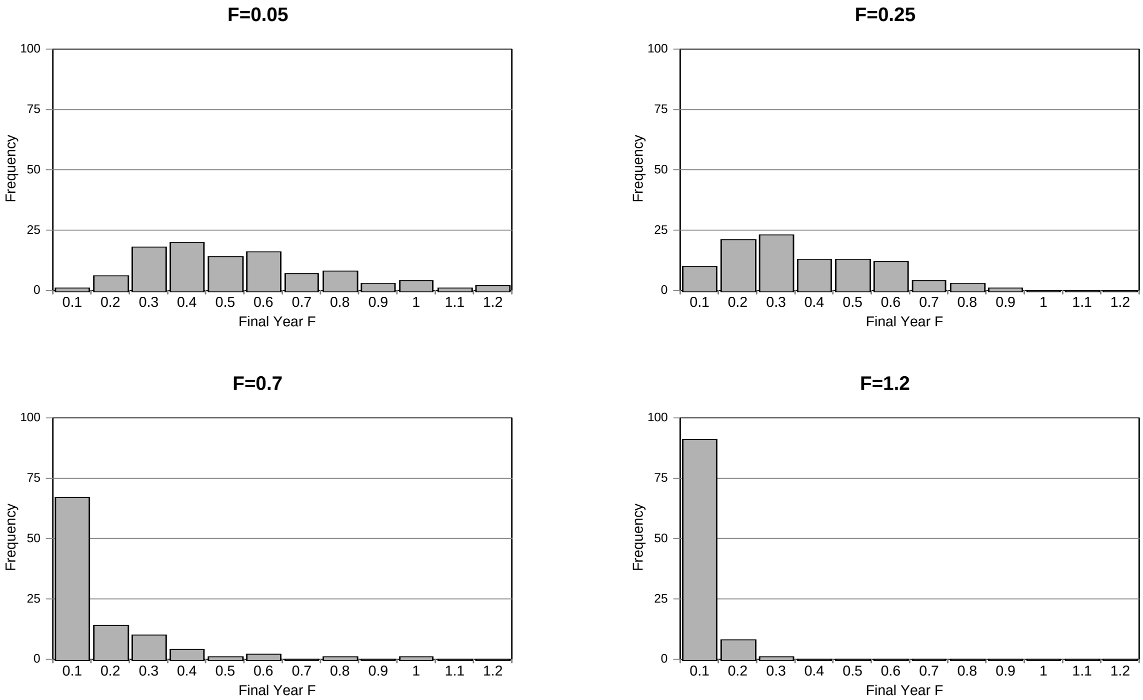


Figure 9. Histograms of final year effort for age-based total mortality estimates, for all $F_{starts}$.

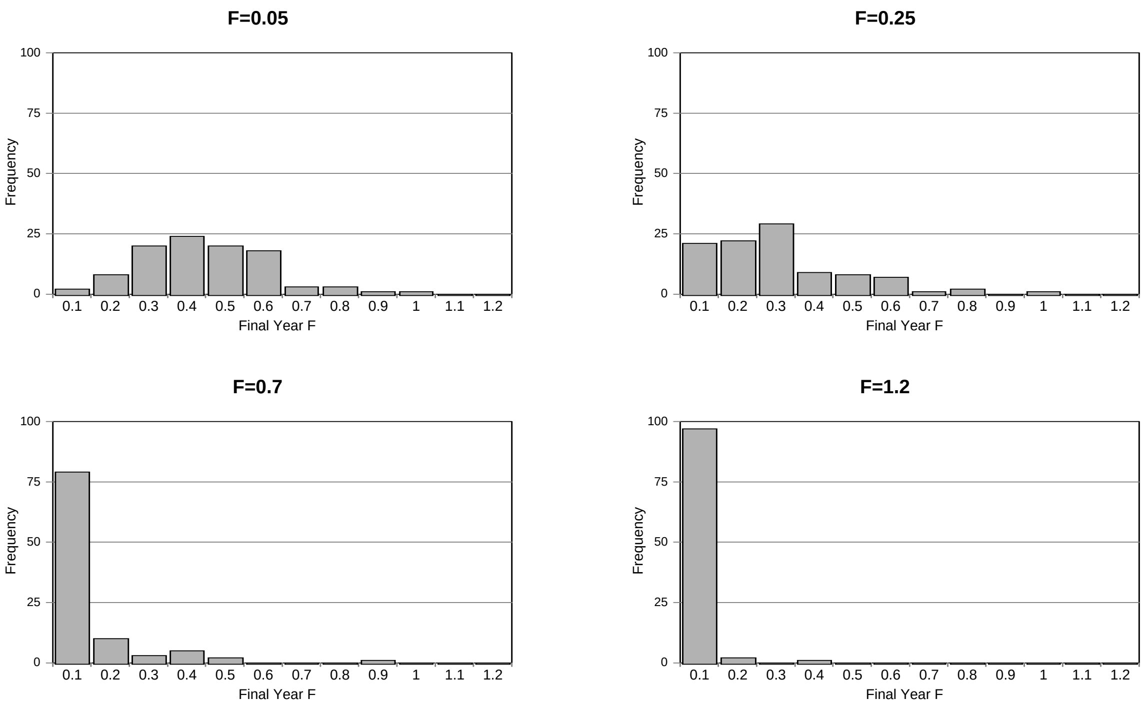


Figure 10. Histograms of final year effort for length-based total mortality estimates, for all $F_{starts}$.

### 3.1.4 Average catch

The average catch per year for each simulation can be compared to the optimal value, the maximum sustainable yield (from simulation outputs, MSY=75 units). Figures 11 and 12 show the average catch per year for each starting effort for both age- and length-based total mortality estimates respectively. At lower $F_{start}$ levels, the use of either total mortality estimate resulted in a wide range of values about the optimum (MSY). At higher $F_{start}$ levels, average catch was below 75 in virtually all runs, the mode being 35 units for age-based total mortality inputs at $F_{start}$=0.7 and for length-based total mortality inputs at both $F_{start}$=0.7 and 1.2, and 15 units for age-based total mortality inputs at $F_{start}$=1.2. For both total mortality estimates, catches tended to decrease with increasing starting effort. This was most notable where age-based total mortality inputs were used.

The results from runs using true effort are presented in Figure 13. In general, there was a slightly narrower range of outcomes when compared to the use of age- or length-based total mortality estimates. However, for all starting efforts, the distribution of average catch when using the true effort remained much closer to the optimum 75 units. Modes of the distributions varied between 55 and 75 units for the different starting efforts.

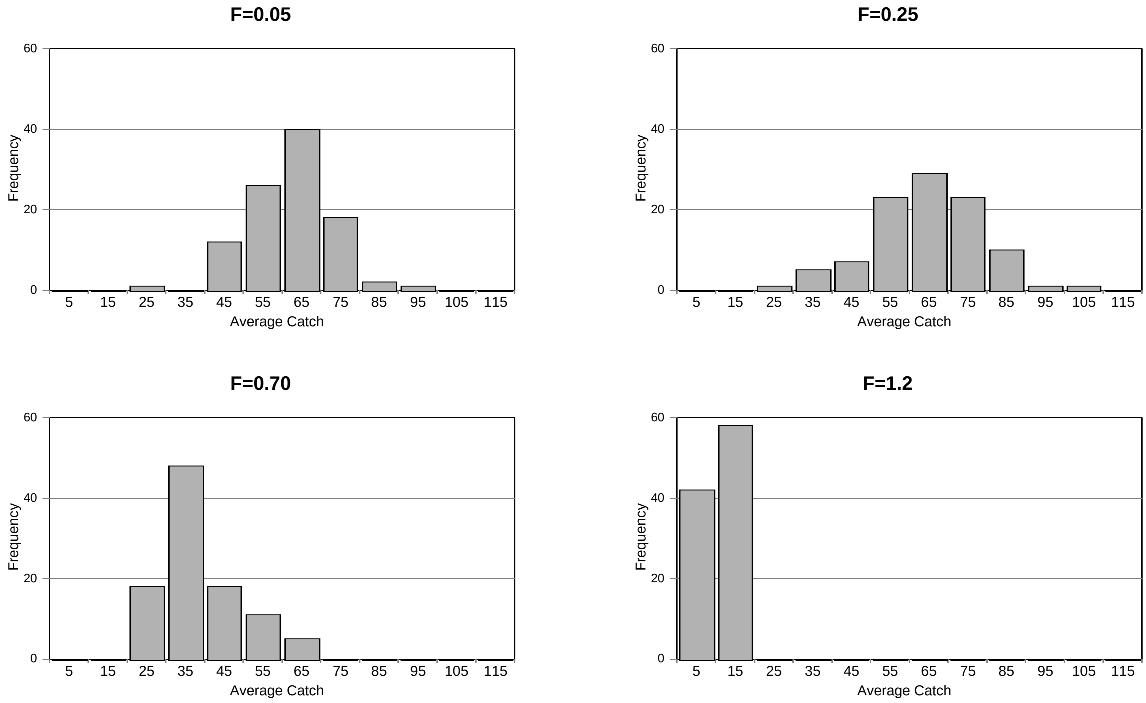


Figure 11. Histograms of average catch for age-based total mortality estimates, for all $F_{starts}$.

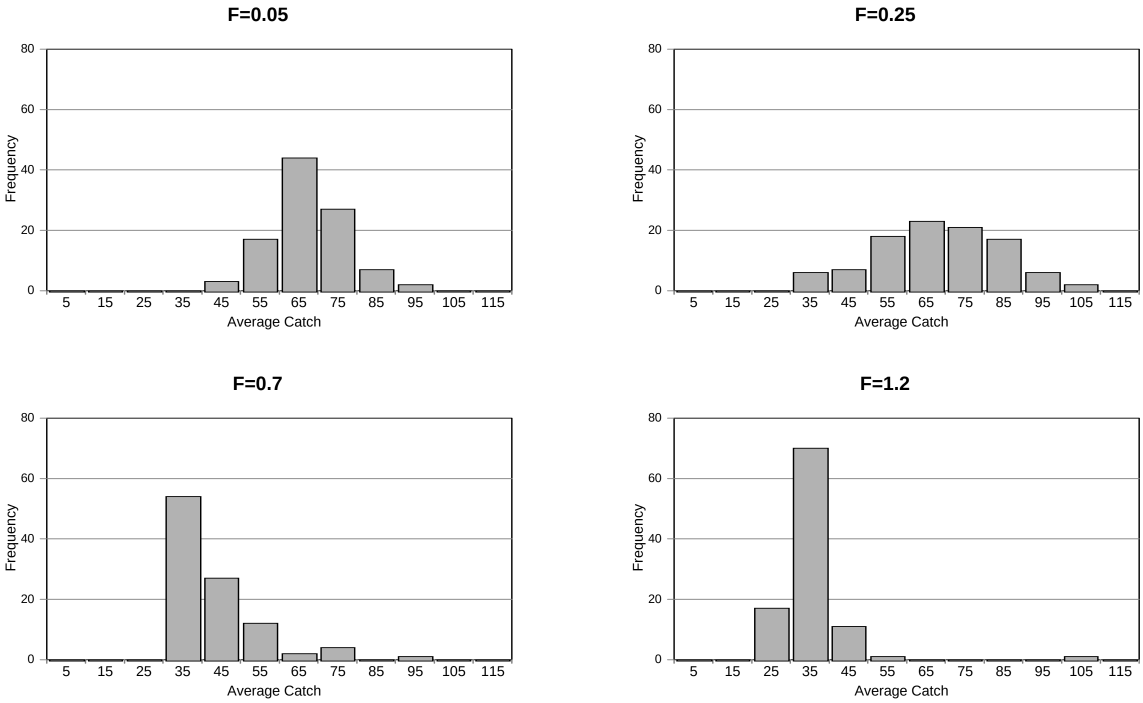


Figure 12. Histograms of average catch for length-based total mortality estimates, for all $F_{starts}$.

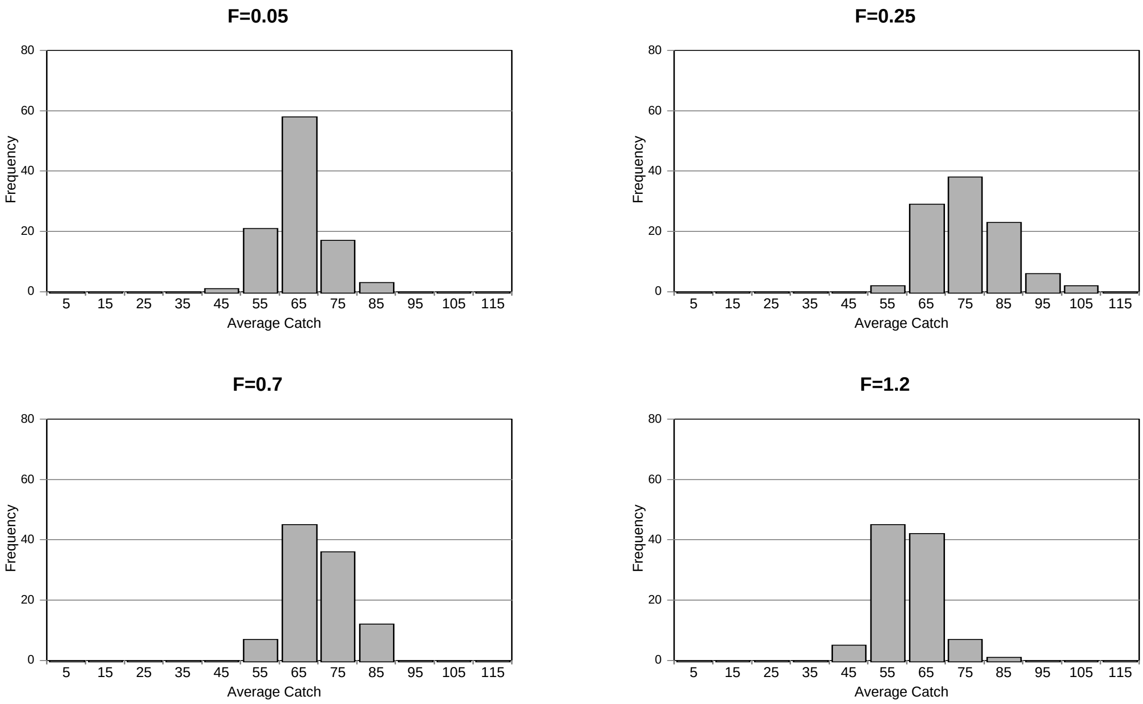


Figure 13. Histograms of average catch for true current F and $F_{0.1}$, for all $F_{starts}$.

### 3.1.5 Conclusions on effects of uncertainties in total mortality estimates

Where either age or length-based total mortality inputs were used in stock assessments, management performance was poor. The different performance measures showed a large degree of variability in outcomes. Also, the optimum value for each measure was often achieved in only a low proportion of runs.

By comparison with runs using the true effort and true value of $F_{0.1}$, management performance was worse when either age- or length-based total mortality estimates were used to derive estimates of current effort. This was indicated most clearly for the final year effort performance measure; using the true effort values resulted in the optimum being achieved by the final year in every run. A similar pattern was found when examining the performance measures of $ExB/ExB_0$ and average catch. Compared to the management performance when using the true effort values, the use of either age- or length-based total mortality estimates resulted in a slightly wider spread of outcomes, and lower frequencies of achieving the optimum value. However, age-based total mortality estimates resulted in improved management performance, compared to the true effort and $F_{0.1}$ value, when assessed against the SSB criterion. In contrast, the use of length-based total mortality estimates in stock assessments resulted in slightly worse management performance when assessed against this performance measure.

The results of these management strategy simulations provided some indication that the use of age-based total mortality estimation methods in stock assessments resulted in slightly improved management than the use of corresponding length-based estimates. However, it is difficult to compare the performance of the two total mortality estimation methods directly, without ensuring that management derived using resulting stock assessments is performing optimally. Tuning of the management target value is required.

## 3.2 Comparing relative performances of length- and age-based total mortality estimation methods

### 3.2.1 Tuning age-based inputs

In the current study, the goal of tuning was to optimise management so that, on average, it achieved an average final year effort of 0.41 ($F_{0.1}$). As in Project R6465, this was achieved by using a multiplying factor, which raised estimates of target effort ($F_{0.1}$).

A range of multiplying factor values were investigated. A starting effort of 0.4 was used (the optimum effort level) to minimise computer simulation time. The resulting mean final year F values are given in Table 2. Given the non-linear relationship between raising factor and average final year effort (Figure 14), a range of likely values was first investigated, and iterative methods used to obtain an average final year effort close to 0.41.

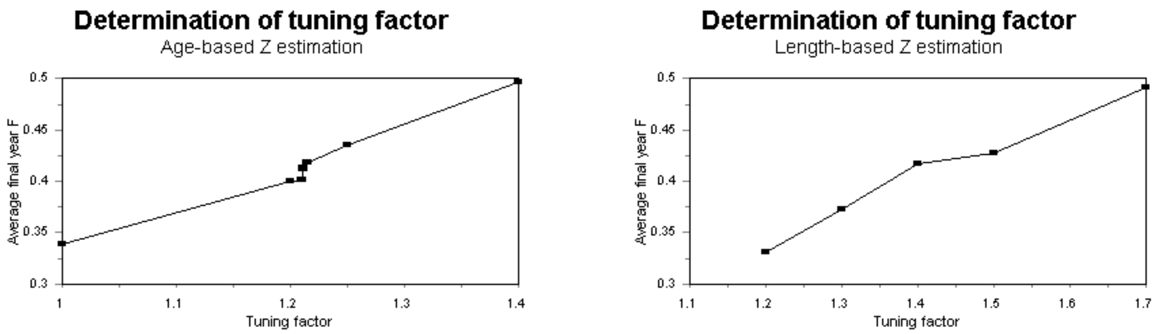


Figure 14. Graph of tuning factor against average final year effort, over the range investigated, for both age-based inputs, for $F_{start}$=0.4. The tuning factors for length-based total mortality estimation (using age-based growth parameters), calculated during Project R6465 are also shown.

Table 2. Summary of the results of using different multiplying factors for estimates of target F ($F_{0.1}$). Starting effort was $F=0.4yr^{-1}$. Age-based and length-based total mortality estimates shown. The latter were calculated during Project R6465.

| Raising factor | Average final year F | |
|---|---|---|
| | Age-based inputs | Length-based inputs |
| 1 | 0.339 | |
| 1.2 | 0.3997 | 0.331 |
| 1.21 | 0.4019 | |
| 1.211 | 0.4127 | |
| 1.215 | 0.4179 | |
| 1.25 | 0.4357 | |
| 1.3 | | 0.3723 |
| 1.4 | 0.4966 | 0.4171 |
| 1.5 | | 0.4271 |
| 1.7 | | 0.491 |

From the results summarised in Table 2 and Figure 14, a multiplying factor of 1.211 was chosen for age-based total mortality estimation methods, and a factor of 1.4 chosen for length-based total mortality estimation methods. These multiplying factors were applied to the estimated fixed input $F_{target}$ parameter (the estimate of $F_{0.1}$) in all subsequent runs.

### 3.2.2 Overall comparison of age- and length-based inputs at the effort level used for tuning

The relative performance of management based on stock assessments using age- or length-based total mortality estimates was examined at F=0.4, the effort level used for tuning. Figure 15 shows the distributions of each performance measure for this starting effort level, for tuned age- and length-based inputs.

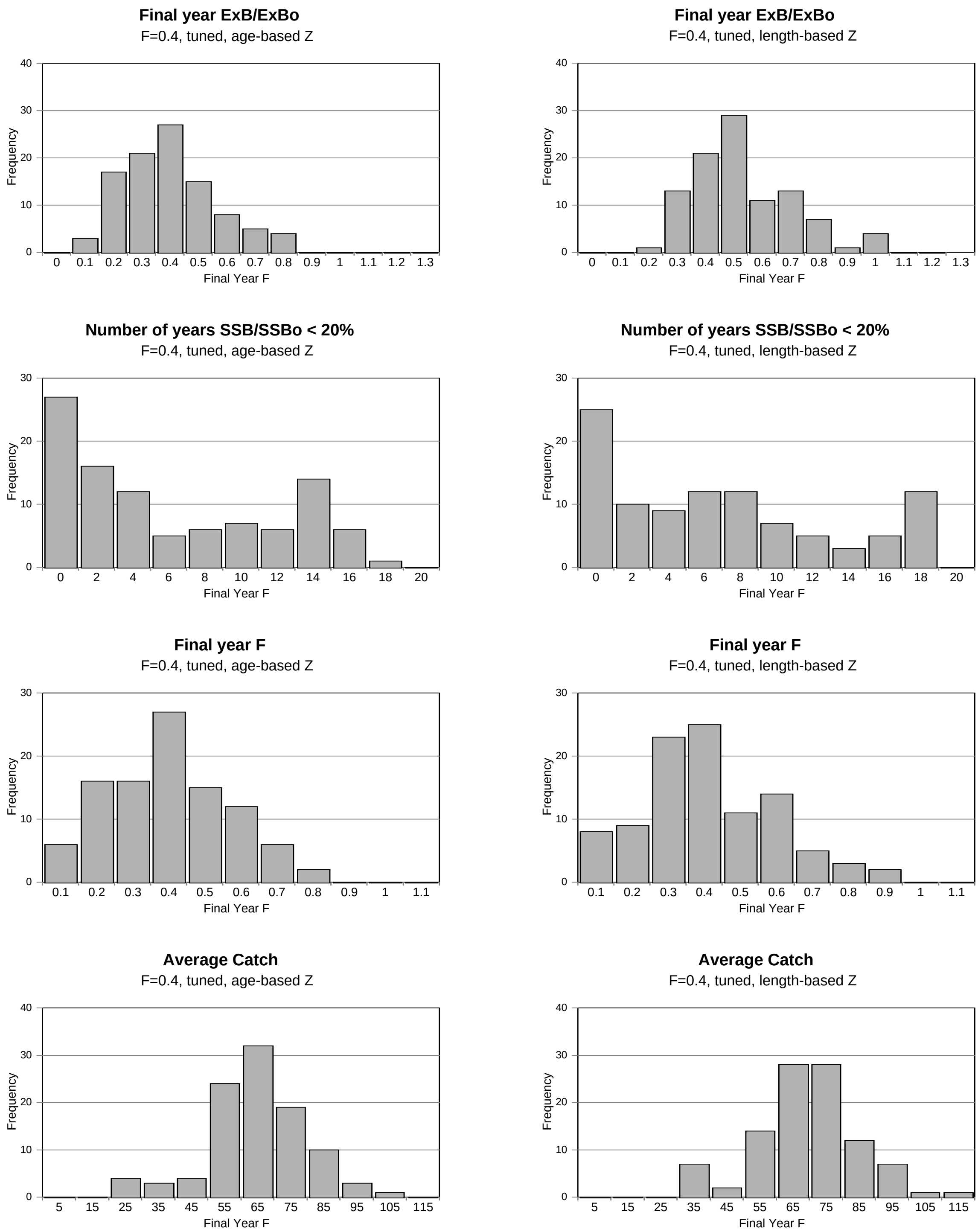


Figure 15. Comparison of each performance measure, for tuned age- and length-based inputs, for $F_{start}$=0.4.

Comparing each performance measure in turn;

**Final year ExB/ExB$_0$**: The range of ExB/ExB$_0$ values was slightly lower for age-based total mortality inputs (0.1-0.8) compared to length-based inputs (0.2-1.0). The optimum value for the ratio, 0.4, was achieved in 27% of runs for age-based inputs, and 21% of cases for length-based inputs.

**Number of years that SSB/SSB0 < 20%**: The proportion of runs in which SSB was never reduced below 20% of $SSB_0$ was slightly greater where age-based inputs were used (27% for age, 25% for length). Also, the number of runs in which SSB was reduced below 20% of $SSB_0$ for 18 out of 20 years of simulation was notably lower (1% of runs for age-based, 12% for length-based).

**Final year effort**: The range of final year F values was slightly lower for age-based inputs (0.1-0.8) compared to length-based (0.1-0.9). Also, the optimum of 0.4 was achieved in 27% of the runs where age-based inputs were used, compared to 25% of runs where length-based inputs were used.

**Average catch**: The range of values of average catch was similar for both age- and length-based inputs (25-105 for age, 35-115 for length). The optimum value of 75 was achieved more frequently when using length-based inputs (28% of runs) rather than age-based inputs (19% of runs).

The selection of average final year effort as the basis for tuning will mean that the other performance measures are not necessarily optimised. It is therefore appropriate to give more weight to the tuning results for final year F when making the direct comparison of management performance using age- and length-based inputs.

The final year effort level performance measure indicated that the use of age-based total mortality estimation methods in stock assessments resulted in better management performance compared to that resulting from the use of length-based estimation methods. Final year $ExB/ExB_0$ and $SSB/SSB_0$ performance measures also showed an improvement when using age-based total mortality estimation methods. In contrast, when assessed against the performance measure of average catch, there was a marginal advantage in using length-based total mortality estimates. Their use resulted in optimum catch levels being achieved in a higher proportion of runs.

Project R6465 noted that tuning the target effort level was required for the effort level appropriate for the fishery in question. To illustrate this for age-based total mortality estimation methods, tuning was repeated for starting efforts of F=0.05 and F=1.2. These represent the extremes of the range of effort levels used in the management strategy simulations. As before, methods were tuned to achieve an average final year F as close as possible to the optimum of 0.41. The appropriate multiplying factors are presented in Table 3. The resulting histograms for each performance measure are shown in Figure 16 ($F_{start}$=0.05) and Figure 17 ($F_{start}$=1.2).

Table 3. Multiplying factors derived for both age- and length-based total mortality inputs for $F_{start}$=0.05 and $F_{start}$=1.2.

| | Age-based inputs | Length-based inputs |
|---|---|---|
| $F_{start}$=0.05 | 0.83 | 0.89 |
| $F_{start}$=1.2 | 2.49 | 3.4 |

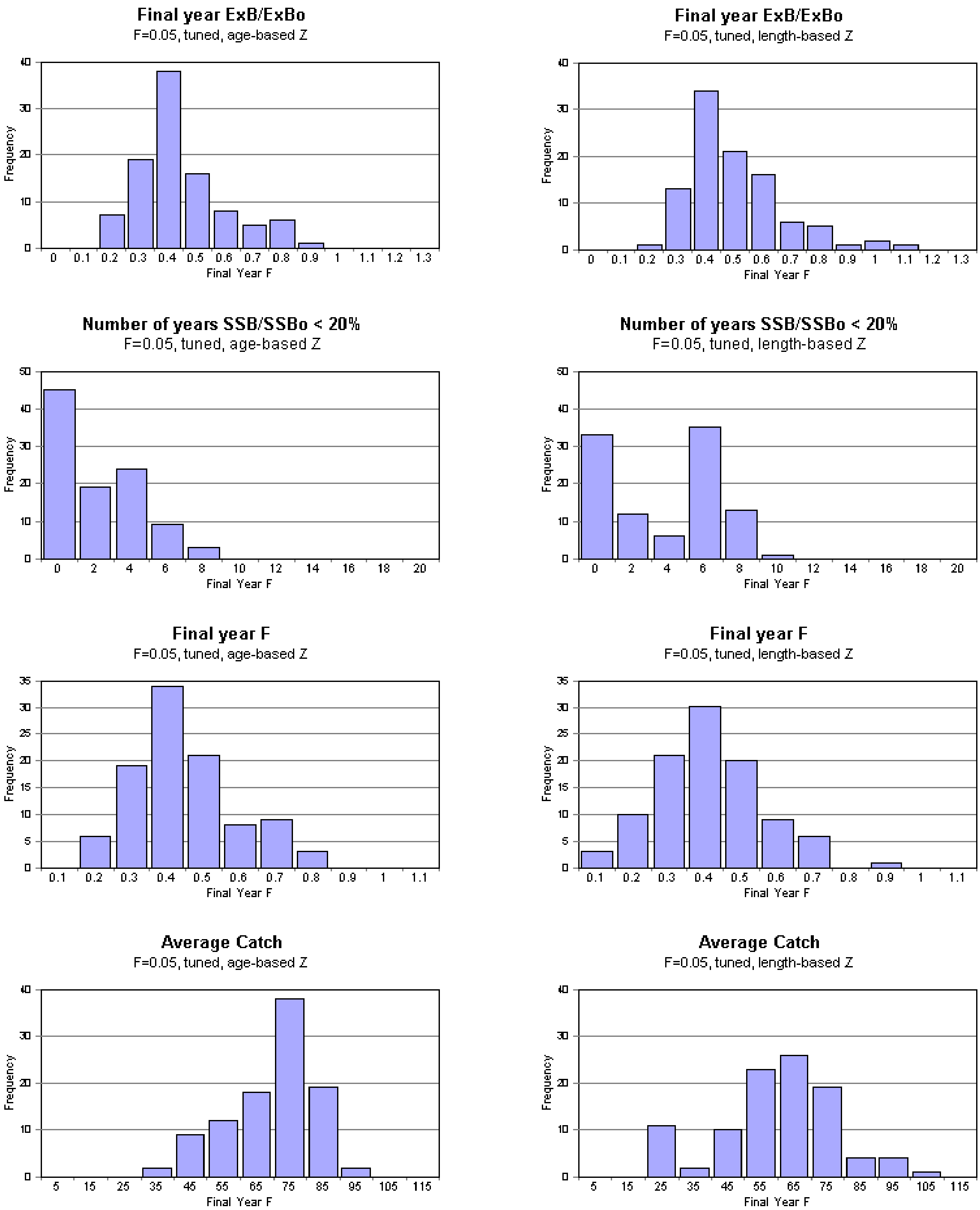


Figure 16. Comparison of performance measures, for tuned age-based and length-based inputs, for $F_{start}$=0.05.

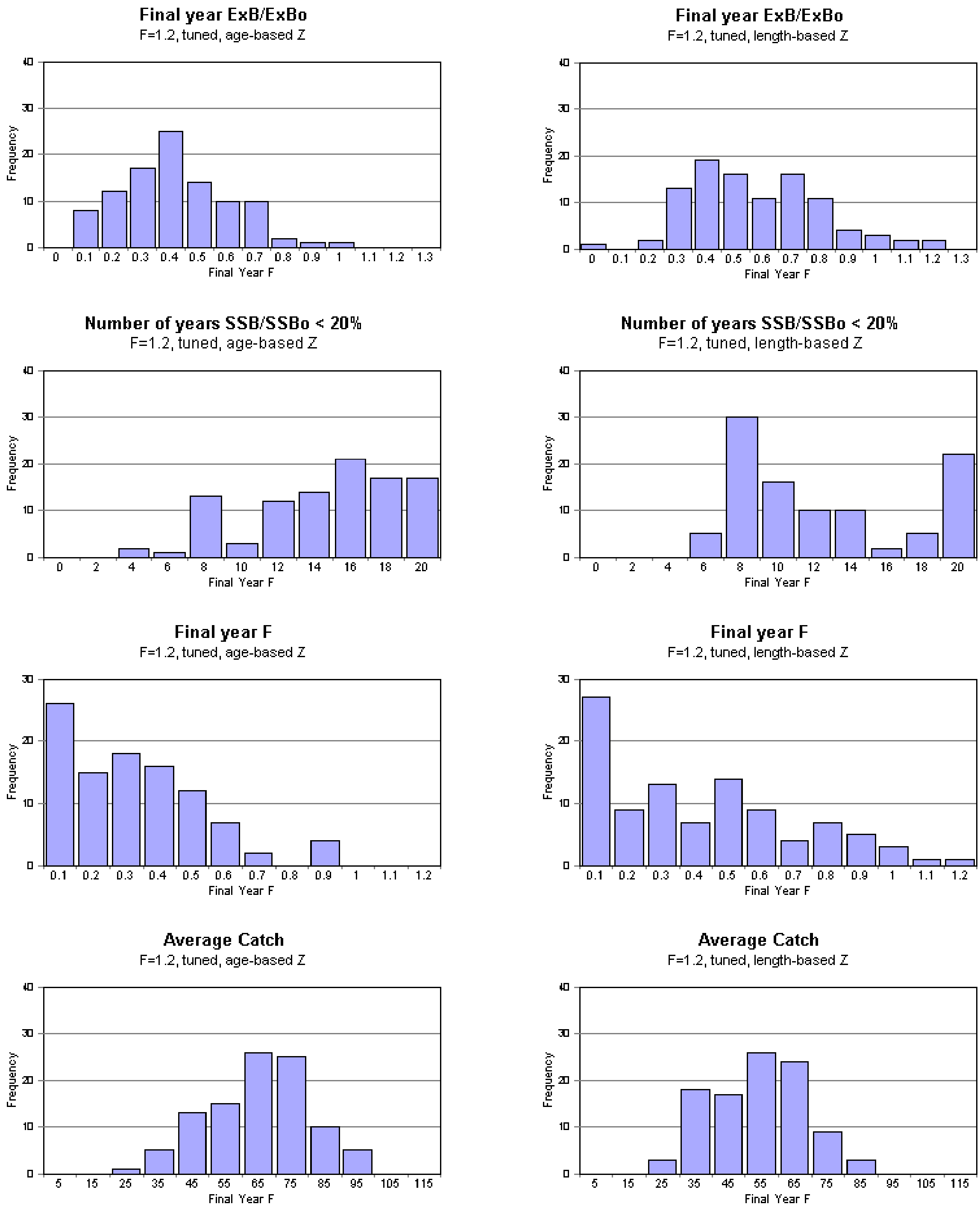


Figure 17. Comparison of performance measures, for tuned age-based and length-based inputs, for $F_{start}$=1.2.

The patterns shown in Figures 16 and 17 indicate that the use of age-based total mortality estimates in stock assessments results in improved management performance, when compared to the use of length-based inputs. This is comparable to the pattern seen in the histograms for outputs from runs tuned at $F_{start}$=0.4. When using age-based inputs, the optimum is generally achieved in a greater proportion of runs, and the range of outputs is narrower. However, it should be noted that at the higher starting fishing mortality levels (F=1.2, Figure 17), the use of either input value results in relatively poor management performance, with a wide spread of output values.

# 4. Discussion

Studies performed during Project R6465 (Pilling et al., 1999) indicated that age-based growth parameter estimates resulted in the most accurate management actions. Despite this, management based on biological reference points derived using these parameter estimates still showed considerable variability. In part, this resulted from uncertainty that remained in the growth parameter estimates, despite the improvements resulting from the use of age-based growth parameter estimation methods. Variability also resulted from the use of length-based methods to assess biological parameters and reference points. It was suggested that the use of further age-based approaches could reduce this uncertainty. These approaches included the use of age-based total mortality estimation methods. This approach avoids the need to use uncertain growth parameter estimates in the estimation process. The current study therefore examined whether the use of age-based methods of total mortality estimation improved the ability of fisheries managers to accurately manage a fish stock using analytical methods such as yield-per-recruit. The performance of management based on stock assessments derived using age- and length-based[3] total mortality estimates was compared.

It should be noted that the aim of this study was not to establish an optimum management strategy. As a result, the comparison of different management strategies was not central to the study. Therefore, the management rule used in Project R6465 was used. This rule was a fixed percentage management rule using a 20% increase and 16.7% decrease. As noted in Project R6465, alternative management actions may achieve different results in terms of management performance.

### 4.1 Management performance measures

In evaluating management performance, four indicators were used; final year $ExB/ExB_0$; the number of years that SSB fell below a threshold value; final year F; and average catch (see Section 2.3). Certain details relating to these indicators were discussed in the final report for Project R6465. That discussion is repeated here for completeness.

**Final year F:** In the simulations, management aimed to achieve (and sustain) the target effort (*i.e.* $F_{0.1}$, F=0.41 for *L. mahsena*) within the 20 year period of management. Examining final year F indicates whether this target was achieved by the end of the 20 year period. Variability in the true final year effort is due to inaccuracies in the estimates of both current effort and $F_{target}$. This results from inaccuracies and variability in the growth parameter estimates (both parameters) and total mortality estimate (current effort). As both estimates of current effort and $F_{target}$ are used each year in the management rule to determine whether to increase or decrease effort in the subsequent year, the inaccuracies and variability in parameter estimates result in a failure to achieve the optimum final year F. This leads to the pattern of over- or under-exploitation observed in the final year $ExB/ExB_0$.

**Spawning stock biomass:** As noted in section 3.1.2, the ratio of spawning stock biomass to

[3] Project R6465 indicated that the use of length-converted catch curves resulted in the best management performance when using age-based growth parameter estimates. This combination was used in the current study.

unexploited levels at the equilibrium target effort level, $F_{0.1}$ (= 0.41), is 21.3%. Thus the choice of a 20% level for this spawning stock biomass performance measure might be questionable. Indeed, a $SSB/SSB_0$ ratio just below the threshold of 20% does not indicate very poor performance, given the target value. The value of the $SSB/SSB_0$ ratio at equilibrium MSY is 10.9%. Thus it might have been more appropriate to use a 10% level for the SSB performance measure. However, the value of 20% was chosen in Project R6465 in relation to estimates quoted in the literature (Mace and Sissenwine, 1993). The use of the 20% level in the current study therefore allowed direct comparison with the results of Project R6465.

While at starting efforts of 0.4 and higher, spawning stock biomass is already at or lower than 20% $SSB_0$ at the start of the simulations, a high number of years in which SSB is below 20% of $SSB_0$ indicates a failure of management to adjust the F level suitably. For the two lowest starting efforts (0.05 and 0.25) the value of the ratio at equilibrium is 80% and 36% respectively. Thus a high number of years below 20% for these two starting efforts is indeed indicative of poor management performance.

**Average catch:** For the actual study fisheries, neither MSY nor $F_{MSY}$ can be estimated, due to a lack of information on the stock recruitment relationship for *L. mahsena*. However, in simulations it is valid to compare performance against the optimum catch that could have been achieved rather than that at $F_{0.1}$ (which can be calculated for the real fishery), as MSY can be determined within the model.

### 4.2 Management simulation objectives

The current study initially examined the management performance resulting from the use of age- and length-based total mortality estimates in stock assessments. While neither method led to particularly good management performance, there appeared to be some improvement when using age-based total mortality estimates.

To compare the two methods directly, the target effort level ($F_{0.1}$) was tuned for the effort level appropriate to the fishery in question. The method selected for tuning was to optimise the average final year effort. When comparing the management performance resulting from the use of age- and length-based inputs directly, this criterion was given more weight. For this measure, the use of age-based total mortality estimation methods resulted in improved management performance when compared to the use of length-based estimates.

The performance of total mortality estimation methods incorporating catch curves, and in particular age-based catch curves, will depend on the level of recruitment variability. If variability is high, the descending limb of the catch curve will be affected, and could potentially become non-linear. For *L. mahsena* the level of recruitment variability appears relatively low (CV of recruitment variability was 61%). For fish species where this variability is greater, estimates derived using length- or age-based methods may be adversely affected. Also, the level of fishing pressure, combined with the life history of the fish species, will also affect the accuracy of total mortality estimates. Where species are short-lived, or fishing effort is high, the number of age classes in the age frequency (or lengths in the length frequency) will be reduced, limiting the number of points in the descending limb of the catch curve, and hence the information available to estimate total mortality. This will affect the accuracy of assessments.

Results from the tuned age-based inputs at the tuning effort level still showed considerable variability. While the use of age-based methods of total mortality estimation led to improved management performance, other stages of the stock estimation process continued to produce inaccuracies in management. Age-based total mortality estimation methods removed uncertainty resulting from the use of growth parameters in its estimation. This improved estimates of $F_{curr}$. However, growth parameters are still used as inputs into the estimation of natural mortality, since empirical formulae are currently used. This parameter strongly influences estimates of $F_{curr}$ and $F_{0.1}$, the parameters on which management decisions were based. While the use of age-based growth parameter and total mortality estimation methods improve management performance compared to corresponding length-based methods, therefore, the lack of an independent estimate of natural mortality means that uncertainty in management remains.

### 4.3 Summary and guidelines

The current study used management strategy simulation methods to examine the effect of uncertainty in total mortality estimates on management performance. Age- and length-based approaches to estimating this parameter were examined. The assumption was made that age-based methods to estimate growth parameters were used, thereby reducing uncertainty in these estimates (see Project R6465; Pilling et al., 1999).

Following tuning of the target effort level to the relevant exploitation level, comparisons of management performance based on stock assessments derived using the two total mortality estimation methods indicated that the use of age-based methods led to improved management performance. The first guideline is therefore:

- use age-based methods of total mortality estimation when performing stock assessments for long-lived, slow growing species.

The cost-effectiveness of this approach for *L. mahsena* was examined during Project R7521. Cost-benefit analyses were performed, based on the outputs of the simulations from the current study. These analyses indicated that where an age-otolith weight relationship existed, the use of this relationship was the most cost-effective method to estimating total mortality. While the method incurred higher costs when compared to the length-based approach, use of the relationship resulted in greater benefits, assessed against criteria of conservation. For long-lived, slow growing species where an otolith weight-age relationship was not available, the most cost-effective approach was to use length-based total mortality estimation methods (and age-based growth parameters). The reduced benefits resulting from the use of this method were outweighed by the reduced costs involved, compared with generating an age frequency through otolith increment counts.

While age-based approaches resulted in improved management performance for *L. mahsena*, it should be noted that care must be taken when using this approach in fisheries where effort levels are high, and for species with faster growth rates and high levels of recruitment variability. A new FMSP Project will examine the implications of using length- and age-based methods of growth and stock assessment for species with different life history characteristics.

Despite improvements in management performance resulting from the use of age-based methods of total mortality estimation in stock assessments, considerable uncertainty remained. The use of natural mortality estimates derived using empirical formulae (reliant on growth parameter estimates) in stock assessments contributed to this poor performance. The value of natural mortality is highly influential in the estimation of current fishing mortality and $F_{0.1}$, the two parameters on which management was based. Therefore, the second management guideline is:

- an independent estimate of natural mortality should be derived to reduce the level of uncertainty in the management of long-lived, slow growing species further.

Approaches to estimate this parameter were suggested in the final technical report to FMSP Project R7521.

# 5. References

Ardil, J. D. (1986). Current status of the fishery in Mauritius. *FAO/SWIOP Document* OISO RAF/79/065/WP/37/87/E, 30pp.

Dalzell, P., S. Sharma and G. Nath (1992). *Estimation of exploitation rates in a multispecies emperor (Pisces: Lethrinidae) fishery in Fiji, based on length frequency data*. Noumea, New Caledonia, South Pacific Commission, p.43-50.

FAO (1998). *FAO yearbook - Fisheries statistics; catches and landings, 1998*. Food and Agriculture Organisation of the United Nations, Rome.714pp.

Haight, W. R., D. R. Kobayashi and K. E. Kawamoto (1993). Biology and management of deepwater snappers of the Hawaiian archipelago. *Marine Fisheries Review* **55**(2): 17-24.

Kailola, P. J., M. J. Williams, P. C. Stewart, R. E. Reichelt, A. McNee and C. Grieve (1993). *Australian fisheries resources*. Canberra, Australia, Bureau of Resource Sciences, Department of Primary Industries and Energy, and Fisheries Research and Development Corporation, 422pp.

Koslow, J. A., F. Hanley and R. Wicklund (1988). Effects of fishing on reef fish communities at Pedro bank and Port Royal Cays, Jamaica. *Marine Ecology Progress Series* **43**: 201-212.

Langi, S. (1990). The applicability of ELEFAN for use in analysing 3 species of deep-sea snappers (*Etelis corruscans*, *Pristipomoides flavipinnis* and *P. filamentosus*, Family Lutjanidae). *Fishbyte* **8**(1): 21-25.

Mace, P. M. (1994). Relationships between common biological reference points used as thresholds and targets of fisheries management strategies. *Can. J. Fish. Aquat. Sci.* **51**: 110-122.

Mace, P. M. and M. P. Sissenwine (1993). How much spawning per recruit is enough? *Risk evaluation and biological reference points for fisheries management*. (S. J. Smith, J. J. Hunt and D. Rivard, eds.). Vol 120, p. 101-118.

Majkowski, J., J. Hampton, R. Jones, A. Laurec and A. A. Rosenberg (1987). Sensitivity of length-based methods for stock assessment: report of working group 3. *In* Length-based Methods in Fisheries Research. Vol. 13. (D. Pauly and G. R. Morgan., eds.) International Centre for Living Aquatic Resources Management, Manila, Philippines, and Kuwait Institute for Scientific Research, Safat, Kuwait. p.363-372.

Manooch, C. S. (1987). Age and growth of snappers and groupers. *In* Tropical Snappers and Groupers: Biology and Fisheries Management. (J. J. Polovina and S. Ralston, eds.). Westview Press Inc., Boulder, Co. p. 329-363.

Mathews, C. P. (1974). An account of some methods of overcoming errors in ageing tropical and sub-tropical fish populations when hard tissue growth markings are unreliable and the data are sparse. *In* Ageing in fish. (T. B. Bagenal ed.) Unwin Brothers Limited**,** Old

Working, Surrey, England. p. 159-166.

Mees, C. C. (1989). The artisanal fisheries of the Seychelles. SFA internal report, SFA, Victoria, Mahé, Seychelles. 12pp.

Mees, C. C. (1993). Population biology and stock assessment of *Pristipomoides filamentosus* on the Mahé Plateau, Seychelles. *Journal of Fish Biology* **43**: 695-708.

Mees, C. C., G. M. Pilling and C. J. Barry (1999). Commercial inshore fishing activity in the British Indian Ocean Territory. *In* Ecology of the Chagos Archipelago. (C. R. C. Sheppard and M. R. D. Seaward, eds.) Linnean Society Occasional Publications 2, Westbury Academic and Scientific Publishing**,** Otley, West Yorkshire. 350p.

Mees, C. C. and J. A. Rousseau (1997). The potential yield of the lutjanid fish *Pristipomoides filamentosus* from the Mahé Plateau, Seychelles: managing with uncertainty. *Fisheries Research* **33**: 73-87.

Morales-Nin, B. (1989). Growth determination of tropical marine fishes by means of otolith interpretation and length frequency analysis. *Aquatic Living Resources Nantes* **2**: 241-253.

Morgan, G. R. (1983). Application of length-based stock assessments to Kuwait's fish stocks. *International Centre for Living Aquatic Resources Management Newsletter* **6**(4): 3-4.

MRAG (1996). Management of multi-species tropical fisheries. A report to the Overseas Development Administration**.** 193pp.

Munro, J. L. (1983). *Caribbean coral reef fishery resources*. Manila, Philippines, ICLARM Study Reviews Vol 7, ICLARM, Manila, Philippines. 127pp.

Munro, J. L. and D. M. Williams (1985). Assessment and management of coral reef fisheries: Biological, environmental and socioeconomic aspects. *Proc. Int. Coral Reef Congr., 5th* **4**: 545-581.

Okamoto, H. (1982). Deep bottom fish surveys in Hawaii. *NOAA 83050410*: 24pp.

Parrish, F. A., E. E. DeMartini and D. M. Ellis (1997). Nursery habitat in relation to production of juvenile pink snapper, *Pristipomoides filamentosus*, in the Hawaiian Archipelago. *Fisheries Bulletin* **95, 1**: 137-148.

Pauly, D., F. Arreguin-Sanchez, J. L. Munro and M. C. Balgos (1996). Biology, fisheries and culture of snappers and groupers: workshop conclusions and updates to 1996. *In* Biology, fisheries and culture of tropical snappers and groupers. (F. Arreguin-Sanchez, J. L. Munro, M. C. Balgos and D. Pauly, eds.) ICLARM, Manila, Philippines. 449pp.

Pilling, G. M., C. C. Mees, C. Barry, G. K. Kirkwood, S. Nicholson and T. Branch (1999). Growth parameter estimates and the effect of fishing on size-composition and growth of snappers and emperors: implications for management. MRAG Ltd, London. 473pp.

Rowling, K. R. and D. D. Reid (1992). Effect of temporal changes in size composition on estimates of von Bertalanffy growth parameters for gemfish, *Rexea solandri*, Gempylidae. *Australian Journal of Marine and Freshwater Resources* **43**: 1229-1239.

Russ, G. R. (1991). Coral reef fisheries: effects and yields. *In* The Ecology of Fishes on Coral Reefs. (P. F. Sale, ed.) Academic Press, London. 725pp.

Shepherd, J. G., G. R. Morgan, J. A. Gulland and C. P. Mathews (1987). Methods of analysis and assessment: report of working group 2. *In* Length-based Methods in Fisheries Research. Vol. 13. (D. Pauly and G. R. Morgan, eds.) International Centre for Aquatic Resources Management, Manila, Philippines, and Kuwait Institute for Scientific Research, Safat, Kuwait. p353-362.

Thompson, R. and J. L. Munro (1974). The biology, ecology and bionomics of the snappers, Lutjanidae. *In* Caribbean Coral Reef Fishery Resources. Vol. 7. (J. L. Munro, ed.) International Centre for Living Aquatic Resources Management, Manila, Philippines. p94-109.

Thompson, R. and J. L. Munro (1983). The biology, ecology and bionomics of the snappers, Lutjanidae. *ICLARM Stud. Rev.* **7**: 94-109.