

# Stock assessment for fishery management

A framework guide to the stock assessment tools of the Fisheries Management Science Programme



**Cover:**

Illustration/photo collage by Emanuela D'Antoni using photographs by A. Conti (FAO/17789) and R. Sozzani.

# Stock assessment for fishery management

A framework guide to the stock assessment tools  
of the Fisheries Management Science Programme

by

**Daniel D. Hoggarth**

**Savitri Abeyasekera**

**Robert I. Arthur**

**John R. Beddington**

**Robert W. Burn**

**Ashley S. Halls**

**Geoffrey P. Kirkwood**

**Murdoch McAllister**

**Paul Medley**

**Christopher C. Mees**

**Graeme B. Parkes**

**Graham M. Pilling**

**Robert C. Wakeford**

**Robin L. Welcomme**

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

ISBN 92-5-105503-3

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holders. Applications for such permission should be addressed to:

Chief

Publishing Management Service

Information Division

FAO

Viale delle Terme di Caracalla, 00100 Rome, Italy

or by e-mail to:

[copyright@fao.org](mailto:copyright@fao.org)

© FAO 2006



Regrettably, while this volume was in press, we heard of the death of Dr Geoff Kirkwood. Geoff had been instrumental in developing many of the techniques that are outlined in this document and his friends and colleagues, as well as fisheries science in general, will miss him greatly.

# Preparation of this document

These guidelines are intended to assist fishery scientists in using a set of stock-assessment computer programs, developed as part of efforts of the UK Department for International Development (DFID, previously ODA) and the Fisheries Department of the Food and Agriculture Organization of the United Nations (FAO) to disseminate appropriate methodologies to the developing world. The software and this supporting documentation are the outcome of a series of studies funded by DFID under its Fisheries Management Science Programme (FMSP). The collation and publication of this document in English, by FAO, was supported by FMSP project R8360.

The CD-ROM included with this paper provides the installation files for each of the four FMSP software programs for fish stock assessment:

1. Length Frequency Distribution Analysis (LFDA);
2. Catch and Effort Data Analysis (CEDA);
3. Yield; and
4. Participatory Fisheries Stock Assessment (ParFish), including toolkit.

These installation files are also available on the FMSP Web site at:  
<http://www.fmsp.org.uk>.

# Abstract

This paper provides guidelines for fish stock assessment and fishery management using the software tools and other outputs developed by the UK Department for International Development's Fisheries Management Science Programme (FMSP) in the years 1992 to 2004. Part 1 describes some key elements of the precautionary approach to fisheries management. A stock assessment process is also outlined that can provide the information needed for such precautionary management. The management process summarized in Chapter 2 is based on recent FAO guidance, including the Code of Conduct for Responsible Fisheries. It emphasizes the need for setting goals and operational objectives; for defining these explicitly as reference points for a range of fishery indicators; for adopting decision control rules that include precautionary thresholds allowing for uncertainties and risk tolerances, and that drive fishery management using a set of measures that are pre-agreed with stakeholders. Chapter 2 also stresses the need to integrate use rights and co-management arrangements into the management framework, where appropriate, as key elements for success.

Chapter 3 presents the process of stock assessment, underlining the need for quantitative assessment of uncertainties and risks and the provision of advice based on the various goals of the fishery and considering both short- and long-term impacts of management strategies. Methods are given to estimate the current status of the fishery either as the stock size, the fishing mortality rate or other ecological or goal-based indicators. Methods are also described for estimating maximum sustainable yield (MSY) and other yield-based reference points, as well as some aimed at protecting the spawning capacity of the stock and avoiding recruitment overfishing. For sustainable exploitation, it is recommended that yield-based reference points are used as targets while spawning capacity reference points are used as limits and given the higher precedence. Precautionary thresholds should be set to prevent the limits being exceeded.

Chapter 4 provides information on the FMSP stock assessment tools and guidelines, including four FMSP software packages – LFDA, CEDA, Yield and ParFish – by which intermediate parameters, indicators and reference points may be estimated. The inputs and outputs and the relative advantages and potential uses of the tools are described. The four chapters in Part 2 further describe these four software tools, providing guidelines on their use and the fitting of models. Full technical details and tutorials are available in the software help files provided on the accompanying CD-ROM.

Part 3 then summarizes the guidelines produced by a number of other FMSP projects relating to stock assessment and management approaches that were introduced in Chapter 4. Chapter 10 uses simulation models to compare the performance of length-based and age-based approaches for two tropical fish species. The analysis demonstrates the benefits of using age based approaches where possible, but it is noted that results may differ for other species and their particular life history strategies. Chapter 11 develops simple relationships for the estimation of potential yield and maximum sustainable fishing mortality based on the Beverton and Holt "life-history invariants". These relationships allow sustainable yields and fishing capacity to be estimated from sparse data, which may either be already available, or can be relatively easily obtained. Chapter 12 derives guidelines for the management of multispecies demersal bank and deep reef slope fisheries exploited principally with hooks and lines. Chapter 13 presents a Bayesian stock assessment applied to the Namibian orange roughy fishery. This case study illustrates the benefits and some of the difficulties found in applying the Bayesian approach and draws out some lessons learnt. Chapter 14 describes a number

of empirical modelling approaches that can be used to support fisheries management, ranging in complexity from simple methods that only require historical catches through to complex multivariate models based on General Linear Modelling and Bayesian network approaches. These approaches may suit data poor circumstances, or when among fishery comparisons are possible, for example under adaptive approaches to (co-) management.

Throughout the framework, the use of adaptive learning and feedback approaches are promoted within the general principle of precaution. Complementary use of these approaches should enable uncertainties to be reduced and long-term benefits to be maximized with reduced risks to the resource base.

**Hoggarth, D.D.; Abeyasekera, S.; Arthur, R.I.; Beddington, J.R.; Burn, R.W.; Halls, A.S.; Kirkwood, G.P.; McAllister, M.; Medley, P.; Mees, C.C.; Parkes, G.B.; Pilling, G.M.; Wakeford, R.C.; Welcomme, R.L.**

Stock assessment for fishery management – A framework guide to the stock assessment tools of the Fisheries Management Science Programme (FMSP).

*FAO Fisheries Technical Paper*. No. 487. Rome, FAO. 2006. 261p. Includes a CD-ROM

# Acknowledgements

Part 1 of this document – the framework for using the FMSP stock assessment tools – was crafted around the outputs of various FMSP projects and studies, mainly by project manager Dan Hoggarth. Thanks are due to Robert Arthur, Ashley Halls, Geoff Kirkwood, Paul Medley, Chris Mees, Catherine O’Neill and Graeme Parkes for their help in defining the framework used in Part 1. Robert Arthur drafted sections 2.3 and 2.4 and contributed to other parts of Chapters 2 and 3; Graham Pilling drafted section 3.6.5; Chris Mees drafted section 4.4. Material for Parts 2 and 3 of the document were mostly drafted by the original researchers of the different FMSP projects, as listed at the start of each section.

The authors are grateful to the participants of the September 2004 FMSP Stock Assessment Tools training workshop held in Mangalore, India, for their useful comments on an early draft of the document; and to John Munro, Kevin Stokes and Catherine O’Neill, as well as Serge Garcia and Kevern Cochrane of FAO for their edits and suggestions on the draft text.

## **CREDITS**

The LFDA and CEDA packages were designed by Dr Geoff Kirkwood, Richard Auckland and Simon Holden and programmed by Richard Auckland, Steve Zara, Mark Bravington and Simon Holden. “Yield” was designed by Dr Geoff Kirkwood and Trevor Branch and programmed by Trevor Branch, Simon Nicholson, Steve Zara and Brian Lawlor. The ParFish software was designed and programmed by Paul Medley. The ParFish toolkit was designed by Paul Medley, Suzannah Walmsley and Charlotte Howard.

## **AUTHORS’ ADDRESSES**

### **Daniel D. HOGGARTH**

Scales Inc., No. 3, C3-12 Graeme Hall Park, Christ Church, Barbados

### **Savitri ABEYASEKERA and Robert W. BURN**

Statistical Services Centre, University of Reading, PO Box 240, Reading RG6 6FN, United Kingdom of Great Britain and Northern Ireland

### **Robert I. ARTHUR, Ashley S. HALLS, Christopher C. MEES, Graeme B. PARKES and Robert C. WAKEFORD**

MRAG Ltd, 18 Queen Street, London W1J 5PN, United Kingdom of Great Britain and Northern Ireland

### **John R. BEDDINGTON**

Division of Biology, Faculty of Life Sciences, Imperial College, South Kensington campus, London SW7 2AZ, United Kingdom of Great Britain and Northern Ireland

### **Geoffrey P. KIRKWOOD, Murdoch McALLISTER and Robin L. WELCOMME**

Renewable Resources Assessment Group (RRAG), Imperial College (as above)

### **Paul MEDLEY**

Sunny View, Main Street, Alne, North Yorkshire YO61 1RT, United Kingdom of Great Britain and Northern Ireland

### **Graham M. PILLING**

Centre for Environment, Fisheries and Aquaculture Science (CEFAS), Pakefield Road, Lowestoft, Suffolk NR33 0HT, United Kingdom of Great Britain and Northern Ireland

# Contents

Preparation of this document	iii
Abstract	iv
Acknowledgements	vi
Foreword	xii
Symbols and abbreviations	xiv

## **PART 1 FRAMEWORK FOR USING THE FMSP STOCK ASSESSMENT TOOLS**

<b>1. Introduction</b>	<b>3</b>
1.1 The new international legal regime	3
1.2 Purpose and content of the guidelines	4
1.3 A framework for fisheries management	5
<b>2. Fishery management systems</b>	<b>9</b>
2.1 Management approaches	9
2.1.1 Comprehensive rational planning	9
2.1.2 The precautionary approach	10
2.1.3 Adaptive management	12
2.2 Management scope	14
2.2.1 Single species management	14
2.2.2 Multispecies and multigear management (technical and biological interactions)	14
2.2.3 Ecosystem management	15
2.3 Use rights	18
2.3.1 Access rights	19
2.3.2 Withdrawal (harvest) rights	19
2.4 Control rights and fisheries co-management	20
2.5 A precautionary management process	23
2.5.1 Goals and operational objectives	24
2.5.2 Indicators and reference points – measuring management performance	26
2.5.3 Harvesting strategies and decision control rules	30
2.5.4 Precautionary reference points – allowing for risk and uncertainty	34
2.5.5 Management strategies and measures	35
2.6 The role of stock assessment in management	41
<b>3. The stock assessment process</b>	<b>43</b>
3.1 Introduction	43
3.1.1 Qualitative or quantitative?	44
3.1.2 Deterministic or stochastic – allowing for uncertainty?	45
3.1.3 Biomass dynamic or analytical models?	46
3.1.4 Equilibrium or dynamic?	46
3.1.5 Age-based or length-based?	47
3.1.6 Include stock-recruitment relationships or make assessments “per recruit”?	49

---

3.2	Collecting fishery data	51
3.2.1	Catch, effort and abundance data	53
3.2.2	Size compositions (catch at age and length-frequency data)	54
3.2.3	Other biological data	55
3.3	Estimating intermediate fishery parameters	55
3.3.1	Growth rates of individual fish	55
3.3.2	Population growth rate and carrying capacity	56
3.3.3	Natural mortality rate	57
3.3.4	Maturity and reproduction	58
3.3.5	Stock and recruitment	58
3.3.6	Exploitation pattern (gear selectivity)	59
3.3.7	Catchability	59
3.4	Indicators – measuring the current status of the fishery	60
3.4.1	Catch, effort and CPUE	60
3.4.2	Stock size	61
3.4.3	Fishing mortality rate	62
3.4.4	Other indicators	64
3.5	Estimating technical reference points	65
3.5.1	MSY reference points	66
3.5.2	Proxies for MSY and other yield-based reference points	68
3.5.3	Reference points for maintaining the reproductive capacity of the stock	69
3.5.4	Risk-defined reference points	72
3.5.5	Multispecies and ecosystem-based reference points	73
3.5.6	Economic and social reference points	74
3.6	Providing management advice	76
3.6.1	Feedback for “control rule” management	77
3.6.2	Making projections: short-term and medium-term advice	77
3.6.3	Recognizing multiple objectives and management options	78
3.6.4	Providing advice on uncertainty and risk	80
3.6.5	Management procedure evaluation	83
<b>4.</b>	<b>The FMSP stock assessment tools and guidelines</b>	<b>85</b>
4.1	Growth and mortality rates from length frequency data (LFDA software)	85
4.1.1	Purpose and methodology	85
4.1.2	Inputs and outputs	86
4.1.3	Applicability and related approaches	86
4.2	Reference points from minimal population parameters (Beverton and Holt “invariants” methods)	87
4.3	Reference points from yield and biomass models (Yield software)	89
4.3.1	Purpose and methodology	89
4.3.2	Inputs and outputs	90
4.3.3	Applicability and related approaches	93
4.4	Managing fishing effort in multispecies fisheries	94
4.4.1	Purpose and methodology	94
4.4.2	Inputs and outputs	96
4.4.3	Applicability and related approaches	96
4.5	Biomass dynamic/depletion models (the CEDA software)	97
4.5.1	Purpose and methodology	97
4.5.2	Inputs and outputs	101
4.5.3	Applicability and related approaches	103

4.6	Bayesian stock assessment approaches	107
4.6.1	Purpose and methodology	107
4.6.2	Participatory Fisheries Stock Assessment (the ParFish software)	110
4.6.3	Comparison with other Bayesian software	113
4.7	Empirical stock assessment approaches	114
4.7.1	Predicting yields from resource areas and fishing effort	114
4.7.2	Multivariate modelling of fishery systems	114
4.8	Special approaches for inland fisheries	115
4.8.1	Integrated flood management for fisheries and agriculture	116
4.8.2	Stocking models and adaptive management	117
<b>5.</b>	<b>Conclusion</b>	<b>119</b>
<b>PART 2 INTRODUCTORY GUIDES TO THE FMSP STOCK ASSESSMENT SOFTWARE</b>		
<b>6.</b>	<b>LFDA software – Length Frequency Data Analysis</b>	<b>127</b>
6.1	Fitting von Bertalanffy growth curves	127
6.1.1	Fitting seasonal growth curves	129
6.1.2	Uncertainty in the LFDA growth parameter estimates	130
6.2	Estimating total mortality rates ( $Z$ )	130
<b>7.</b>	<b>The Yield software</b>	<b>133</b>
7.1	Including parameter uncertainties	133
7.2	Estimating equilibrium per-recruit reference points	133
7.3	Estimating equilibrium yield and biomass reference points	134
7.4	Yield projections and the “risk-based” Transient SSB reference point	135
7.4.1	Making non-equilibrium projections under variable recruitment	135
7.4.2	Estimating the Transient SSB reference point	137
<b>8.</b>	<b>CEDA software – Catch Effort Data Analysis</b>	<b>139</b>
8.1	The CEDA models	139
8.2	Guide to fitting models	141
8.2.1	Sensitivity analysis	141
8.2.2	Choosing the right model	142
8.2.3	Model diagnostics – residual plots	142
8.2.4	Outliers and influential points	143
8.2.5	Model diagnostics – using the “goodness-of-fit”	144
8.2.6	Finding point estimates using non-linear minimization	145
8.2.7	Fitting confidence intervals	145
8.3	Making projections in CEDA	146
<b>9.</b>	<b>ParFish – Participatory Fisheries stock assessment</b>	<b>149</b>
9.1	Introduction	149
9.2	Background	150
9.3	Overview	150
9.4	The target simulation model	151
9.5	Controls	152
9.5.1	Effort	152
9.5.2	Catch quota	152
9.5.3	Refuge	152
9.6	Control reference points	153
9.7	Probability assessment	153

9.8	Models fitted to data	155
9.8.1	Approach	155
9.8.2	Population models	156
9.8.3	Stock assessment interview	156
9.9	Utility	158
9.9.1	Overview	158
9.9.2	Preference interview	159
9.9.3	The catch-effort scenarios	160
9.9.4	Scoring	161
9.9.5	Errors and feedback	161
9.9.6	Preference model	161
 <b>PART 3 OTHER FMSP ANALYSES AND GUIDELINES</b>		
<b>10.</b>	<b>Comparisons of length- and age-based stock assessment methods</b>	<b>165</b>
10.1	Introduction	165
10.2	Method	165
10.2.1	Growth parameter estimation	165
10.2.2	Management strategy simulation	166
10.3	Results	167
10.3.1	Growth parameter estimation	167
10.3.2	Management strategy simulation	168
10.4	Discussion	169
10.4.1	Growth parameters	169
10.4.2	Assessment of management performance	169
<b>11.</b>	<b>The estimation of potential yield and stock status using life history parameters</b>	<b>175</b>
11.1	Introduction	175
11.2	Potential yield	176
11.2.1	Constant recruitment	178
11.2.2	Recruitment varying with stock size	179
11.3	Stock status	183
11.3.1	Constant recruitment	183
11.3.2	Recruitment varying with stock size	184
11.4	Caveats	185
11.5	Assessing stock status	186
11.6	Concluding remarks	186
<b>12.</b>	<b>Managing fishing effort in multispecies fisheries</b>	<b>189</b>
12.1	Introduction	189
12.2	Some key findings from the study	189
12.3	Guidelines for data collection and management of multispecies fisheries	190
12.3.1	Data collection	190
12.3.2	Summary of biological guidelines for management	191
12.3.3	Rules of thumb for evaluating the status of key species and management response	192
<b>13.</b>	<b>Bayesian stock assessment of the namibian orange roughy (<i>Hoplostethus atlanticus</i>) fishery</b>	<b>195</b>
13.1	Introduction	195

---

13.2	Namibian orange roughy: biology, exploitation and scientific research	196
13.3	Initiation of the fishery and stock assesement of Namibian orange roughy	196
13.4	The 1999 revised Bayesian stock assesement procedure for Namibian orange roughy	198
13.5	Some key features of this application	200
13.6	Results	202
13.7	Discussion	208
<b>14.</b>	<b>Empirical modelling approaches</b>	<b>211</b>
14.1	A simple model to predict potential yield from catch time series	211
14.2	Empirical multispecies yield models	213
14.2.1	Models based upon habitat variables	213
14.2.2	Models incorporating fishing effort	214
14.3	Multivariate models	218
14.3.1	The general linear model approach	223
14.3.2	Bayesian Network (BN) models	228
	Annexes	237
<b>15.</b>	<b>References</b>	<b>247</b>

# Foreword

Fishery analysts require stock assessment tools to provide advice to managers but may be constrained in choosing the best tools by the difficulty in identifying the real benefits and costs of the alternative options. This guide attempts to help stock assessment advisors (and in some countries the managers themselves) to choose appropriate tools for their needs. It focuses particularly on a suite of products developed by the Fisheries Management Science Programme (FMSP) of the UK Department for International Development (DFID, previously known as ODA).

The FMSP was established by DFID to generate improved livelihood benefits for poor people through the application of new knowledge in both capture and enhancement fisheries. Since its creation in 1992, the FMSP has produced a series of outputs on the assessment and management of exploited fish stocks. These outputs range from new methods and software for assessing fish stocks and providing guidance to fishery managers, to applied research on specific country fisheries. The first FMSP software packages (LFDA and CEDA) were developed in the early 1990s and have already been used by an estimated 150 fishery scientists in developing countries. FMSP projects have been undertaken by many different scientists, usually involving collaborations between United Kingdom and developing country researchers and managers. Much of the output has already been disseminated by the individual projects, e.g. at symposia, in journal papers, via collaborating country institutions and so on. Many of the technical reports and papers from the projects are available on the FMSP web site (<http://www.fmsp.org.uk/>), maintained by the programme manager MRAG Ltd.

This document attempts to synthesize the various FMSP tools, guidelines and other outputs into a single, integrated guide about stock assessment as it relates to fishery management. The materials included in the document originate from over twenty FMSP projects (see list below), out of the total of 48 carried out since 1992. Other FMSP projects have focused on a range of topics including floodplain river and reservoir fisheries ecology; fish aggregating devices; economics and management of foreign fisheries in Exclusive Economic Zones (EEZs); prawn fisheries enhancement; and the understanding of fisheries livelihoods.

The framework presented here integrates the need for precautionary and adaptive management processes and, as such is compatible with (and partly derived from) the management framework currently promoted by FAO (FAO, 1997; Cochrane, 2002a). Much of the same terminology is deliberately adopted. It is designed to support the new paradigm of precautionary management as described in the Code of Conduct for Responsible Fisheries (FAO, 1995a, 1996) and the 1995 UN "Fish Stocks Agreement", which entered into force in 2001. This guide attempts to facilitate and support the implementation of these instruments by describing the range of possible stock assessment approaches that may be used to feed information into the management process, and by providing some tested tools for their application.

While attempts are made to describe the alternative possible routes that stock assessments may follow, it is stressed that fish stock assessment is a complex and much studied field, with many variants of the different models available and in use around the world. This manual does not attempt to describe all the possible approaches, but instead aims to describe the FMSP tools that have been developed within an overall framework of the options available. Elementary comparisons are made with some of the other software packages that have been produced. The details of the mathematics involved in different approaches is mostly left to the help files available for each of the

different FMSP software, included on the companion CD-ROM. It is assumed therefore that readers will have at least a basic understanding of the alternative stock assessment techniques and fisheries models and their operation. Further details on the mathematics and assumptions behind the different methods may be found in fisheries textbooks such as Gulland (1983), Hilborn and Walters (1992), Sparre and Venema (1998), Quinn and Deriso (1999) and Cadima (2003).

### List of FMSP projects covered in this guide

- R4517 Development of Computer Aids for Fish Stock Assessment and Management Policy
- R4823 Guidelines for harvesting species of different lifespans
- R5030 Synthesis of simple predictive models for river fish yields in major tropical rivers
- R5050CB Computer Aids in fish stock assessment - Field development
- R5484 Analysis of Multispecies Tropical Fisheries
- R5953 Fisheries Dynamics of Modified Floodplains in Southern Asia
- R5958 Culture fisheries assessment methodology
- R6178 Synthesis of simple predictive models for fisheries in tropical lakes
- R6436 The performance of Customary Marine Tenure (CMT) in the management of community fishery resources in Melanesia
- R6437 Management strategies for new or lightly exploited fisheries in developing countries
- R6465 Growth parameter estimation and the effect of fishing on size composition and growth of snappers and groupers: implications for management - Phase I and II
- R6494 Evaluation of the biological and socio-economic benefits of enhancement of floodplain fisheries
- R7040 Strategic assessment of tropical coastal fisheries management
- R7041 Software for estimating potential yield under uncertainty
- R7042 Information systems for co-management of artisanal fisheries
- R7043 Selection criteria and co-management guidelines for harvest reserves in tropical river fisheries
- R7335 Adaptive learning approaches to fisheries management
- R7521 Implementing management guidelines arising from project R6465 - an assessment of utility in the BIOT inshore fishery
- R7522 The potential for improved management performance with fully age-based stock assessments: Extension of the management strategy simulations to incorporate age-based assessments
- R7834 Interdisciplinary multivariate analysis (IMA) for adaptive co-management
- R7835 Investigation of the implications of different fish life history strategies on fisheries management
- R7947 Integrated fisheries management using Bayesian multi-criterion decision making
- R8210 The use of sluice gates for stock enhancement and diversification of livelihoods
- R8285 Fisheries data collection and sharing mechanisms for (co-) management.
- R8292 Uptake of adaptive learning approaches for enhancement fisheries

# Symbols and abbreviations

Note: A **glossary** is not provided with this publication. Readers are instead invited to refer to the glossary given by Cochrane (2002a), which uses much of the same terminology (see <http://www.fao.org/DOCREP/005/Y3427E/y3427e0c.htm#bm12>). The detailed FAO Fisheries Department glossary is also available at <http://www.fao.org/fi/glossary/default.asp>.

## Symbols

$a$	Coefficient in the length-weight relationship
$a$	In Chapter 11, used as a constant “multiplier”, conditional on one or more other parameters, e.g. $a(L_c)$ ; $a(L_c, b)$
$b$	Power in the length-weight relationship
$B$	Biomass
$B_0$	Biomass at start of exploitation (sometimes assumed equal to $K$ )
$B_{inf}$	Carrying capacity or unexploited biomass (i.e. $K$ ), as used in ParFish
$B_{now}$	Current biomass (as used in chapters 1-5) or current biomass as a proportion of the unexploited biomass, $K$ (as used in the ParFish chapter 9)
$C$	Catch, in number
$C$	Oscillation amplitude in seasonal VBGF, as used in LFDA
$f$	Fishing effort
$F$	Instantaneous coefficient of fishing mortality
$F_{eq}$	Fishing mortality rate, estimated by methods assuming equilibrium conditions over age and time
$F_{now}$	Current fishing mortality rate
$F_{ny}$	Next year’s fishing mortality rate
$h$	Density dependence or steepness in the Beverton and Holt SRR, as used in “Yield” and Beverton-Holt “invariant” methods
$K$	Growth rate of individual fish, as in the von Bertalanffy growth model
$K$	Carrying capacity or unexploited biomass, as in biomass dynamic models
$l$	Total length of an individual
$l_c$	Smallest length fully represented in sample (in Beverton-Holt $Z$ estimator, used in LFDA, etc.); mean length at first capture in “Yield”
$L_c$	Knife-edged length at first capture, as a proportion of $L_\infty$ , as used in “Beverton-Holt invariants” methods (in Section 4.2, Chapter 11)
$L_{c50}$	Length at which 50 percent of fish are captured (selected) by the fishery (in Chapters 10 and 11)
$l_m$	Mean length at maturity, as used in “Yield”
$L_m$	Knife-edged length at first maturity, as a proportion of $L_\infty$ , as used in “Beverton-Holt invariants” methods (in Section 4.2, Chapter 11).
$L_{m50}$	Length at which 50 percent of fish reach first maturity
$L_\infty$	Asymptotic length towards which fish grow, according to the VBGF
$M$	Instantaneous coefficient of natural mortality
$N$	Number of individuals remaining in a cohort in depletion models, as in CEDDA, etc.
$q$	Catchability coefficient (proportion of the stock taken by one unit of fishing effort; also the constant of proportionality between $f$ and $F$ )
$r$	Intrinsic population growth rate in biomass dynamic models (in CEDDA, etc.)

$R^2$	Statistical coefficient of determination (or $R$ -squared)
$R$	Recruitment to the exploitable phase
$RY$	Replacement yield, i.e. that would maintain stock size at its current level, as estimated by CEDA
$S$	Stock size (numbers or biomass)
$t$	Age (usually measured in years, but may be days or weeks for fast growing species)
$t_c$	Mean age at first capture, in “Yield”
$T_{c50}$	Age at which 50 percent of fish are captured (selected) by the fishery (in Chapter 10)
$t_m$	Mean age at maturity, in “Yield”
$T$	Ambient temperature in the Pauly (1980) natural mortality equation
$t_0$	Theoretical age ( $t$ ) at zero length according to the VBGF
$t_s$	Winter point in seasonal VBGF
$W$	Individual weight
$X$	Proportional escapement (in Section 4.5.3)
$Y$	Yield or catch in weight
$Z$	Instantaneous coefficient of total mortality
$z$	Shape parameter in Pella-Tomlinson DRP model used in CEDA

### Technical reference points

$B_{LOSS}$	Biomass at the lowest historically observed spawning stock size
$B_{MSY}$	Biomass that would produce the MSY
$F_{0.1}$	$F$ at which the slope of the YPR curve is 10 percent of its slope at the origin (also $F_{0.2}$ , $F_{0.x}$ etc)
$F_{\%SPR}$	$F$ that reduces SPR to the specified percentage of its level in an unfished stock
$F_{\%SSB}$	$F$ that reduces SSB to the specified percentage of its level in an unfished stock, as estimated in “Yield”
$F_{\%FB}$	$F$ that reduces the fishable biomass (FB) to the specified percentage of its level in an unfished stock, as estimated in “Yield”
$F_{crash}$	The point on an equilibrium yield curve at which both the biomass and the catches are reduced to zero
$F_{LOSS}$	$F$ associated with the lowest historically observed spawning stock size
$F_{low}$	Like $F_{med}$ , the $F$ corresponding to the 10 <sup>th</sup> percentile of the observed points
$F_{high}$	Like $F_{med}$ , the $F$ corresponding to the 90 <sup>th</sup> percentile of the observed points
$F_{max}$	$F$ giving the maximum YPR in a dynamic pool model (also $F_{maxYPR}$ ); in Chapter 11, $F_{max}$ as used in the variable recruitment model is equivalent to $F_{MSY}$
$F_{med}$	$F$ corresponding to a SSB/ $R$ equal to the inverse of the 50 <sup>th</sup> percentile of the observed $R/SSB$ (in Section 3.5.3)
$F_{MSY}$	$F$ that would produce the MSY
$F_{\tau}$ ( $F$ -tau)	$F$ corresponding to the slope of the SRR at the origin (equivalent to $F_{crash}$ )
$F_{transient}$	$F$ giving a specified probability that the %SSB will fall below a specified level during a forward projection of $x$ years, as predicted by the “Yield” software
MBAL	Minimum biologically acceptable level, of spawning stock size, required to avoid recruitment overfishing, as observed in plots of SR data
MEY	Maximum economic yield
MSY	Maximum sustainable yield
$B_{50\%R}$	Biomass at which recruitment is 50 percent of the maximum predicted in a SRR

**Conceptual reference points (used in defining control rule frameworks)**

$B_{lim}$	Biomass associated with the LRP
$B_{pa}$	Precautionary biomass reference point, usually set above $B_{lim}$ according to measured uncertainty and agreed risk tolerance (equivalent to NAFO's $B_{buf}$ and ICCAT's $B_{thresh}$ )
$F_{lim}$	Fishing mortality rate associated with the LRP
$F_{pa}$	Precautionary fishing mortality reference point, usually set below $F_{lim}$ according to measured uncertainty and agreed risk tolerance
LRP	Limit reference point
PRP	Precautionary reference point
TRP	Target reference point

**Other abbreviations**

BPR	Biomass per recruit
CBD	Convention on Biological Diversity
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEDA	FMSP Catch and Effort Data Analysis software
CI	Confidence interval
DFID	Department for International Development of the UK government
DRP	Deterministic recruitment/production models, e.g. Schaefer, Fox models etc., as fitted in CEDA software
ELEFAN	Pauly's (1987) length-based growth rate estimator, as used in LFDA, FiSAT, etc.
FiSAT II	FAO-ICLARM stock assessment tools software
FMSP	Fisheries Management Science Programme of DFID
ICCAT	International Commission for the Conservation of the Atlantic Tunas
ICES	International Council for the Exploitation of the Sea
ICLARM	International Center for Living Aquatic Resources Management
IPOA	International Plans of Action
ITQ	Individual transferable quota (the right to a share of an annual catch quota)
IUU	Illegal, Unreported and Unregulated Fishing
LFDA	FMSP Length Frequency Distribution Analysis software
MEY	Maximum Economic Yield
MPA	Marine Protected Area
MSY	Maximum Sustainable Yield
NAFO	Northwest Atlantic Fisheries Organization
ParFish	FMSP Participatory Fisheries stock assessment software
PROJMAT	Projection matrix method of fitting VBGF, as used in LFDA
SLCA	Shepherd's length composition analysis, as used in LFDA
SRR	Stock-recruitment relationship
SSB	Spawning stock biomass
SSBPR	Spawning stock biomass per recruit (or SSB/R)
SPR	Spawning products per recruit
%SPR	SPR as a percentage of the level that would occur in an unfished stock
TAC	Total allowable catch
TURF	Territorial use rights in fisheries
UNCED	United Nations Conference on Environment and Development
UNCLOS	United Nations Convention on the Law of the Sea
VBGF	von Bertalanffy growth function
VPA	Virtual population analysis
WSSD	World Summit on Sustainable Development
YPR	Yield per recruit