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Stock assessment for fishery management

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

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

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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.

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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.

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Contents

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. $a(L_c)$; $a(L_c, h)$
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 propertie 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_∞, 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_∞, 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_∞	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 CEDA, 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 CEDA, 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^{th} percentile of the observed points
F_{high}	Like F_{med}, the F corresponding to the 90^{th} 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^{th} percentile of the observed R/SSB (in Section 3.5.3)
F_{MSY}	F that would produce the MSY
F_{τ} (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 Atantic 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