© Copyright Commonwealth Scientific and Industrial Research Organisation
('CSIRO') Australia 2007

All rights are reserved and no part of this publication covered by copyright may be reproduced or copied in any form or by any means except with the written permission of CSIRO.

The results and analyses contained in this Report are based on a number of technical, circumstantial or otherwise specified assumptions and parameters. The user must make their own assessment of the suitability for its use of the information or material contained in or generated from the Report. To the extent permitted by law, CSIRO excludes all liability to any party for expenses, losses, damages and costs arising directly or indirectly from using this Report.

Tuck, Geoffrey N. (Geoffrey Neil).

Stock assessment for the southern and eastern scalefish and shark fishery : 2006 - 2007. Vol. 1, 2006 / G. N. Tuck.

ISBN 978-1-921424-29-8 (Volume 1)

1. Fish stock assessment - Australia, Southeastern.
2. Shark fisheries - Australia, Southeastern.
3. Fisheries - Australia, Southeastern.
I. CSIRO. Marine and Atmospheric Research.
II. Australian Fisheries Management Authority.

333.9560994

Preferred way to cite this report

Tuck, G.N. (ed.) 2007. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2006-2007. Volume 1: 2006. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 570 p.

Acknowledgements

All authors wish to thank the science, management and industry members of the slope, shelf, deepwater, GAB and shark resource assessment groups for their contributions to the work presented in this report. Authors also acknowledge support from CAF (for fish aging data), ISMP (for the on-board and port length-frequencies) and AFMA (in particular John Garvey, for the log book data). Leonie Wyld and Louise Bell are also greatly thanked for their assistance with the production of this report and Bruce Barker for the cover photographs of SESSF fish.

Cover photographs

Front cover, from left: blue-eye trevalla (top), deepwater flathead, orange roughy, jackass morwong, blue-eye trevalla, pink ling

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2006-2007

Volume 1: 2006

G.N. Tuck
December 2007
Report 2006/813

Australian Fisheries Management Authority

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2006-2007

TABLE OF CONTENTS

1. NON-TECHNICAL SUMMARY 1

1.1 OUTCOMES ACHIEVED 1
1.2 GENERAL 1
1.3 SLOPE SPECIES 3
1.4 SHELF SPECIES 6
1.5 DEEPWATER SPECIES 8
1.6 GREAT AUSTRALIAN BIGHT SPECIES 9
1.7 SHARK SPECIES 9

2. BACKGROUND 12

3. NEED 13

4. OBJECTIVE 13

5. COMPARISON OF SEF1 AND SEF2 CATCHES FOR SESSF SPECIES TO 2005 14

Malcolm Haddon 14

5.1 INTRODUCTION 14

6. STANDARDIZED COMMERCIAL CATCH-EFFORT DATA FOR SELECTED SHELF AND SLOPE ASSESSMENT GROUP SPECIES FOR 1986 - 2005 31

Malcolm Haddon 31

6.1 INTRODUCTION 31
6.2 GENERAL METHODS 32
6.3 RESULTS 35
6.4 DISCUSSION 84
6.5 REFERENCES 84

7. NATURAL MORTALITY VALUES USED FOR SESSF SPECIES 85

Jemery Day 85

7.1 NATURAL MORTALITY VALUES 85
7.2 REFERENCES 89

8. UPDATED STOCK ASSESSMENT FOR BLUE GRENADIER (*MACRURONUS NOVAEZELANDIAE)* IN THE SOUTHERN AND EASTERN SCALEFISH AND SHARK FISHERY BASED ON DATA UP TO 2005: JULY 2006 91

Geoffrey N. Tuck 91

8.1 INTRODUCTION 91
8.2 THE FISHERY 91
8.3 RESULTS AND DISCUSSION 100
8.4 ACKNOWLEDGEMENTS 104
8.5 REFERENCES 104

9. UPDATED STOCK ASSESSMENT OF BLUE GRENADIER (*MACRURONUS NOVAEZELANDIAE)* BASED ON DATA UP TO 2005: APPLICATION OF NEW BASE-CASE MODELS, HARVEST CONTROL RULES AND DECISION ANALYSIS 118

Geoffrey N. Tuck and André E. Punt 118

9.1 SUMMARY 118
9.2 INTRODUCTION 119
9.3 THE FISHERY 119
9.4 DATA 120
9.5 ANALYTIC APPROACH 127
9.6 RESULTS AND DISCUSSION 129
9.7 ACKNOWLEDGEMENTS 137
9.8 REFERENCES 138
9.9 FIGURES 139
9.10 APPENDIX: THE POPULATION DYNAMICS MODEL AND LIKELIHOOD MODEL 153

10. BLUE WAREHOU CATCHES WITHIN THE INDUSTRY SURVEY STRATA 159

Malcolm Haddon 159

10.1 INTRODUCTION 159
10.2 METHODS 159
10.3 RESULTS 161
10.4 DISCUSSION 164
10.5 REFERENCE 165

11. FURTHER ANALYSIS OF THE BLUE WAREHOU INDUSTRY SURVEY 166

Malcolm Haddon 166

11.1 INTRODUCTION 166
11.2 METHODS 166
11.3 EDEN 168
11.4 HORSE SHOE STRATUM 172
11.5 MAIN DRAG 176
11.6 PORT MACDONNELL 179
11.7 APPENDIX 1. STRATUM DEFINITIONS 182
11.8 APPENDIX 2. SHOT BY SHOT DATA (VESSEL NAMES OMITTED) 183
11.9 APPENDIX 3. R CODE FOR ANALYSES (BWSURVEY_STAND.R). 185

12. UPDATED STOCK ASSESSMENT OF BLUE WAREHOU (*SERIOLELLA BRAMA*) BASED ON DATA UP TO 2006 187

André E. Punt 187

12.1 SUMMARY 187
12.2 BACKGROUND AND FISHERY 187
12.3 DATA AVAILABLE FOR ASSESSMENT PURPOSES 189
12.4 STOCK ASSESSMENT METHOD 203
12.5 RESULTS AND DISCUSSION 205
12.6 FURTHER WORK 218
12.7 ACKNOWLEDGEMENTS 219
12.8 REFERENCES 219
12.9 APPENDIX A: COMPARISON OF ASSESSMENT MODELS BASED ON THE DATA USED FOR THE 2005 ASSESSMENT 231
12.10 APPENDIX B: FITS TO THE LENGTH-FREQUENCY DATA 236

13. ADDENDUM: UPDATED STOCK ASSESSMENT OF BLUE WAREHOU (*SERIOLELLA BRAMA*) BASED ON DATA UP TO 2006 239

André E. Punt 239

14. UPDATED STOCK ASSESSMENT OF PINK LING (*GENYPTERUS BLACODES*) IN THE SOUTH EAST FISHERY, AUGUST 2006 241

Bruce Taylor 241

14.1 SUMMARY 241
14.2 METHOD 241
14.3 RESULTS AND DISCUSSION 243
14.4 ACKNOWLEDGEMENTS 244
14.5 REFERENCES 245

15. 2006 ASSESSMENT REPORT FOR SPOTTED WAREHOU 264

Bruce Taylor 264

16. STOCK ASSESSMENT OF JACKASS MORWONG (*NEMADACTYLUS MACROPTERUS*) AND RBC CALCULATIONS FOR 2007 USING DATA UP TO 2005 265

Gavin Fay 265

16.1 SUMMARY 265
16.2 BACKGROUND 266
16.3 DESCRIPTION OF ASSESSMENT UPDATE 267
16.4 ANALYTICAL APPROACH 268
16.5 RESULTS AND DISCUSSION 269
16.6 REFERENCES 272
16.7 APPENDIX A: COMPARISON OF CPUE STANDARDISATION METHODS FOR JACKASS MORWONG 282

17. SMALL SHOTS AND RELATED CPUE SERIES FOR JACKASS MORWONG (*NEMADACTYLUS MACROPTERUS*) 2006 286

Jemery Day 286

17.1 REFERENCES 295

18. UPDATED STOCK ASSESSMENT FOR SILVER TREVALLY (*PSEUDOCARANX DENTEX)* IN THE SOUTH EAST FISHERY: AUGUST 2006 296

Jemery Day, Kevin Rowling and André E. Punt 296

18.1 SUMMARY 296
18.2 INTRODUCTION 297
18.3 METHODS 299
18.4 RESULTS 301
18.5 DISCUSSION 304
18.6 ACKNOWLEDGEMENTS 304
18.7 REFERENCES 304
18.8 TABLES 306
18.9 FIGURES 307

19. UPDATED STOCK ASSESSMENT OF TIGER FLATHEAD (*NEOPLATYCEPHALUS RICHARDSONI*) BASED ON DATA UP TO 2005 320

Neil L. Klaer 320

19.1 BACKGROUND 320
19.2 DATA AVAILABLE FOR ASSESSMENT PURPOSES 322
19.3 ANALYTICAL FRAMEWORK 330
19.4 RESULTS 331
19.5 FUTURE WORK 344
19.6 ACKNOWLEDGEMENTS 344
19.7 REFERENCES 345

20. REVISED STANDARDIZED CATCH-RATE SERIES FOR SCHOOL AND GUMMY SHARK BASED ON DATA UP TO 2005 346

André E. Punt and Anne S. Gason 346

20.1 ABSTRACT 346
20.2 INTRODUCTION 346
20.3 METHODOLOGY 347
20.4 RESULTS AND DISCUSSION 348
20.5 REFERENCES 353

21. UPDATED STOCK ASSESSMENT OF GUMMY SHARK (*MUSTELUS ANTARCTICUS*) BASED ON DATA UP TO 2005 364

André E. Punt, Fred Pibac, Terence I. Walker and Anne S. Gason 364

21.1 ABSTRACT 364
21.2 INTRODUCTION 364
21.3 DATA 365
21.4 ANALYTICAL APPROACH 367
21.5 RESULTS AND DISCUSSION 369
21.6 FUTURE WORK 383
21.7 REFERENCES 384

22. IMPLICATIONS OF A CHANGE TO THE MIX OF GEAR-TYPES USED WHEN FISHING FOR GUMMY SHARK 394

André E. Punt and Terry I. Walker 394

22.1 RBCS FOR GUMMY SHARK 394
22.2 IMPACT OF THE BY-CATCH OF SCHOOL SHARK 396

23. STOCK ASSESSMENT OF SCHOOL SHARK BASED ON DATA UP TO 2005 398

André E. Punt, Fred Pibac, Terence I. Walker, and Anne S. Gason 398

23.1 ABSTRACT 398
23.2 INTRODUCTION 398
23.3 METHOD 399
23.4 RESULTS AND DISCUSSION 400
23.5 REFERENCES 403

24. A NOTE REGARDING THE SENSITIVITY OF THE SCHOOL SHARK ASSESSMENT TO THE LAST YEAR FOR WHICH CATCH-RATE DATA ARE USED 410

André E. Punt 410

24.1 REFERENCES 410

25. STOCK ASSESSMENT OF THE CASCADE PLATEAU ORANGE ROUGHY 2006 411

Sally Wayte and Nic Bax 411

25.1 SUMMARY 411
25.2 INTRODUCTION 412
25.3 METHODS 414
25.4 THE ASSESSMENT MODEL 420
25.5 RESULTS 420
25.6 DISCUSSION AND CONCLUSIONS 425
25.7 ACKNOWLEDGEMENTS 426
25.8 REFERENCES 426
25.9 APPENDIX: COMPARISON OF PREVIOUS MODEL WITH SS2 428

26. EASTERN ZONE ORANGE ROUGHY **429**

Sally Wayte *429*

26.1 INTRODUCTION 429
26.2 METHODS 430
26.3 RESULTS 440
26.4 DISCUSSION AND CONCLUSIONS 446
26.5 ACKNOWLEDGEMENTS 447
26.6 REFERENCES 447

27. UPDATED STOCK ASSESSMENT FOR DEEPWATER FLATHEAD (*NEOPLATYCEPHALUS CONATUS*) AND BIGHT REDFISH (*CENTROBERYX GERRARDI*) IN THE GREAT AUSTRALIAN BIGHT TRAWL FISHERY USING DATA TO JUNE 2006 **448**

Neil L. Klaer and Jemery Day *448*

27.1 BACKGROUND 448
27.2 DATA AVAILABLE FOR ASSESSMENT PURPOSES 450
27.3 ANALYTICAL FRAMEWORK 458
27.4 RESULTS 459
27.5 FUTURE WORK 472
27.6 ACKNOWLEDGEMENTS 472
27.7 REFERENCES 472

28. YIELD AND TOTAL MORTALITY VALUES AND TIER 3 ESTIMATES FOR SELECTED SHELF AND SLOPE SPECIES IN THE SOUTH EAST FISHERY **474**

Neil L. Klaer and Robin B. Thomson *474*

28.1 INTRODUCTION 474
28.2 METHODS 474
28.3 RESULTS 479
28.4 TIER 3 CALCULATIONS 493
28.5 ACKNOWLEDGEMENTS 496
28.6 REFERENCES 496
28.7 APPENDIX: DETAILED CATCH CURVE RESULTS 498

29. TIER 3 CALCULATIONS FOR BLUE EYE TREVALLA *(HYPEROGLYPHE ANTARCTICA)* USING DATA UP TO AND INCLUDING 2005 **520**

Gavin Fay *520*

29.1 SUMMARY 520
29.2 DATA 520
29.3 ESTIMATION METHODS 521
29.4 CURRENT ESTIMATE OF Z 521
29.5 VALUES FOR M 522
29.6 TIER 3 MULTIPLIERS 523
29.7 DISCUSSION 523
29.8 REFERENCES 524

30. SCHOOL WHITING CATCH CURVES 2006 **528**

Mark Bravington, David Peel and Neil L. Klaer *528*

30.1 SUMMARY OF MULTI-YEAR CATCH CURVE METHOD 528
30.2 STEPS IN FITTING SCHOOL WHITING 529

31. TIER 4 ANALYSES 1994 - 2005 **534**

Malcolm Haddon *534*

31.1 INTRODUCTION 534
31.2 METHODS 535
31.3 RESULTS 535
31.4 DISCUSSION 535
31.5 WESTERN GEMFISH 536
31.6 INSHORE OCEAN PERCH (<=200 M DEPTH) 537
31.7 OFFSHORE OCEAN PERCH (> 200M DEPTH) 539
31.8 BLUE WAREHOU (EAST) 540
31.9 REDFISH 542
31.10 SILVER TREVALLY 543
31.11 FLATHEAD 545
31.12 BLUEEYE 546
31.13 JACKASS MORWONG 548
31.14 ROYAL RED PRAWN 549
31.15 PINK LING (EAST) 551
31.16 PINK LING (WEST) 552
31.17 REFERENCE 553

32. TIER 4 HARVEST CONTROL RULE APPLIED TO DEEPWATER SPECIES **554**

Sally Wayte *554*

32.1 INTRODUCTION 554
32.2 TIER 4 554
32.3 SUGGESTED INTERIM MODIFICATIONS FOR 2006 555

33. BENEFITS **565**

34. CONCLUSION **566**

35. APPENDIX A - INTELLECTUAL PROPERTY **569**

36. APPENDIX B – STAFF **570**

1. Non-Technical Summary

Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery: 2006

PRINCIPAL INVESTIGATOR: Dr Geoffrey N. Tuck

ADDRESS: CSIRO Marine and Atmospheric Research
GPO Box 1538
Hobart, Tasmania 7001
Australia
Telephone: 03 6232 5222 Fax: 03 6232 5053

OBJECTIVE:

- Provide quantitative and qualitative species assessments in support of the five SESSFAG resource assessment groups.

1.1 Outcomes Achieved

The 2006 assessments of stock status of the key Southern and Eastern Scalefish and Shark fishery species are based on the methods presented in this report. Documented are the latest quantitative assessments for key SESSF quota species. Typical assessment results provide indications of current stock status, in addition to an application of the recently introduced Commonwealth fishery harvest control rules that determine a Recommended Biological Catch (RBC). These assessment outputs are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SESSFRAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

1.2 General

Yield and Total Mortality Estimates

This chapter provides yield and total mortality estimates for major commercial fish species from the shelf and slope in the South East Fishery. Yield estimates are made using a yield-per-recruit model with the following input: selectivity-at-age, length-at-age, weight-at-age, age-at-maturity, and natural mortality. Total mortality values corresponding to various reference equilibrium biomass depletions were calculated for each species.

Recent average total mortality was estimated from catch curves constructed from length frequency information. Length frequency data were from three sources: the NSW Sydney Fish Market measurement program; the Kapala slope cruises of 1976/77 and 1996/97; and the ISMP port measurement data.

Tier 3 calculations use the estimates of total mortality, natural mortality and average recent catches to decide the Recommended Biological Catch (RBC) for next year. Methods detailed elsewhere were used to calculate total mortality rates for school whiting and blue-eye. Tier 3 RBC values for flathead, redfish, morwong, blue warehou, school whiting, ling, blue grenadier and blue-eye were all less than recent average catches. Tier 3 RBC values for spotted warehou and John dory and mirror dory were greater than recent average catches. Due to probable dome-shaped selectivity for silver trevally caught by trawl, it has been recognized that simple catch curve methods as these should not be applied to that species.

Catch rate standardisation

Catch-per-unit-effort (CPUE) data is an important input to many of the stock assessments conducted within the South East and Southern Shark Fishery (SESSF) where it is used as an index of relative abundance through time. The catch and effort log-book data from the SESSF, which is the source of CPUE data, derives from a wide range of vessels, areas (zones), months, depths, and fishing gears. The catch rates used in the assessments are standardized to reduce the effects of factors such as which vessel fished, where and when fishing occurred, what gear was used, did fishing occur during the day or night. The intent is to focus on any changes in catch rates that occurred between years as a result of changes in stock size rather than changes brought about by any of these other factors.

Catch rates, generally as kilograms per hour fished, were natural log-transformed to normalize the data and stabilize the variance. The statistical models were subsets of the form: LnCE = Year + Vessel + Month + DepthCategory + Zone + Daynight. For some fisheries weeknumber or gear type was also included as were the categorized relative catch levels of associated species. Generally, only those vessels which had been active in each fishery for more than two years were included in the analysis and often a restriction focusing on vessels that had captured more than some minimum annual catch were included (for example median annual catches greater than 1 tonne. This was used as a preliminary data selection to focus attention on those vessels contributing significantly to each fishery.

The catch rates for 18 different stocks or fisheries for eight different species were analysed including Silver Trevally, Flathead, Redfish, Blue Warehou, Blue Grenadier, Blue Eye, Jackass Morwong, and Spotted Warehou. The statistical package SAS 9.0 was used for all analyses.

The standardization generates a set of yearly coefficient that represent the catch rate relative to some selected reference year. Unfortunately, even if the standardization accounts for a large proportion of the variability in the data there are no guarantees that

catch effort, even standardized catch effort, can act as a good proxy for stock size. Instead of the statistical success of the standardization, one should be able to argue from the nature of the fishery and the species concerned whether or not there is likely to be even an approximate relationship between catch rates and stock size.

Tier 4 Harvest Control Rule

The TIER4 assessments are empirical rule based assessments based on trends in catch rates and catches, where the catches include all Commonwealth catches as well as State catches and discards. The TIER 4 analysis considers the gradient in catch rates over the previous four years and adjusts the recommended biological catch accordingly, increasing the RBC if the gradient is positive and decreasing it if it is negative.

A total of twelve analyses were completed on eleven different species: Western Gemfish, Inshore Ocean Perch, Offshore Ocean Perch, Blue Warehou, Redfish, Silver Trevally, Flathead, Blue Eye, Jackass Morwong, Royal Red Prawn, and Pink Ling.

The TIER4 analyses are designed for those species for which available data is limited; their outcomes should be more precautionary than those possible from higher TIER analyses.

1.3 Slope Species

Blue Grenadier

Blue grenadier (*Macruronus novaezelandiae*) are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Blue grenadier are caught by demersal trawling. The global agreed TAC in 2006 was 3730 tonnes, down from 4200t in 2005 (which includes a voluntary industry reduction of 800t), 7000t in 2004, 9000t in 2003 and 10000t the previous year, the level at which it had been since 1994. There are two defined sub-fisheries: the winter spawning fishery off Tasmania and the non-spawning fishery (all other areas and times). The non-spawning fishery catches have been relatively consistent over the last few years (at just under 2000t), whereas the spawning fishery catches showed a marked increase during the mid-1990s before decreasing from 2003. The spawning and non-spawning fishery catches are currently at similar levels.

The 2006 assessment of blue grenadier uses the age-structured integrated analysis model developed during 1998 and 1999. The model uses catch (including discards), standardised catch rates and catch-at-age data as well as estimates of absolute abundance based on the egg production method and acoustic biomass estimates. The new base-case model established in 2005 was applied. The base-case for blue grenadier uses the base-case egg estimates, lower acoustic estimates and 2-times turnover. In addition, as new information has become available on blue grenadier breeding biology, the sensitivity to these changes was considered. Following these sensitivity tests, the new biological parameters were adopted by SlopeRAG for the base-case parameter set.

Due to the large differences in magnitude of the estimates of spawning biomass from the acoustic surveys, two models of biological status were explored. These models apply

1) the higher estimates of spawning biomass from the acoustic surveys (Macauley, 2004) and double the egg survey estimates. This model is referred to as the High model.

2) the lower estimates of spawning biomass from the acoustic surveys (Cordue, 2000) and the base-case egg survey estimates of female spawning biomass. This model is referred to as the Low model.

The integrated analysis model for blue grenadier was updated by the inclusion of the 2005 calendar year data (catch, discard, age-composition, survey data, age-reading error). The cohort spawned in 1994 is estimated to be approximately 11 times the size predicted by the deterministic stock-recruit relationship. While an increase in recruitment is estimated by the model for years 2003 and 2004, these will not have been well estimated (as these fish have mostly not moved into the available population to any noticeable extent) and the real strength of these cohorts will need to be determined over the next few years.

Results conclude that the female spawning biomass in 2005 is around 40% of the reference biomass. However, not surprisingly, the magnitude of the biomass differs substantially between the two models (Low, High). This is reflected in the application of the harvest control rules, where the Recommended Biological Catches (RBCs) for 2007 are between 11,000 t and 18,000 t for the High model and between 2,000 t and 3,300 t for the Low model. The long-term RBCs also differ markedly; with RBCs of 20,000 t for the High model and 5,500 t for the Low model. Simulations showed that if the annual catch is fixed at the current TAC of 3,730 then, under the Low resource model, the depletion gradually rises to about 60% of the reference biomass in 10 years. For the High model, by 2016 the depletion is at or above 70% of the reference biomass.

Blue Warehou

The 2006 stock assessment of blue warehou (*Seriolella brama*) is based on there being two stocks of blue warehou off southern Australia (east and west of Bass Strait). The putative stock boundary was selected based on evidence from a variety of methods of identifying stock structure. The stock assessment is based on an age- and size-structured population dynamics model (Stock Synthesis 2, SS2) fitted to data on catches, catch-rates, survey indices of relative abundance, discard rates, age-length keys and length-frequency information. The assessment of the stock to the west of Bass Strait is based on a single trawl fishery while that of the stock to the east of Bass Strait is based on three fleets (trawl, non-trawl and Tasmanian meshnet). Uncertainty is quantified by conducting analyses by changing the assumptions of the assessment. Discards are treated differently for the two stocks because discarding in the east is primarily of small fish whereas the sizes of fish discarded in the west are very similar to those landed.

The Stock Synthesis 2 platform can be configured to produce results that are nearly identical to those on which the 2005 assessment was based. This indicates that changes in stock status between the 2005 and 2006 assessments are due primarily to changes in data inputs, although the change to the status of the western stock is also a consequence of the removal of a penalty on fishing mortality and the ability to estimate B_0 within rather than external to the assessment.

The results for the eastern stock are qualitatively identical to those from the 2004 and 2005 assessments; the stock is depleted to well below the target reference point and there is no evidence for a recovery. In contrast to the situation for the eastern stock, the western stock recovered from below the overfished threshold of $0.2B_0$ to close to the B_{MSY} proxy of $0.4B_0$ in 2005, but has declined since owing primarily to lack of good recruitment.

The model predicts that the western stock will drop below the overfished threshold by 2007 if the landed catches are as high as suggested by the industry members of SlopeRAG, and if recruitment is average. Under this projection, the Recommended Biological catch (RBC) for the western stock is 0 for 2007. However, under the base model, the ABC catches (a constant fishing mortality rate equal to the fishing mortality rate which leave the stock at the target level) are 151-195t for the western stock and 225-325t for the eastern stock. Moreover, given the short-lived nature of blue warehou, RBCs for 2008 are predicted to be non-zero for both stocks, although the actual magnitude of the 2008 RBC depends on future recruitment. The assessments, particularly that for the eastern stock, remain highly uncertain.

Blue eye Trevalla

Current rates of total mortality for blue eye trevalla (blue eye) are estimated using catch curve analyses, and RBC calculated under the tier 3 HCR. Analyses are limited to data up to 2005 from the longline sector of the fishery, although results of analyses that use dropline data, and apply multi-year catch curve analysis to the longline data are presented for comparison. Estimates of total mortality are generally consistent among estimation methods and the types of data included in the analyses. Under the assumption of a value of 0.08 yr^{-1} for the rate of natural mortality, calculated tier 3 multipliers to current catch range from 0.5 – 1.1, with lower multipliers (implying larger reductions in catch) being obtained when the catch curves are applied on an area-specific basis.

Pink Ling

The catch of pink ling (*Genypterus blacodes*) in 2005 was 1372 tonnes, divided between the east (508 t trawl, 260 t, non-trawl) and the west (245 t trawl, 360 t, non-trawl). An assessment of pink ling was attempted using Stock Synthesis 2 (SS2) assuming separate stocks in the east and west of the fishery. The data was updated to include 2005 data, catches from 1977-1984 and catch rates for the non-trawl fishery. It had also included length frequency data for years where no age length keys were available. This updated assessment includes estimates of growth parameters, use of conditional age at length

data, revised standardisation of catch rates, revised length at maturity and, in the east, the inclusion of data from Kapala surveys.

At the August 2006 meeting of SlopeRAG, members identified apparent inconsistencies between biomass trends and the history of the fishery that could not be immediately resolved. The assessment model was therefore considered to be not robust enough yet for use in the application of the Tier 1 harvest control rules. The application of Tier 3 rules was also rejected because of concerns about dome-shaped selectivity for the trawl fishery and the impact this has on estimates of fishing mortality. Tier 4 was therefore selected as the most appropriate Tier level for pink ling with the condition that the RBC calculations be made separately for east and west stocks.

In the absence of a robust assessment model, the main indicator that is relevant to the assessment of the status of pink ling is the standardised CPUE. In the west this shows a declining trend for both trawl and non-trawl sectors. In the east CPUE for the trawl sector has fallen to levels of about 60% of those observed in the mid-1980s, and for the non-trawl sector CPUE has recently fallen to the low levels previously observed in 2000.

1.4 Shelf Species

Silver Trevally

Silver trevally (*Pseudocaranx dentex*) occur in estuarine and near-shore ocean waters to a depth of about 100 m from southern Queensland to Western Australia. Catches from NSW, Victorian and Tasmanian waters were considered to be from a single stock for this assessment. Demersal fish trawling account for around half the catch reported, with the rest of the catch comprising fish trapping and line fishing in ocean waters, the use of hauling nets in estuarine waters and recreational fishing.

Catch data from 1985 was obtained from Commonwealth trawl logbooks and for a range of gear types in state waters. The total catch data shows a peak at around 1500t in 1990 with catches then averaging around 900t through until 1996 and declining further since 1998 to catches of around 500t per year. Data collected included catch at length data from Commonwealth trawl records and from NSW state fisheries data, a single year of catch at age data and a standardised CPUE series from commonwealth trawl records.

The 2006 silver trevally assessment is an update to the 2005 assessment (Day et al., 2005) including a transfer from the package Coleraine (Hilborn et al., 2000) to Stock Synthesis 2, or SS2, (Methot, 2006) and the inclusion of additional data. The 2006 assessment uses all catch data, starting from 1945. This assessment uses length based selectivity and a separate one fleet and a 4 fleet model. A base case assessment was constructed with length based selectivity assuming a single fleet, with some sensitivity analyses performed on key parameters. A four fleet model was also constructed.

Analyses of the 1 fleet model have shown that the model is sensitive to a number of key parameters and assumptions. In some scenarios, selectivity is narrow and biomasses are large, and with small changes in parameters, selectivity can be broad and biomasses can be small. This sensitivity has been seen in growth parameters, inclusion or exclusion of length frequency data and the year for the start of recruitment estimates. Difficulties were encountered in getting stable results with both the one fleet and the four fleet version of this model, with some runs giving quite pessimistic results and others giving unrealistic very large single recruitments, resulting in a very large biomass being fished down. While the results are very uncertain, the runs with very large biomasses appear to be less plausible than those with very small biomasses.

Tiger Flathead

The stock assessment for tiger flathead (*Neoplatycephalus richardsoni*) was migrated to stock synthesis 2 (SS2) for the 2006 assessment. To show the comparability of the new method, results from the 2005 assessment were largely duplicated using SS2. A number of differences were introduced into the 2006 assessment including separation of age and length frequency samples within the model, use of an automated SESSF data processing system to produce stock assessment input files and inclusion of estimates of discards for early catch by steam trawl.

The stock of tiger flathead off NSW and Eastern Bass Strait is estimated to be presently at 42% of unfished spawning stock biomass. If Tasmanian catches are included and Tasmania is treated as a separate fishing fleet the stock is estimated to be at 43% of unfished spawning stock biomass. The Recommended Biological Catch (including state catch and discards) for the combined stock including Tasmania was 2,903t for the 20:40:40 catch control rule and 2,245t using the 20:40:48 rule.

Jackass Morwong

The 2004 assessment of jackass morwong (*Nemadactylus macropterus*) in the eastern areas of the SESSF is updated to provide estimates of stock status in 2006. The age-structured stock assessment model was re-fit to take advantage of data that have become available since the last assessment. Changes to the 2004 assessment model include the addition of age and length composition data for 2003-2005, the updating of standardised CPUE indices for the otter trawl fleets for 1986-2005. As with the 2004 assessment, no consideration is made for discarding, or for catches from areas west of Tasmania.

The assessment results are sensitive to the data included when calculating the standardised CPUE indices. Base-case estimates of 2006 spawning depletion when the model is fit to the updated CPUE indicate that the stock is at low levels, around 15% of the unfished equilibrium state, leading to 2007 RBCs of zero under all tier 1 and tier 2 harvest control rules. When fit to the CPUE indices used in the previous assessment, estimates of current stock status are more optimistic, with 2006 spawning depletion estimated to be 35% of the unfished state. Analyses that fit to a new CPUE index from the ISMP data provide more optimistic estimates of current stock status, suggesting that the stock is slightly above 40% of the unfished spawning biomass. As with the 2004 assessment, model results are sensitive to the values used in the assessment for

steepness and the rate of natural mortality. For the base-case, the stock is assessed to be below the tier 1 and tier 2 target biomass values. 2007 RBCs using the 2004 CPUE range from 787–1,540 mt under tier 1, and from 337–677 mt under tier 2. Due to the sensitivity of the results to the standardised CPUE indices, it is of extreme importance to determine what CPUE data are representative of changes in relative abundance.

1.5 Deepwater Species

Orange Roughy

In the SEF there are 5 orange roughy management zones: Eastern, Southern, Western, Cascade Plateau and South Tasman Rise. The stock structure of orange roughy is uncertain with Southern Zone fish appearing to migrate to the Eastern Zone to spawn. Maatsuyker fish (western end of Southern zone) may be more closely associated with Western Zone fish although the evidence is not well documented or verified. Summer aggregations have been fished in the Western and Southern zones but only one large consistent winter spawning aggregation site for orange roughy has been discovered in the Eastern Zone (St Helens and St Patricks fishing grounds). Sporadic spawning is thought to occur in other zones. A small spawning stock has been fished on the Cascade Plateau and intermittently spawning fish have been taken on the South Tasman Rise. The Cascade Plateau and South Tasman Rise fish have been shown to be distinct stocks. South Tasman Rise is managed separately under a MOU with New Zealand. In 2006 assessments were performed for the Eastern Zone and Cascade Plateau orange roughy.

Eastern Zone

In 2006 a substantial update from the previous formal stock asssessment in 2002 was performed. The 2006 assessment differed from that in 2002 by the addition of: catch data for 2002-2006, 2004 age composition data from St Helens Hill and St Patricks Head, and towed-body acoustic abundance estimates for 1999 and 2006. The software for conducting the assessment was updated to Stock Synthesis 2 (SS2).

The model results provided essentially two scenarios :

1. When all data were used, a reduced recruitment of fish aged between 30-60 in 2006 led to a stock biomass below the 20% limit reference point, at which catches should be set at zero. Stock biomass was predicted to rise above 20% in 2013.

2. When age composition data were not used to estimate recruitment residuals, and constant average recruitment was assumed, the stock biomass was estimated at 27% of unfished biomass, and the Recommended Biological Catch calculated using Tier 1 of the SESSF harvest strategy framework was between 672 t – 1,087 t (depending on which harvest control rule was used).

Cascade Plateau

A quantitative integrated assessment of Cascade Plateau orange roughy was performed in 2006 using SS2. The 2005 acoustic biomass estimate was approximately three times

higher than the 2003 and 2004 estimates, and thus was used on its own as an absolute estimate, rather than as a third point in a relative index.

Three alternative values of the 2005 acoustic biomass estimate, representing different assumptions about target strengths, proportion spawning and turnover, were used in sensitivity tests. For the base case, current female spawning biomass was estimated to be 73% of unfished biomass, for the lowest biomass index this proportion was 62% , and for the largest biomass index it was 82%. The RBC for 2007 ranges from 283 t to 1,307 t for the three estimates of 2005 biomass, and three versions of the harvest control rule.

1.6 Great Australian Bight Species

Deepwater Flathead and Bight Redfish

This chapter presents the results of attempts to improve the assessments of deepwater flathead (*Neoplatycephalus conatus*) and Bight redfish (*Centroberyx gerrardi*) populations in the GABTF. The models have been updated from the 2005 assessment extending the analysis to include 2005/06 catches and catch at age data and survey data collected in 2006.

The stock assessment for both species was migrated to SS2 for the 2006 assessment. To show the comparability of the new method, results from the 2005 assessments were largely duplicated using SS2. A number of differences were introduced into the 2006 assessment including independent estimation of annual recruitment deviations and estimation of recruitment deviations for a period prior to commencement of the fishery. The assessments now each include 2 absolute abundance estimates from survey. It is understood that the survey will provide relative indices in the long-term.

For deepwater flathead the unexploited biomass estimate for the base case models was 10,087t and current depletion was estimated to be 50%. Under the Tier 1 catch control rule using 20:40:40 the RBC value 1,544t, and using a Tier 2 20:50:50 rule the RBC value was 1,070t.

For Bight redfish the unexploited biomass estimate for the base case models was 31,660t and current depletion was estimated to be 94%. Under the Tier 1 catch control rule using 20:40:40 the RBC value was >4,700t, and using a Tier 2 20:50:50 rule the was >4,040t.

1.7 Shark Species

Gummy Shark

The assessment of gummy shark (*Mustelus antarcticus*) is based on an age- and sex-structured population dynamics model tailored to the specifics of a shark species. The model accounts for the nature of the pupping process and explicitly includes five gear-

types (four mesh sizes of gillnets and longlines). The model is applied assuming that there are separate populations of gummy shark in Bass Strait and off Tasmania and South Australia. Evidence in support of this assumption includes operational and biological factors. The 2006 assessment represents the first time an assessment has been conducted of gummy shark off Tasmania, and reflects that the time-series of standardized catch-rates for this area is now sufficiently long to justify its use for population assessment. The free parameters of the assessment model are the sizes of each population at the start of 1927, the annual deviations in pup survival, natural mortality, and parameters related to density-dependence and availability. Unlike most other SESSF stock assessments, the stock assessment for gummy shark is not yet based on SS2, as SS2 is currently unable to make use of tagging data.

The populations of gummy shark in Bass Strait and off Tasmania are estimated to be comfortably above $0.4B_0$ while the population off South Australia is again estimated to be below this level. The RBC for Bass Strait for 2007 based on the Tier 1 rules is a landed catch between 750-1016t, depending on the target level for the Tier 1 control rule and the breakpoint in this control rule. Equivalent ranges for Tasmania and South Australia are 234-274t and 210-343t respectively. The total (all State) RBC for 2007 ranges between 1194 and 1632t. The long-term RBCs for Tasmania are lower than those for 2007 while the long-term RBCs for South Australia are higher than those for 2007.

The assessment is based on very few data for 2005. The declining amount of information for 2005 continues a trend of declining amounts of new information (length-frequency data and tag recaptures) over recent years. The ability to provide reliable assessments depends on the data collection scheme providing sufficient information to support estimation of, for example, recruitment. Furthermore, the dependence of the assessment on catch-rates (even after standardization) remains a concern given changes over time in, for example, fishing practices in the shark fishery. This problem can only be rectified if fishery-independent data begin to be collected systematically across the fishery

School shark

The 2001 stock assessment of school shark (*Galeorhinus galeus*) was updated based on catch data from 2000-2005, new tagging data, and catch-rate indices of relative abundance based on ISMP sampling on trawl vessels. The assessment was based on a spatial multi-stock age- and sex-structured population dynamics model tailored to the specifics of a shark species, fitted to data on catches, catch-rates, length-frequency, age-composition and tagging data. The model accounts for the nature of the pupping process and explicitly includes five gear-types (four mesh sizes of gillnets and longlines).

Evaluation of stock status for school shark is based on the expected amount of pup production relative to that at the start of the fishery in 1927. The results of the 2006 assessment suggest that the size of the school shark resource at the start of 2000 is somewhat larger than inferred from the 2001 assessment. There is, however, no evidence for an increase in the abundance of school shark since 2000, although there is some evidence that the biomass and pup production may have stabilized. Pup production in 2005 is estimated to have been below 20% of the pre-fishery pup

production, so the Recommended Biological Catch under both the Tier 1 and Tier 2 rules is zero.

The reliability of the school shark assessment continues to deteriorate owing to lack of new data. Specifically, the main sources of new data included in the 2006 assessment are fishery catch rates, ISMP-based indices of abundance and a few tag-recaptures. However, it is questionable whether commercial catch-rates currently provide reliable indices of abundance for school shark owing to marked changes in targeting practices over recent years. Furthermore, the ISMP indices, except perhaps those for the west (Central South Australia, South Australia-Victoria, Western Bass Strait and Western Tasmania combined) are very imprecise and likely have little potential to provide information on short-term changes in abundance. A fishery-independent survey may resolve this issue, but the patchy distribution of school shark may lead to most surveys having high sampling coefficients of variation making detection of all but very large changes in abundance difficult to detect.

KEYWORDS: fishery management, southern and eastern scalefish and shark fishery, stock assessment, trawl fishery, non-trawl fishery

2. Background

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a Commonwealth-managed, multi-species and multi-gear fishery that catches over 80 species of commercial value and is the main provider of fresh fish to the Sydney and Melbourne markets. Precursors of this fishery have been operating for more than 85 years. Catches are taken from both inshore and offshore waters, as well as offshore seamounts, and the fishery extends from Fraser Island in Queensland to south west Western Australia.

Management of the SESSF is based on a mixture of input and output controls, with over 20 commercial species or species groups currently under quota management. For the previous South East Fishery (SEF), there were 17 species or species groups managed using TACs. Five of these species had their own species assessment groups (SAGs) – orange roughy (ORAG), eastern gemfish (EGAG), blue grenadier (BGAG), blue warehou (BWAG), and redfish (RAG). The assessment groups comprise scientists, fishers, managers and (sometimes) conservation members, meeting several times in a year, and producing an annual stock assessment report based on quantitative species assessments. In addition to these five key species, quantitative assessments for several additional species each year were also conducted. Species for which such assessments have been conducted recently include school whiting, pink ling and spotted warehou. The previous Southern Shark Fishery (SSF), with its own assessment group (SharkFAG), harvested two main species (gummy and school shark), but with significant catches of saw shark and elephantfish.

In 2003, these assessment groups were restructured and their terms of reference redefined. Part of the rationale for the amalgamation of the previous separately managed fisheries was to move towards a more ecosystem-based system of fishery management (EBFM) for this suite of fisheries, which overlap in area and exploit a common set of species. The restructure of the assessment groups was undertaken to better reflect the ecological system on which the fishery rests. To that end, the assessment group structure now comprises:

- SESSFRAG (an umbrella assessment group for the whole SESSF)
- Shelf Resource Assessment Group (Shelf RAG)
- Slope Resource Assessment Group (Slope RAG)
- Deepwater Resource Assessment Group (Deepwater RAG)
- Shark Resource Assessment Group (Shark RAG)
- Great Australian Bight Resource Assessment Group (GAB RAG)

Each of the three depth-related assessment groups is responsible for undertaking stock assessments for a suite of key species, and for reporting on the status of those species to SESSFRAG. The Shark RAG is responsible for assessments of all chondrichthyan species, and the GAB RAG for those species in the Great Australian Bight.

The plan for the five resource assessment groups (Shelf, Slope, Deepwater, GAB and Shark RAGs) is to focus on suites of species, rather than on each species in isolation,

which has tended to be the practice to date. This approach has helped to identify common factors affecting these species (such as environmental conditions), as well as consideration of marketing and management factors on key indicators such as catch rates. Assessments are also identifying where catches of two species are inversely related due to targeting.

The quantitative assessments produced annually by the Resource Assessment Groups are a key component of the TAC setting process for the Southern and Eastern Scalefish and Shark Fishery. To support the assessment work of the five Assessment Groups, the aims of the work conducted in this report were to develop new assessments, and update and improve existing ones for priority species in the SESSF.

3. Need

A stock assessment that includes the most up-to-date information and considers a range of hypotheses about the resource dynamics and the associated fisheries is a key need for the management of a resource. In particular, the information contained in a stock assessment is critical for selecting harvest strategies and setting Total Allowable Catches.

4. Objective

- Provide quantitative and qualitative species assessments in support of the five SESSFAG resource assessment groups.

5. Comparison of SEF1 and SEF2 Catches for SESSF Species to 2005

Malcolm Haddon [1]

[1]Marine Research Laboratory, Tasmanian Aquaculture and Fisheries Institute,
University of Tasmania, Private Bag 49, Hobart, TAS 7001

5.1 Introduction

The estimated catches from the commercial catch and effort database are not taken to be as accurate as the estimates of landed catches. This document tabulates and plots the catches and raw catch rates (where available) for a range of SESSF species.

5.1.1 Pink Ling

There were 52,919 records available in the SEF2 database for Pink Ling (CSIRO code 37228002).

Table 5.1. Reported (SEF2) and Estimated (SEF1) catches of Pink Ling.

Year	SEF2	SEF1
1986		678.977
1987		765.024
1988		567.356
1989		672.357
1990		667.942
1991		735.038
1992	548.893	566.926
1993	823.279	891.896
1994	903.215	894.920
1995	1268.382	1208.562
1996	1421.978	1230.879
1997	1703.217	1444.302
1998	1680.159	1394.226
1999	1692.985	1368.296
2000	1586.653	1255.485
2001	1347.127	1066.466
2002	1072.639	851.706
2003	1131.284	888.426
2004	904.071	747.469
2005	751.869	627.101

In all cases except 1992 the SEF2 catches are greater than the SEF1 estimated catches.

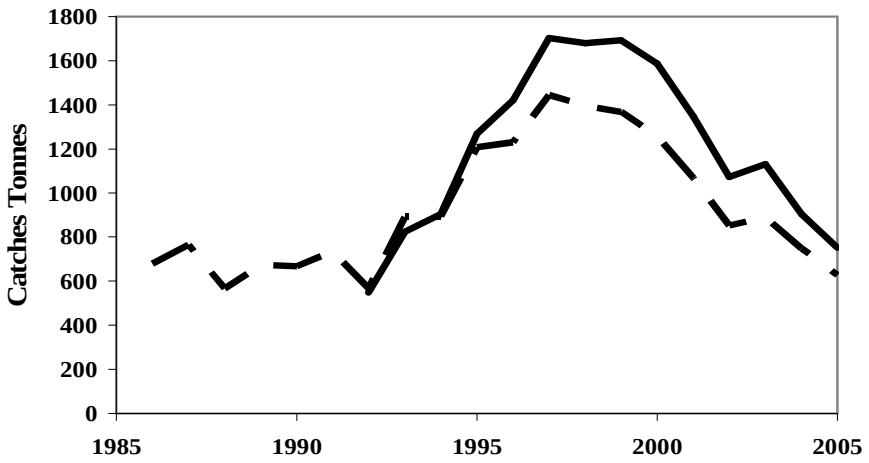


Figure 5.1. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Pink Ling.

5.1.2 Blue Warehou

There were 17,146 records available in the SEF2 database for Blue Warehou (CSIRO code 37445005).

Table 5.2. Reported (SEF2) and Estimated (SEF1) catches of Blue Warehou

Year	SEF2	SEF1
1986		211.877
1987		405.828
1988		544.221
1989		776.041
1990		880.978
1991		1288.285
1992		933.840
1993	570.159	829.348
1994	847.769	940.826
1995	763.109	813.776
1996	842.388	724.348
1997	783.242	661.546
1998	920.438	820.225
1999	353.973	313.926
2000	432.201	389.683
2001	297.156	259.378
2002	306.392	284.124
2003	250.346	227.942
2004	260.219	228.721
2005	311.249	336.109

Figure 5.2. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Blue Warehou.

5.1.3 Blue Grenadier

There were 25,439 records available in the SEF2 database for Blue Grenadier (CSIRO code 37227001).

Table 5.3. Reported (SEF2) and Estimated (SEF1) catches of Blue Grenadier

Year	SEF2	SEF1
1986		1454.980
1987		2243.037
1988		1820.441
1989		1876.091
1990		2257.415
1991		3667.992
1992	2594.201	2470.653
1993	2698.502	2479.879
1994	3110.697	2314.967
1995	2753.159	1929.236
1996	2968.289	2278.143
1997	2672.929	3627.544
1998	5735.799	4163.569
1999	9301.026	7514.882
2000	8647.457	7453.759
2001	9124.872	8340.418
2002	9161.373	7962.772
2003	8471.727	7051.030
2004	6463.518	5856.944
2005	4256.806	4088.609

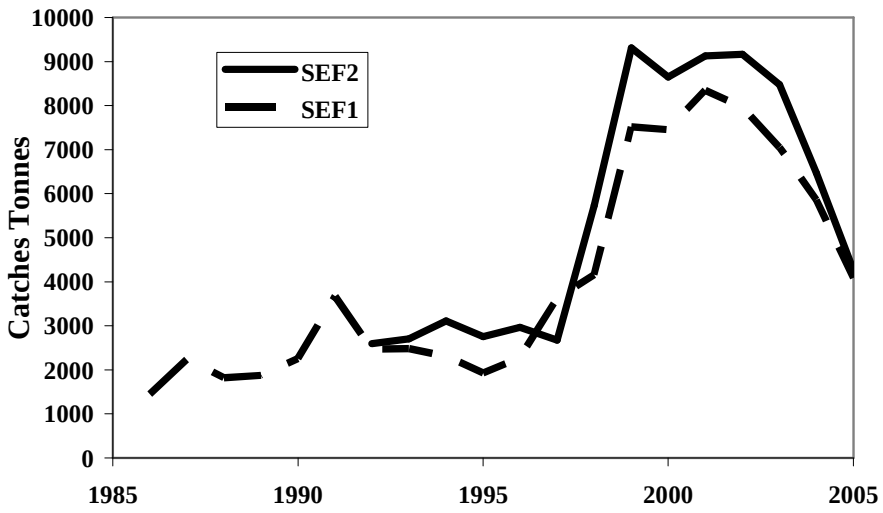


Figure 5.3. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Blue Grenadier.

5.1.4 Gemfish

There were 14,662 records available in the SEF2 database for Gemfish (CSIRO code 37439002).

Table 5.4. Reported (SEF2) and Estimated (SEF1) catches of Gemfish

Year	SEF2	SEF1
1986		3635.685
1987		4659.370
1988		3508.900
1989		1843.457
1990		1196.321
1991		566.063
1992		478.425
1993		347.087
1994		216.361
1995		159.162
1996		338.424
1997	0.104	491.134
1998	430.994	314.630
1999	429.772	295.153
2000	441.967	299.892
2001	335.854	234.142
2002	195.916	126.394
2003	245.739	168.789
2004	224.483	168.141
2005	230.113	184.597

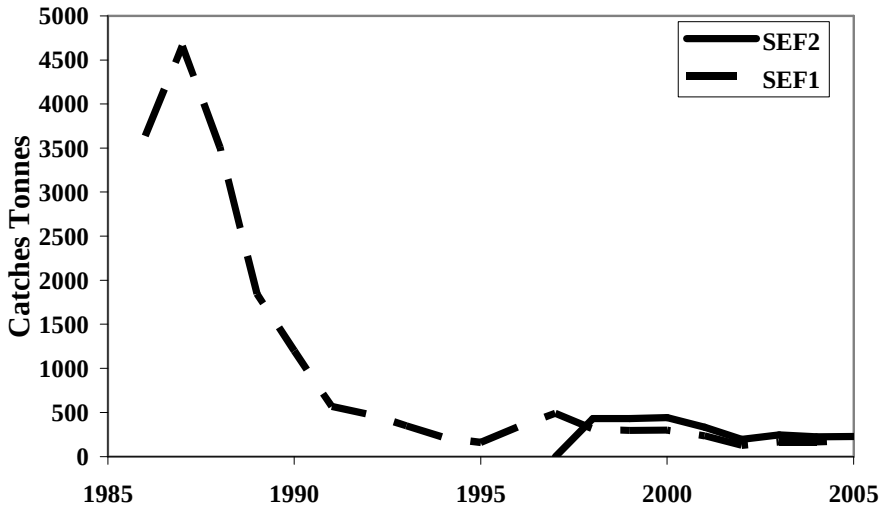


Figure 5.4. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Gemfish.

5.1.5 Tiger Flathead

There were 69,813 records available in the SEF2 database for Tiger Flathead (CSIRO code 37296001).

Table 5.5. Flathead Reported (SEF2) and Estimated (SEF1) catches of Tiger Flathead

Year	SEF2	SEF1
1986		1920.257
1987		2458.506
1988		2472.065
1989		2598.153
1990		2029.108
1991		2225.799
1992	2010.652	2375.366
1993	1401.033	1879.140
1994	1470.564	1710.404
1995	1698.297	1800.356
1996	1889.721	1879.707
1997	2505.248	2355.254
1998	2541.885	2305.308
1999	3455.156	3114.062
2000	3221.782	2779.453
2001	2845.312	2598.101
2002	3137.999	2875.501
2003	3498.540	3230.774
2004	3381.309	3223.348
2005	3001.108	2831.976

Figure 5.5. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Tiger Flathead.

5.1.6 Redfish

There were 32,924 records available in the SEF2 database for Redfish (CSIRO code 37258003).

Table 5.6. Reported (SEF2) and Estimated (SEF1) catches of Redfish. In Tonnes

Year	SEF2	SEF1
1986		1696.704
1987		1264.036
1988		1126.808
1989		716.163
1990		935.030
1991		1583.306
1992	801.900	1636.312
1993	478.258	1921.317
1994	611.604	1487.717
1995	1210.323	1240.572
1996	1435.741	1344.049
1997	1536.661	1392.465
1998	1751.621	1548.575
1999	1252.037	1108.866
2000	832.463	749.660
2001	794.025	738.170
2002	879.822	801.535
2003	677.230	614.551
2004	498.474	477.274
2005	532.268	486.285

Figure 5.6. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Redfish.

5.1.7 Jackass Morwong

There were 35,092 records available in the SEF2 database for Jackass Morwong (CSIRO code 37377003).

Table 5.7. Reported (SEF2) and Estimated (SEF1) catches of Jackass Morwong in Tonnes.

Year	SEF2	SEF1
1986		967.651
1987		1076.192
1988		1441.887
1989		1616.055
1990		955.524
1991		1104.873
1992	698.362	712.554
1993	816.116	968.386
1994	791.536	771.575
1995	820.809	736.597
1996	883.222	781.825
1997	1115.474	987.675
1998	877.780	761.370
1999	933.048	821.321
2000	880.101	773.802
2001	814.191	728.760
2002	847.915	749.200
2003	744.517	658.377
2004	755.357	660.807
2005	792.075	682.743

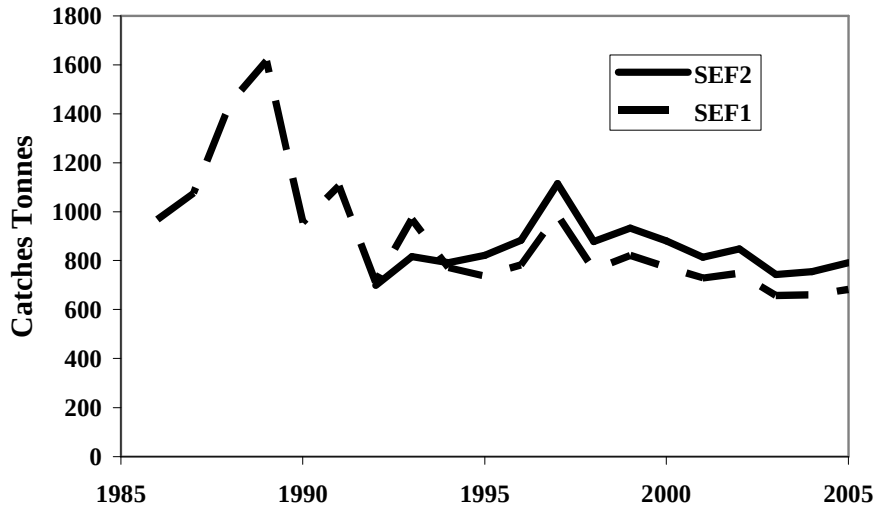


Figure 5.7. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Jackass Morwong.

5.1.8 Spotted Warehou

There were 26,052 records available in the SEF2 database for Spotted Warehou (CSIRO code 37445006).

Table 5.8. Reported (SEF2) and Estimated (SEF1) catches of Spotted Warehou in Tonnes.

Year	SEF2	SEF1
1986		1156.533
1987		782.211
1988		1644.953
1989		932.485
1990		1344.415
1991		1447.539
1992	1191.502	733.215
1993	1462.869	1815.791
1994	1862.920	2309.289
1995	2052.466	2002.687
1996	2513.784	2186.379
1997	2685.933	2383.927
1998	2402.252	2049.200
1999	3238.917	2770.064
2000	3724.423	3348.660
2001	3299.450	2965.068
2002	4110.420	3822.429
2003	3027.948	2734.247
2004	3326.207	3207.922
2005	2887.300	2626.243

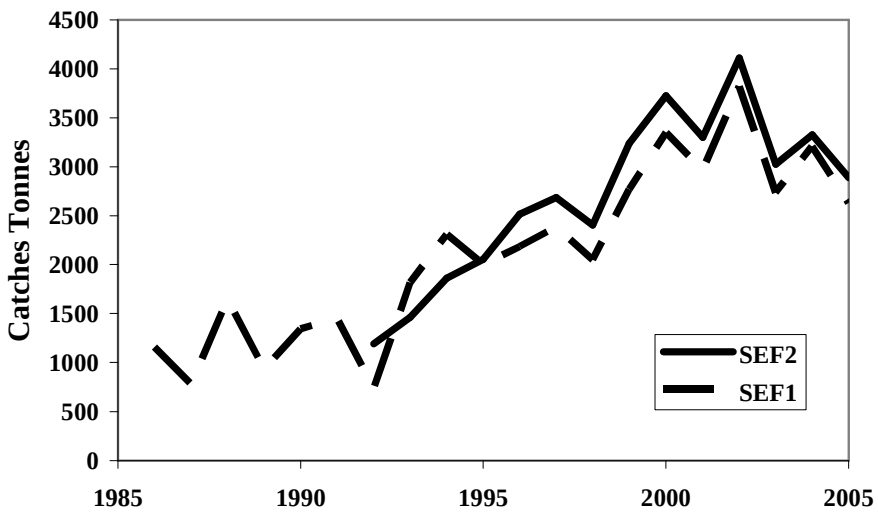


Figure 5.8. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Spotted Warehou.

5.1.9 Mirror Dory

There were 35,248 records available in the SEF2 database for Mirror Dory (CSIRO code 37264003).

Table 5.9. Reported (SEF2) and Estimated (SEF1) catches of Mirror Dory in Tonnes.

Year	SEF2	SEF1
1986		410.583
1987		476.386
1988		346.240
1989		591.111
1990		295.514
1991		240.908
1992	184.202	166.860
1993	263.418	306.005
1994	270.263	294.242
1995	263.146	242.970
1996	380.347	341.746
1997	521.617	455.254
1998	415.854	354.877
1999	343.239	305.107
2000	204.971	164.299
2001	295.770	238.907
2002	523.002	445.345
2003	668.144	609.012
2004	523.484	500.391
2005	587.466	573.973

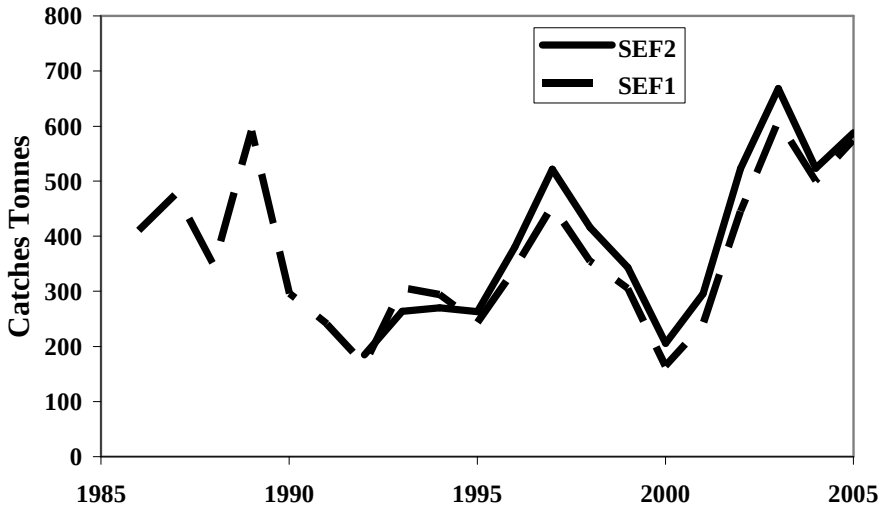


Figure 5.9. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Mirror Dory.

5.1.10 John Dory

There were 45,242 records available in the SEF2 database for John Dory (CSIRO code 37264004).

Table 5.10. Reported (SEF2) and Estimated (SEF1) catches of John Dory in Tonnes.

Year	SEF2	SEF1
1986		230.317
1987		204.965
1988		180.769
1989		216.385
1990		167.011
1991		168.602
1992	91.652	129.572
1993	100.508	238.617
1994	112.961	266.663
1995	114.405	185.042
1996	134.897	160.171
1997	89.745	86.960
1998	114.818	106.524
1999	137.528	129.264
2000	169.628	159.201
2001	134.771	126.534
2002	162.508	148.046
2003	164.698	152.551
2004	166.032	163.292
2005	102.650	104.622

Figure 5.10. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for John Dory.

5.1.11 Silver Trevally

There were 18,321 records available in the SEF2 database for Silver Trevally (CSIRO code 37337062).

Table 5.11. Reported (SEF2) and Estimated (SEF1) catches of Silver Trevally in Tonnes.

Year	SEF2	SEF1
1986		469.058
1987		198.430
1988		277.476
1989		375.303
1990		449.986
1991		322.924
1992	192.809	292.493
1993	155.454	375.708
1994	131.457	392.403
1995	201.880	411.524
1996	215.207	339.114
1997	167.082	314.332
1998	99.700	193.620
1999	72.529	131.981
2000	92.313	128.118
2001	153.708	264.883
2002	157.875	227.317
2003	123.759	308.292
2004	138.598	408.367
2005	96.016	273.399

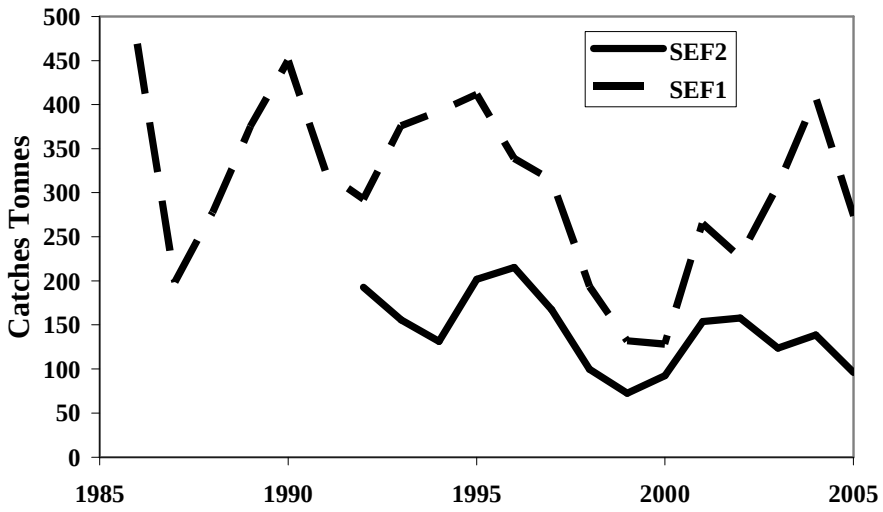


Figure 5.11. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Silver Trevally. The SEF2 are far less than the SEF1 because they do not include the State catches.

5.1.12 Ocean Perch

There were 38,277 records available in the SEF2 database for Ocean Perch (CSIRO code 37287001).

Table 5.12. Reported (SEF2) and Estimated (SEF1) catches of Ocean Perch in Tonnes.

Year	SEF2	SEF1
1986		262.794
1987		198.567
1988		186.712
1989		206.758
1990		180.560
1991		223.188
1992	183.733	169.669
1993	277.739	259.310
1994	259.943	257.241
1995	271.718	239.951
1996	317.318	263.040
1997	390.212	290.281
1998	349.951	270.561
1999	369.363	282.502
2000	339.700	253.831
2001	349.245	267.243
2002	306.136	231.266
2003	338.914	269.767
2004	298.508	229.882
2005	294.078	229.507

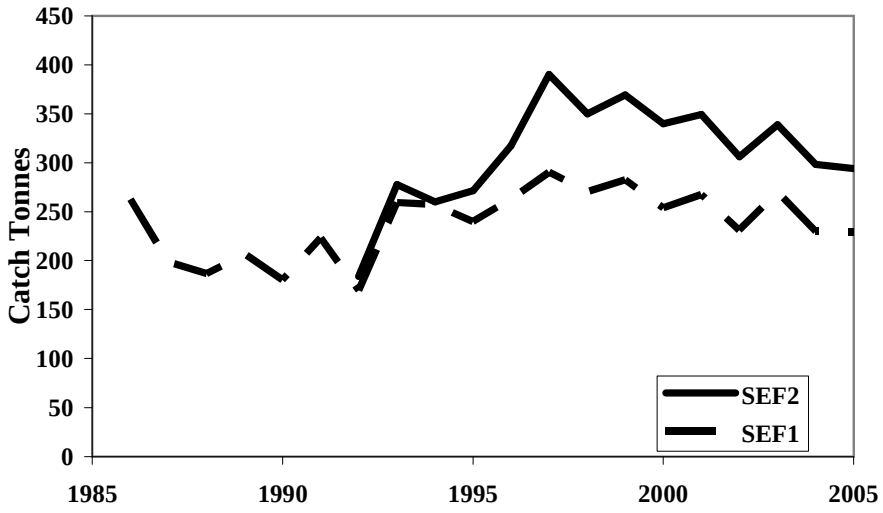


Figure 5.12. Comparison of the reported SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Ocean Perch.

5.1.13 Blue Eye

There were 11,482 records available in the SEF2 database for Blue Eye (CSIRO code 37445001) captured by Trawl.

Table 5.13. Reported (SEF2) and Estimated (SEF1) trawl catches of Blue Eye in Tonnes.

Year	SEF2	SEF1
1986		38.562
1987		15.467
1988		101.767
1989		87.691
1990		76.373
1991		80.149
1992	51.140	49.275
1993	67.151	59.519
1994	87.854	109.730
1995	66.206	57.967
1996	79.734	71.245
1997	109.343	103.464
1998	95.473	79.878
1999	108.182	95.572
2000	98.629	83.665
2001	82.933	105.539
2002	84.676	69.231
2003	31.764	35.555
2004	84.853	45.736
2005	45.968	34.507

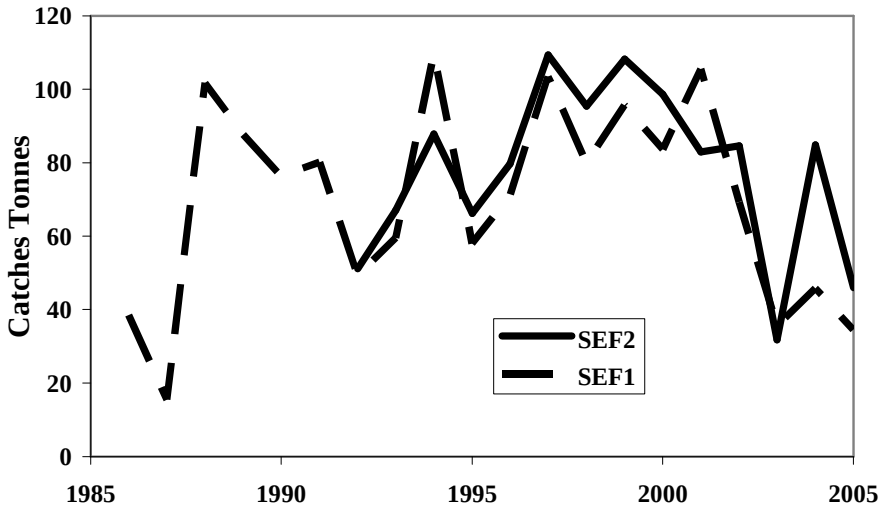


Figure 5.13. Comparison of the reported trawl caught SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Blue Eye.

5.1.14 Orange Roughy

There were 5,252 records available in the SEF2 database for Blue Eye (CSIRO code 37255009) captured by Trawl.

Table 5.14. Reported (SEF2) and Estimated (SEF1) trawl catches of Orange Roughy in Tonnes.

Year	SEF2	SEF1
1986		4578.078
1987		5886.896
1988		7197.088
1989		27648.810
1990		43808.930
1991		22434.425
1992	315.845	17121.335
1993	83.936	10474.669
1994	173.826	7554.486
1995	22.059	4929.635
1996	0.256	4709.756
1997	71.435	5328.411
1998	4157.468	7061.329
1999	4460.857	6374.154
2000	4154.230	4791.706
2001	3914.529	4458.038
2002	3696.852	3620.142
2003	2958.285	2877.610
2004	2810.898	2747.574
2005	2492.607	2363.586

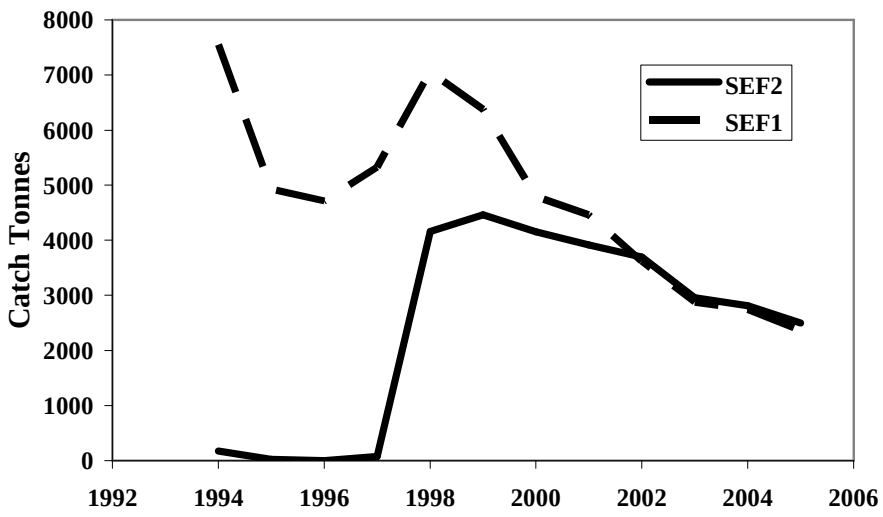


Figure 5.14. Comparison of the reported trawl caught SEF2 catches (solid line) with the estimated SEF1 catches (dashed line) for Orange Roughy.

5.1.15 School Whiting

There were 17,182 records available in the SEF2 database for School Whiting (CSIRO code 37330014) captured by Trawl.

Table 5.15. Reported (SEF2) trawl catches of School Whiting in Tonnes.

Year	SEF2
1992	715.107
1993	1195.936
1994	880.200
1995	1080.370
1996	656.362
1997	386.569
1998	417.795
1999	436.948
2000	491.711
2001	501.517
2002	525.352
2003	564.269
2004	423.322
2005	455.110

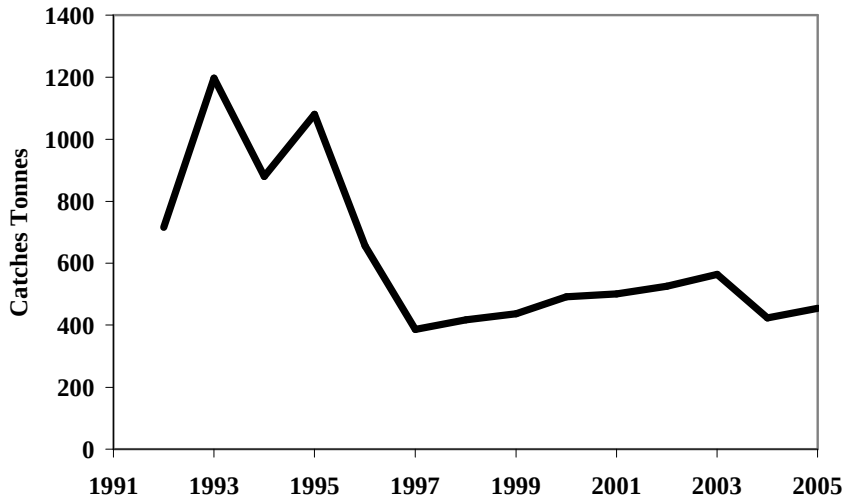


Figure 5.15. Reported trawl caught SEF2 catches for School Whiting.

5.1.16 Royal Red Prawn

There were 8,260 records available in the SEF2 database for Royal Red Prawn (CSIRO code 27701004) captured by Trawl.

Table 5.16. Reported (SEF2) trawl catches of Royal Red Prawn in Tonnes.

Year	SEF2
1992	159.225
1993	146.725
1994	147.774
1995	193.516
1996	267.278
1997	187.737
1998	210.571
1999	376.004
2000	416.692
2001	242.229
2002	433.740
2003	188.165
2004	172.228
2005	166.487

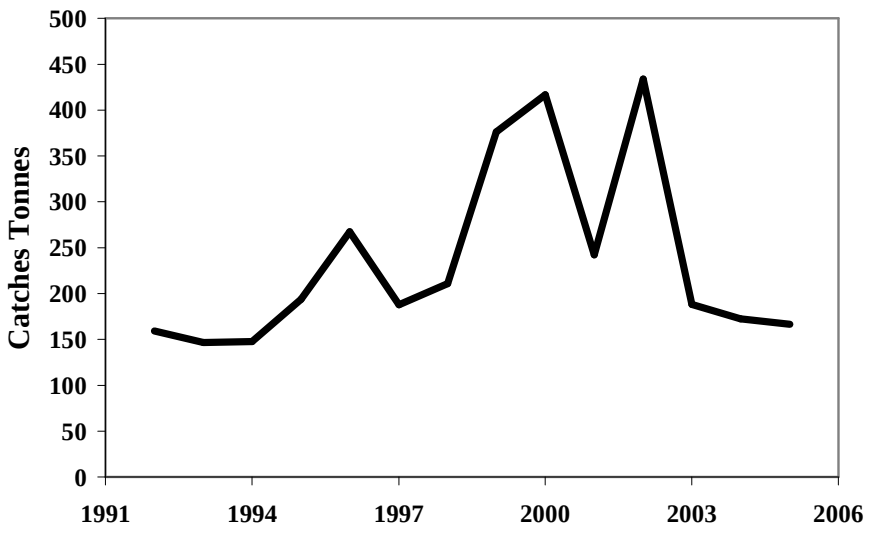


Figure 5.16. Reported trawl caught SEF2 catches for Royal Red Prawn.

6. Standardized Commercial Catch-Effort Data for Selected Shelf and Slope Assessment Group Species for 1986 - 2005

Malcolm Haddon[1]

[1]Marine Research Laboratory, Tasmanian Aquaculture and Fisheries Institute,
University of Tasmania, Private Bag 49, Hobart, TAS 7001

6.1 Introduction

The catch and effort data available from the AFMA log-book database for the South East Fishery (SEF) derives from a wide range of zones (areas), vessels, months, depths, and fishing gears. It is well known that catch-rates can be affected by all these factors (plus others unfortunately not recorded in the database). If the range of vessels that fish, or the areas and depths that are fished, vary from year to year, or the season of maximum fishing varies from year to year, we may observe changes in catch-effort which have nothing to do with changes in the stock biomass. Rather, such changes would be related to fleet dynamics and the distribution of fishing effort. We should therefore not simply average the available data to obtain representative catch-effort figures through time. Instead we should attempt to determine catch-effort figures standardized in terms of the factors depth, fishing zone, month, and fishing vessel. After standardization, the catch-effort data should then provide a better indication of the relative status of the stock upon which the fishery is based. In effect standardization acts to remove the effects, or at least reduce the obscuring effects, of the factors being included in the standardization (e.g. depth, season, zone, etc). Once the effects of these factors have been neutralized the remaining variation, or at least that associated with a year factor, should provide a better representation of the relative changes in catch rates through time.

As Kimura (1981, p211) says: “Since the 1950s it has been recognized that fishing power generally differs among vessels, and if c.p.u.e. is to be proportional to abundance, effort measurements must be standardized.” The most commonly used method of standardization is to include the various factors thought to effect catch rates into a generalized linear model and to include Year as a factor, in this way the parameters derived for each year become the indices of relative abundance (Vignaux, 1992, 1993; Klaer, 1994).

We can only standardize using factors for which there is data available. It would be highly desirable, for example, to standardize for changes to the ability of fishing vessels to detect fish e.g. colour echo-sounders, improved engine and net technology. However, in the absence of information regarding when each vessels improved its technological support, we cannot include these factors into the standardization.

After standardization we are left with a set of yearly coefficients that represent the catch rate relative to some reference year (usually the first or last in the time series).

Unfortunately, even if the standardization accounts for a large proportion of the variability in the data there are no guarantees that catch effort, even standardized catch effort, can act as a good proxy for stock size. Instead of the success of the standardization, one should be able to argue from the nature of the fishery and the species concerned whether or not there is likely to be even an approximate relationship between catch rates and stock size. This is an area of great debate and interest. An obvious question to ask is whether the inferences it is possible to draw from the catch effort information are consistent with the implications of the catch-at-age data. When both data types are consistent then confidence tends to be increased in the assessment. If the different data are inconsistent then it becomes clear that some form of uncertainty is not being accounted for in the modelling or data collection.

6.2 General Methods

The changes through time to the logbooks used in the SEF, as reflected in the SEF1 database records, lead to major problems in collating the data necessary for these analyses. One extremely influential factor influencing CPUE is which vessel is doing the fishing. The vessel names are needed as an approximate proxy for differences in gear and fishing power. From 1985 to 1998 a unique number was allocated to each vessel in the database. Following that date this number was altered each year. In short, the solution to keeping track of individual vessels was to develop a lookup table of vessel names (be they literal vessel names, call-signs or other identifying marks) against a new unique VesselID number, and it is now this arbitrary but constant identifier that is used as a dummy variable in the analyses. In this way, obvious errors in the database, such as slightly different name spellings could be accounted for (e.g. Gail Jeanette 3 versus Gail Jeanette III, or Zeehan versus Zeehaan, plus many others). These errors needed to be corrected prior to analysis because, otherwise, the GLM factor, BoatName, would have provided confused results. The database used for this year's analyses came from the original character separated variable files provided for the years 1986 – 1999, for April 2000-December 2000, and for 2001 – 2004. The missing three months in 2000 came about because of large changes made to the database at that time. Data from the months of January 2000 – March 2000 were extracted from a database provided by Michael Fuller of CSIRO Marine, Hobart, entitled "SEF_Historical_GenLog.mdb". In addition, to distinguish between Danish Seine vessels and trawlers a table from the AFMA data section listing 41 different Danish seine boats was used. All data is now available in a flatfile structure listing the following species: Pink Ling, Blue Warehou, Blue Grenadier, Gemfish, Orange Roughy, Flathead, Redfish, Jackass Morwong, Spotted Warehou, Mirror Dory, John Dory, Silver Trevally, Ocean Perch, and Blue Eye. This data relates to the SEF1 database which includes only estimates of total catch. For accurate estimates of landed catch the SEF2 database is to be preferred as the values included in this have some degree of verification.

A further issue relates to the recording of estimated processed weights rather than estimated whole weights. In practice we have treated all reported weights as whole weights up until 2004. For data from the year 2004 the data were treated as processed weights and were multiplied by the conversion factor provided in the database. This date was used as a transition because the data section at AFMA provided the opinion that

most skippers were providing processed weights after that date. The various RAGs need to consider this issue and confirm that from now on the reported weights should be treated as processed weights and multiplied by the appropriate conversion factor.

As in previous years generalized linear models were fitted to different combinations of various factors for which information was available (year, month, depth category, boat name, and zone). Some of the interaction terms between various factors were also considered. These were limited to those combinations for which sensible interpretations could be ascribed; such as zone x month, which would relate to seasonal movement of effort between zones. In all cases SAS version 9.1 was used to generate the GLMs from which the standardizations are derived. This prevented any problems with computer memory limitations that could have arisen because of the large number of observations available (sometimes 100s of thousands of records).

All catch rates were log-transformed and a General Linear Model was used rather than using a Generalized Linear Model with a log-link; this has advantages in terms of normalizing the data while stabilizing the variance, which the Generalized Linear Model approach does not always achieve appropriately (Venables & Dichmont, 2004).

All factors are treated as dummy variables and the factors used in the various species and GLMs were:

Vess – unique vessel identifier. In addition, a flag was present to enable Danish Seine vessels to be distinguished from trawlers.

Year – was the calendar year in each case. The parameters for this factor, once back-transformed from the logarithmic form, are used as the index of relative abundance in the assessment models.

Month – was the ordinary calendar month

DepCat – depth category - a set of 50m depth categories (for some species this was sometimes truncated at some given maximum depth to avoid unlikely data).

Zone – was a standard set of regions for each species, generally these were the same as in previous years (zones 10, 20, to 60).

EW – which was a demarcation between the east and western areas. East was Zones 10, 20, and 30, while west was defined as zones 40 and 50.

DumBG, DumRed, DumFH, DumJM, DumPL, were a set of dummy variables used to characterize any associated catches of blue grenadier (BG), redfish (Red), flathead (FH), jackass morwong (JM), and pink ling (PL). These catch categories were, in each case, 0 was no recorded catch, 1 was >0 and <=100kg, 2 was >100 and <=200kgs, 3 was >200 and <=500kgs, and 4 was >500kgs.

For the standardizations not all data records were always used. Generally, only those vessels active in the fishery for more than two years and with some given median annual catch were included. The specific details of the selection criteria are given in the results for each species. The number of observations available in each year for each species for each analysis was also listed. Sensitivity tests were conducted on the selection criteria by considering how the results varied when the minimum of three years and minimum median catch was varied. In all cases the selection used provided a working solution.

It should be noted that the output from a GLM does not guarantee that a relation exists between stock size and standardized catch per unit effort. It is possible that factors not included in the GLM model (through no information being available) may be obscuring any effects of changes in stock biomass. In this case, however, there are no other data available to be included in the statistical models so the potential analyses are thus limited.

The statistical models used all have a form akin to:

LnCE = const+ year+ month+ zone + DepCat + Vess + DumPL + zone*month

which can contain single factors like zone, co-occurring species like DumPL, and interaction terms like zone*month.

6.2.1 The Statistical Models

It is possible to define the so-called 'full model' for the set of factors being considered. This would include all of the factors and the entire set of interaction terms possible between them. It would be difficult to provide a real interpretation for some of the interaction terms possible and their value in describing the data is marginal. However, there is no doubt that the more parameters used in a statistical model the more likely we are to describe a larger proportion of the variation in the available data. But just adding more and more parameters to a model is not necessarily an improvement when parameter correlation exists. What is required is a compromise between the variability of the data described by the statistical model and its complexity.

One way of selecting such a compromise, which is becoming more and more accepted as such a criterion, is the use of the Akaike's Information Criterion (AIC). This is usually based around a maximum likelihood framework but, in the special case of a least squares estimation with normally distributed additive errors, the AIC can be expressed as:

$$\boldsymbol{AIC = nLn\left(\hat{\sigma}^2\right) + 2K}$$

where

$$\hat{\sigma}^2 = \frac{\sum \varepsilon^2}{\boldsymbol{n}}$$

is the maximum likelihood estimator of σ^2, ε^2 is the estimated sum of squared residuals for the candidate model, K is the total number of estimated parameters, including the intercept and σ^2, and n is the total number of observations (Burnham & Anderson, 1998). The criterion is selected which gives rise to the smallest AIC.

In addition, the analyses were usually terminated when the impact of adding new factors or interactions had not visual affect on the yearly parameters derived from the GLMs. This was estimated more precisely by calculating the squared residual difference between each sequential statistical model. As this deviance estimate became very small additional factors made very little effect on the trends expressed by the yearly parameter estimates.

6.3 Results

6.3.1 Silver Trevally (TRE)

The data restrictions used in selecting the data for analysis were:
Only data from zones 10 and 20 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 200 m.

The major restrictions were the limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years. With these two conditions (plus those above) there were 30,408 records available for analysis. If no restrictions are placed on the median catch and years in the fishery there would be 50,410 records. Thus, 60.3% of available records are used and these represent 73.8% of all estimated catches (Table 6.1).

Table 6.1. Number of records used in the CPUE standardization in each year for trawlers only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 200m, and only zones 10 and 20. The geometric mean and the two optimum models (see Figure 6.1) are relative to 1986

Year	Records Used	Geometric Mean (Model1)	Model 8	Model 13
1986	1068	1.0000	1.0000	1.0000
1987	634	1.1577	1.0975	1.1156
1988	1026	1.1483	1.2594	1.2031
1989	1379	1.4180	1.7452	1.7114
1990	1499	1.3655	1.8658	2.0214
1991	1573	1.0203	1.6019	1.7925
1992	1335	0.7824	1.0087	1.1916
1993	1784	0.7929	0.9752	1.1829
1994	2221	0.8276	0.8690	1.0155
1995	2148	0.8106	0.9389	1.0634
1996	2003	0.6269	0.8532	0.9321
1997	1662	0.6785	0.8270	0.8502
1998	1445	0.5384	0.6494	0.6555
1999	1017	0.6583	0.7474	0.7740
2000	1092	0.5402	0.6410	0.6466
2001	2100	0.7055	0.7784	0.8483
2002	1530	0.5952	0.7509	0.7953
2003	1626	0.7547	0.7095	0.7272
2004	1972	0.9535	0.7973	0.7988
2005	1294	0.8530	0.6707	0.6732

13 statistical models were considered for the data from Silver Trevally (Table 6.2). Model 1 represents the geometric mean catch rates and Model 8 is the optimum model that does not include the effects of co-occurring species. Model 13 is the statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects, although in this case they appear small, as a comparison of Model 8 and Model 13 demonstrates (Table 6.1, Figure 6.1).

Table 6.2. The structure of the thirteen statistical models trialled with silver trevally. The factor names are as listed in Section 6.2. Model 13 differs from 12 by omitting the Month*DumJM factor. This improved the AIC values so that the overall optimal model was 13 (Table 6.3).

Model	Factors
model 1	Year
model 2	Year DepCat
model 3	Year DepCat Vess
model 4	Year DepCat Vess Month
model 5	Year DepCat Vess Month Zone
model 6	Year DepCat Vess Month Zone*DepCat
model 7	Year DepCat Vess Month Zone*DepCat Zone*Month
model 8	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat
model 9	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat DumRed
model 10	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat DumRed DumFH
model 11	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat DumRed DumFH DumJM
model 12	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat DumRed DumFH DumJM Month* (DumRed DumFH DumJM)
model 13	Year DepCat Vess Month Zone*DepCat Zone*Month Zone*Month*DepCat DumRed DumFH DumJM Month* (DumRed DumFH)

The statistical outcomes for each model show a steady increase in variability accounted for by the various models (Table 6.3). The optimum model without co-occurring species was Model 8, while with co-occurring species was model 13 (Table 6.1). The difference between these two options is minor after 1996 (Figure 6.1).

Table 6.3. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum models (one with co-occurring species – Model 13 - and one without – Model 8, are bolded. Model 1 is the base case.

Model	N	Var%	df Params	df Resids	ModelSS	Resid SS	# Param	AIC
Model 1	**30549**	**0.0263**	**19**	**30529**	**2087.8**	**77431.3**	**20**	**28452.4**
Model 2	30408	0.0817	23	30384	6472.3	72713.2	24	26558.2
Model 3	30408	0.1645	49	30358	13022.2	66163.3	50	23739.8
Model 4	30408	0.1781	60	30347	14103.4	65082.1	61	23260.8
Model 5	30408	0.1790	61	30346	14173	65012.5	62	23230.2
Model 6	30408	0.1797	65	30342	14226.1	64959.5	66	23213.4
Model 7	30408	0.1844	76	30331	14604.9	64580.5	77	23057.5
Model 8	**30408**	**0.1933**	**149**	**30258**	**15302.6**	**63882.9**	**150**	**22873.3**
Model 9	30408	0.2081	153	30254	16482.3	62703.2	154	22314.5
Model 10	30408	0.2220	157	30250	17576.5	61609.1	158	21787.2
Model 11	30408	0.2225	161	30246	17616.2	61569.3	162	21775.6
Model 12	30408	0.2322	292	30115	18386.8	60798.7	293	21654.6
Model 13	**30408**	**0.2307**	**249**	**30158**	**10267.4**	**60918.1**	**250**	**21628.2**

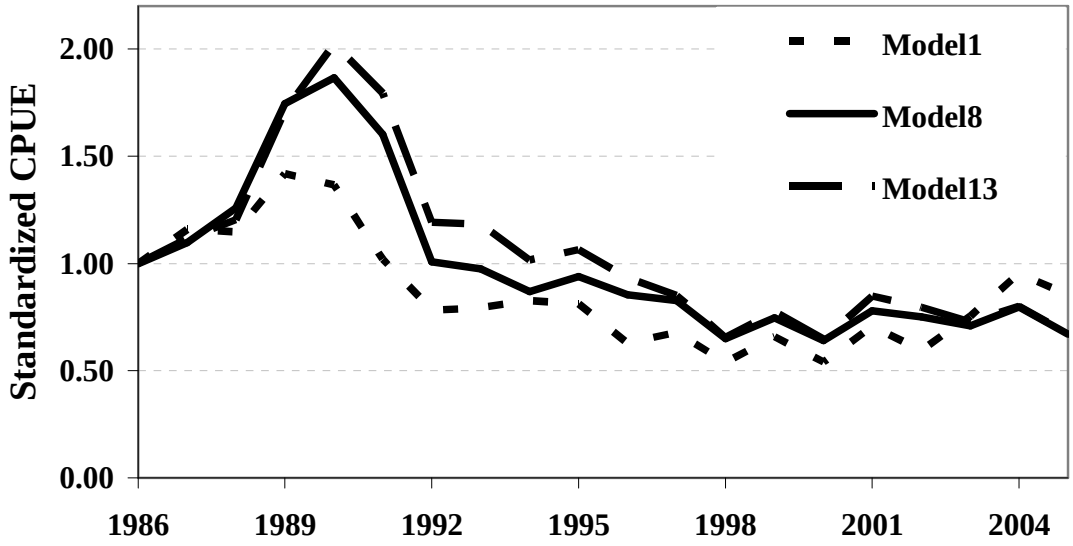


Figure 6.1a. The standardized catch per unit of effort per year for silver trevally relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 8 – solid line), and with co-occurring species (model 13 - dashes). Model descriptions in Table 6.2.

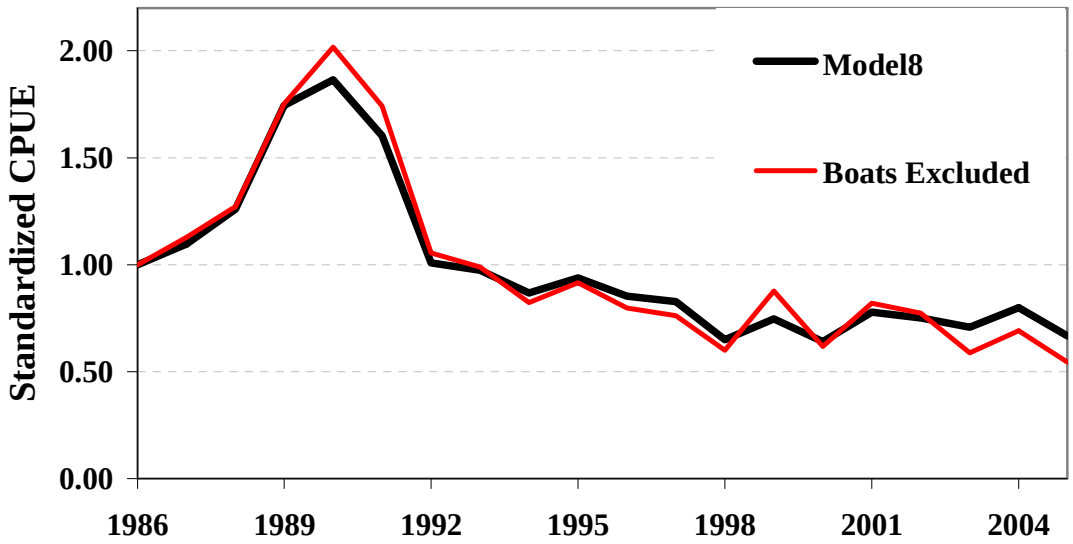


Figure 6.1b. The hump in apparent catch rates over the period 1988 to 1991 has been suggested to be the result of exceptional vessels being included in the analysis. Six vessels were identified by Industry members and the analysis repeated. Surprisingly, the early peak increased and the current catch rates dropped significantly. Removing such vessels focuses attention on the remaining vessels, which constitutes a form of standardization (it assumes the selected vessels are more representative of the fishery than before the selection). It is not known on what basis these vessels were selected for removal from the analysis and this result cannot be recommended to the RAG.

6.3.2 Flathead (Trawl only) FLT

The data restrictions used in selecting the data for analysis were:
Only data from zones 10, 20, and 60 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

For flathead taken by trawl the limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years did not reduce the number of records by any great amount. With these two conditions (plus those above) there were 221,449 records available for analysis. If no restrictions are placed on the median catch and years in the fishery there would be 235,109 records. Thus, 94.2% of available records are used and these represent 96% of all catches (Table 6.4).

Table 6.4. Number of records used in the CPUE standardization in each year for trawlers only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 10, 20, and 60. The geometric mean (Model 1) and the two optimum models (see Figure 6.2) are relative to 1986. Model 6 is the optimum model without the influence of other species in the catch.

Year	Records	Model 1	Model 6	Model 10
1986	9828	1.0000	1.0000	1.0000
1987	9339	1.4759	1.3847	1.3788
1988	10711	1.5684	1.4559	1.4324
1989	10403	1.4797	1.3777	1.3504
1990	8930	1.6093	1.5048	1.4907
1991	9323	1.5519	1.4165	1.4101
1992	8799	1.4952	1.2582	1.2400
1993	10195	1.2805	1.2219	1.2174
1994	11634	0.9416	0.8897	0.8945
1995	11038	0.9430	0.9199	0.9215
1996	11546	0.8448	0.8069	0.8032
1997	11342	0.8298	0.8229	0.8115
1998	10762	0.9351	0.8366	0.8244
1999	11023	1.0702	0.9948	0.9710
2000	11925	1.2426	1.2906	1.2479
2001	12503	1.2327	1.1485	1.1254
2002	13096	1.3951	1.2630	1.2415
2003	14058	1.3963	1.2996	1.2607
2004	13227	1.1443	1.1036	1.0710
2005	11767	0.9463	0.9628	0.9335

Ten statistical models were considered for the flathead data from trawlers (Table 6.5). Model 1 represents the overall geometric mean and Model 6 is the optimum model that does not include the effects of co-occurring species. Model 10 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects, although they appear small for flathead (Table 6.4).

Table 6.5. The factors involved in each of the ten statistical models trialled with flathead from trawlers. The factor names are as listed in Section 6.2.

Model	Factors
model 1	Year
model 2	Year Zone
model 3	Year Zone VesselID
model 4	Year Zone VesselID DepCat
model 5	Year Zone VesselID DepCat Zone*Month*DepCat
model 6	Year Zone VesselID DepCat Zone*Month*DepCat Month
model 7	add Reddum
model 8	add DumRed DumST
model 9	add DumRed DumST DumJM
model 10	add DumRed DumST DumJM Month*(DumRed DumST DumJM)

The statistical outcomes for each model show a steady increase in variability accounted for by the various models (Table 6.6). The optimum model without co-occurring species was Model 6, while with co-occurring species was model 10 (Table 6.4). The difference between these two optimal models is minor (Figure 6.2; Table 6.4 and Table 6.6).

Table 6.6. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum models (one with co-occurring species – Model 10 - and one without – Model 6, are bolded. Model 1 is the base case.

Model	N	Var%	df Params	df Resids	ModelSS	Resid SS	# Param	AIC
Model 1	**222563**	**3.15**	**19**	**222543**	**10263.7**	**315741**	**20**	**77873**
Model 2	222563	16.15	131	222431	52637.1	273367.7	132	46024.64
Model 3	222563	19.07	133	222429	62169.9	263834.9	134	38128.93
Model 4	221449	21.51	141	221307	69794.6	254630.4	142	31202.88
Model 5	221449	21.98	152	221296	71314.1	253110.9	153	29899.43
Model 6	**221449**	**25.95**	**420**	**221028**	**84181.3**	**240243.7**	**421**	**18881.6**
Model 7	221449	26.09	424	221024	84636.2	239788.8	425	18469.86
Model 8	221449	26.21	428	221020	85022.5	239402.5	429	18120.82
Model 9	221449	26.25	432	221016	85151.5	239273.5	433	18009.46
Model 10	**221449**	**26.68**	**564**	**220884**	**86556.4**	**237868.6**	**565**	**16969.4**

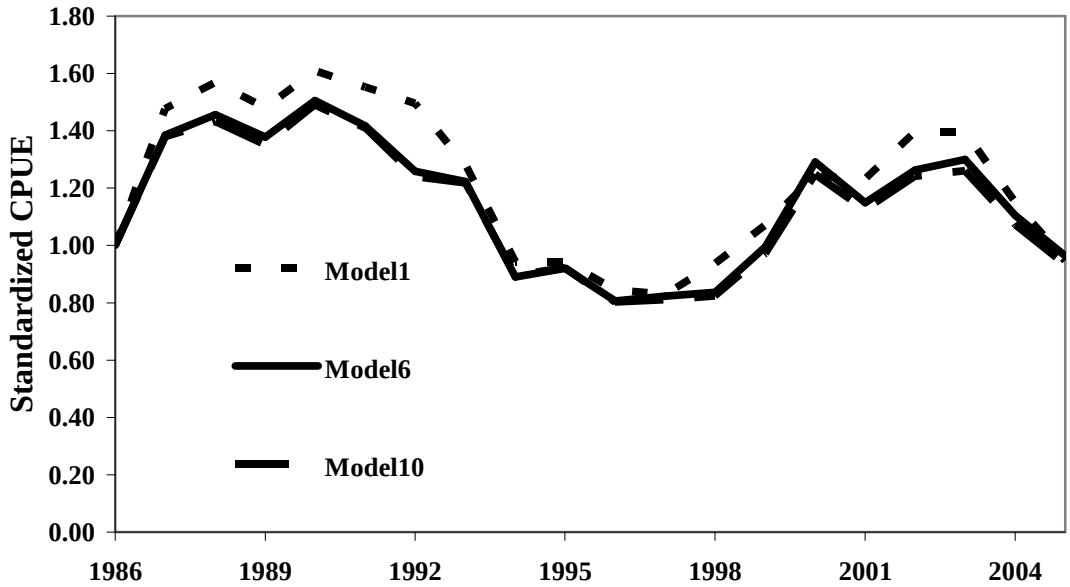


Figure 6.2. The standardized catch per unit of effort per year for flathead taken by trawl relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 6 – solid line), and with co-occurring species (model 10 – dashes, only just visible below the solid line) (see Table 6.4 for parameter values).

6.3.3 Flathead (Danish Seine only) FLT

The data restrictions used in selecting the data for analysis were:
Only data from zones 20 and 60 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for Danish Seine vessels only (i.e. exclude trawl vessels), and
depths less than 200 m.

As with flathead taken by trawl, the limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years did not reduce the number of records by any great amount. With these two conditions (plus those above) there were 88,293 records available for analysis for flathead taken by Danish Seine. If no restrictions are placed on the median catch and years in the fishery there would be 90,830 records. Thus, 96.98% of available records are used and these represent 97.2% of all estimated Danish Seine catches (Table 6.7).

Table 6.7. Number of records used in the CPUE standardization in each year for flathead from Danish Seiners only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 200m, and only zones 20 and 60. The geometric mean (Model 1) and the two optimum models (see Figure 6.3) are relative to 1986.

Year	Records	Model1	Model6	Model9
1986	2966	1.0000	1.0000	1.0000
1987	3069	1.9219	1.1232	1.1465
1988	3276	1.8475	1.2731	1.2831
1989	3362	1.6126	1.1784	1.1966
1990	2828	1.0078	0.7700	0.7814
1991	2987	1.5518	0.9874	1.0081
1992	4115	1.8233	1.1209	1.1565
1993	3365	0.8218	0.6988	0.7247
1994	4185	0.8255	0.6409	0.6580
1995	3529	0.7708	0.5692	0.5910
1996	5080	0.8579	0.7215	0.7342
1997	6483	1.4324	0.9890	0.9797
1998	7660	1.4418	0.7794	0.7815
1999	6488	2.3139	1.2589	1.2882
2000	6145	1.9068	0.9114	0.9149
2001	6316	1.7934	1.1398	1.1216
2002	5965	2.2084	1.2919	1.2838
2003	4096	2.7862	1.4732	1.4895
2004	3079	2.4796	1.2898	1.2740
2005	3299	2.2804	1.1513	1.1341

Nine statistical models were considered for the flathead data from Danish Seine vessels (Table 6.8). Attempts were made to include Silver Trevally as a dummy variable but this factor was not found to be significant and so was removed from the analysis. Model 1 represents the overall geometric mean and Model 6 is the optimum model that does not include the effects of co-occurring species. Model 9 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects, although they appear small for flathead (Table 6.7, Table 6.9; Figure 6.3).

Table 6.8. The factors involved in each of the nine statistical models trialled with flathead from trawlers. The factor names are as listed in Section 6.2.

Model	**Factors**
model 1	Year
model 2	Year VesselID
model 3	Year VesselID Zone
model 4	Year VesselID Zone DepCat
model 5	Year VesselID Zone DepCat Month
model 6	Year VesselID Zone DepCat Month Zone*Month*DepCat
model 7	add DumRed
model 8	add DumRed DumJM
model 9	add Month*(DumRed DumJM)

Table 6.9. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum models (one with co-occurring species – Model 9 - and one without – Model 6, are bolded. Model 1 is the base case.

Model	N	Var%	df Params	df Resids	ModelSS	Resid SS	# Param	AIC
Model 1	**89261**	**5.79**	**19**	**89241**	**12976**	**211001**	**20**	**76830.9**
Model 2	89261	12.89	37	89223	28860	195116	38	69880.7
Model 3	89261	26.92	38	89222	60294	163682	39	54202.3
Model 4	88293	34.48	42	88250	76329	145039	43	43909.4
Model 5	88293	39.13	53	88239	86618	134750	54	37434.5
Model 6	**88293**	**42.23**	**148**	**88144**	**93491**	**127876**	**149**	**33002.0**
Model 7	88293	42.29	151	88141	93622	127745	152	32917.4
Model 8	88293	42.73	155	88137	94598	126770	156	32248.6
Model 9	**88293**	**42.84**	**206**	**88086**	**94844**	**126523**	**207**	**32178.7**

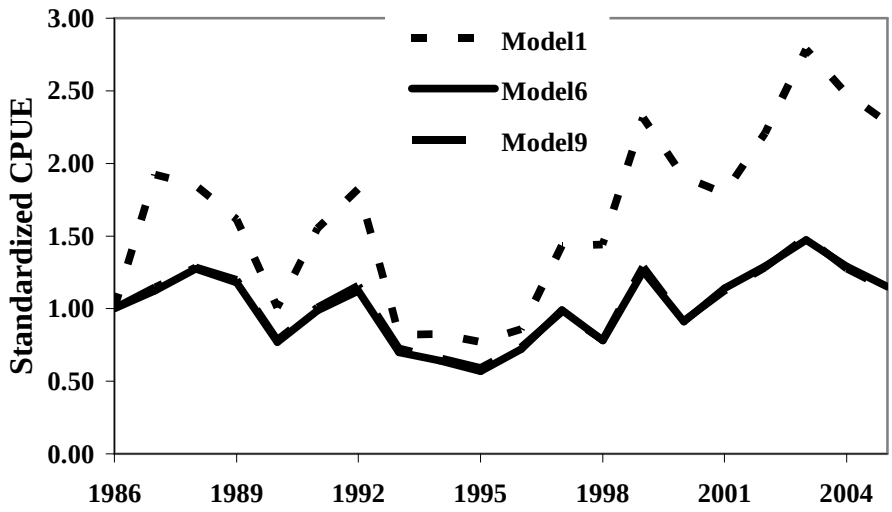


Figure 6.3. The standardized catch per unit of effort per year for flathead taken by Danish Seine relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 6 – solid line), and with co-occurring species (model 9 - dashes) (see Table 6.7 for parameter values). The effect of the co-occurring species is trivial and the dashed line is only just visible under the solid line.

A comparison of the standardized catch rates for trawls and Danish Seine indicates that the trends were effectively the same after 1996 and were similar before that (Figure 6.4).

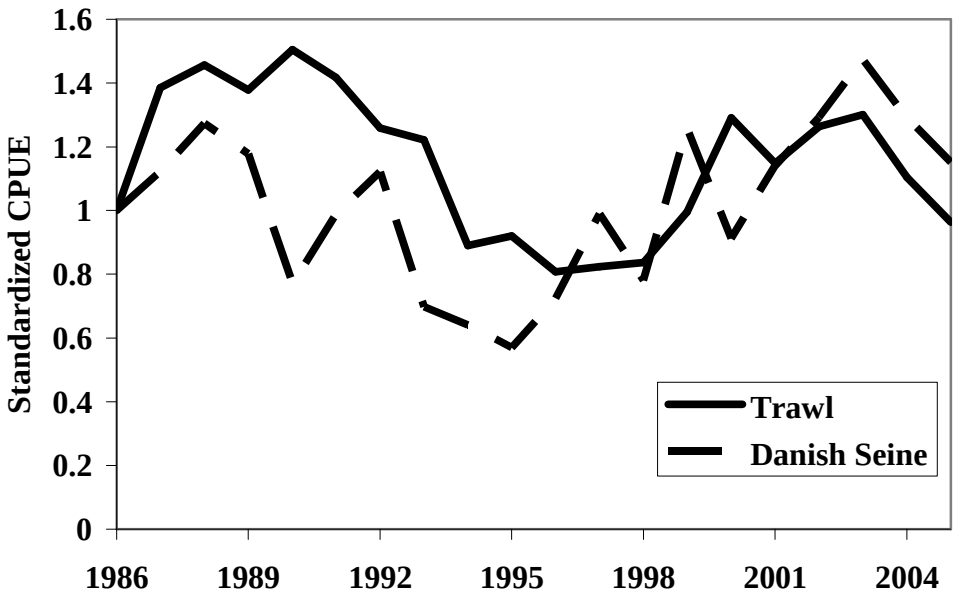


Figure 6.4. Comparison of the optimum Model 6 of standardized CPUE from both Danish Seine and Trawlers for flathead.

6.3.4 RedFish Zone 11 Only

Redfish are assessed as two separate populations: Zone 11 is within Zone 10 and includes all fishing north of 36^0, while Zone 21 is all catches in the east south of 36^0. Here they will be treated as two independent standardizations.
The data restrictions used in selecting the data for analysis were:
Only data from zone 11 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years did not reduce the number of records by any great amount. With these two conditions (plus those above) there were 33,792 records available for analysis for Redfish taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 36,899 records. Thus, 91.6% of available records are used and these represent 95.7% of all catches (Table 6.10).

Table 6.10. Number of records used in the CPUE standardization in each year for Redfish from trawls only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 11. The geometric mean (Model 1) and the two optimum models (see Figure 6.5) are relative to 1986.

Year	Records	Model1	Model5	Model9
1986	2532	1.0000	1.0000	1.0000
1987	2267	0.9362	0.8770	0.9451
1988	1650	0.8811	0.8237	0.9124
1989	1361	0.8035	0.7716	0.9068
1990	961	1.3154	1.5095	1.8464
1991	1296	1.1785	1.3084	1.6507
1992	1509	1.5029	1.3745	1.4878
1993	2073	1.3529	1.6433	1.7488
1994	2590	0.7783	1.0353	1.1994
1995	2469	0.7963	0.8015	0.9388
1996	1923	0.7747	0.6724	0.7820
1997	1370	0.9052	0.8163	0.9006
1998	1428	1.3433	1.0988	1.2165
1999	1576	0.9580	0.8571	0.9854
2000	1541	0.7326	0.5599	0.6734
2001	1603	0.6796	0.6257	0.7687
2002	1610	0.8020	0.6239	0.8142
2003	1341	0.7168	0.5858	0.7189
2004	1447	0.5597	0.4603	0.5416
2005	1245	0.4724	0.3625	0.3760

Nine statistical models were considered for the Redfish data from trawl vessels in Zone 11 (Table 6.11). Model 1 represents the overall geometric mean and Model 5 is the optimum model that does not include the effects of co-occurring species. Model 9 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects. For Redfish, co-occurring species certainly influence the apparent trend (Table 6.10, Table 6.12, Figure 6.5).

Table 6.11. The factors involved in each of the ten statistical models trialled with Redfish from trawlers in Zone 11. The factor names are as listed in Section 6.2.

Model	Factors
model 1	Year
model 2	Year VesselID
model 3	Year VesselID DepCat
model 4	Year VesselID DepCat Month
model 5	Year VesselID DepCat Month Month*DepCat
model 6	add DumFH
model 7	add DumFH DumST
model 8	add DumFH DumST DumJM
model 9	add DumFH DumST DumJM Month*(DumFH DumST DumJM)

Table 6.12. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum models (one with co-occurring species – Model 9 - and one without – Model 5, are bolded. Model 1 is the base case.

Model	N	Var %	df Params	df Resids	Model SS	Resid SS	# Param	AIC	Deviance
Model1	**33884**	**2.34**	**19**	**33864**	**2518.5**	**105112.7**	**20**	**38399.7**	
Model2	33884	14.23	78	33805	15320.3	92310.9	79	34117.2	0.255788
Model3	33792	17.18	86	33705	18433.4	88881.8	87	32853.7	0.226924
Model4	33792	17.37	97	33694	18641.5	88673.6	98	32796.4	0.008445
Model5	**33792**	**19.96**	**181**	**33610**	**21421.6**	**85893.6**	**182**	**31888.1**	**0.009216**
Model6	33792	21.7	185	33606	23282.5	84032.7	186	31155.9	0.193791
Model7	33792	23.54	189	33602	25257.9	82057.2	190	30360.0	0.118976
Model8	33792	23.75	193	33598	25483.9	81831.3	194	30274.9	0.005223
Model9	**33792**	**24.64**	**312**	**33479**	**26447.3**	**80867.9**	**313**	**30112.7**	**0.010283**

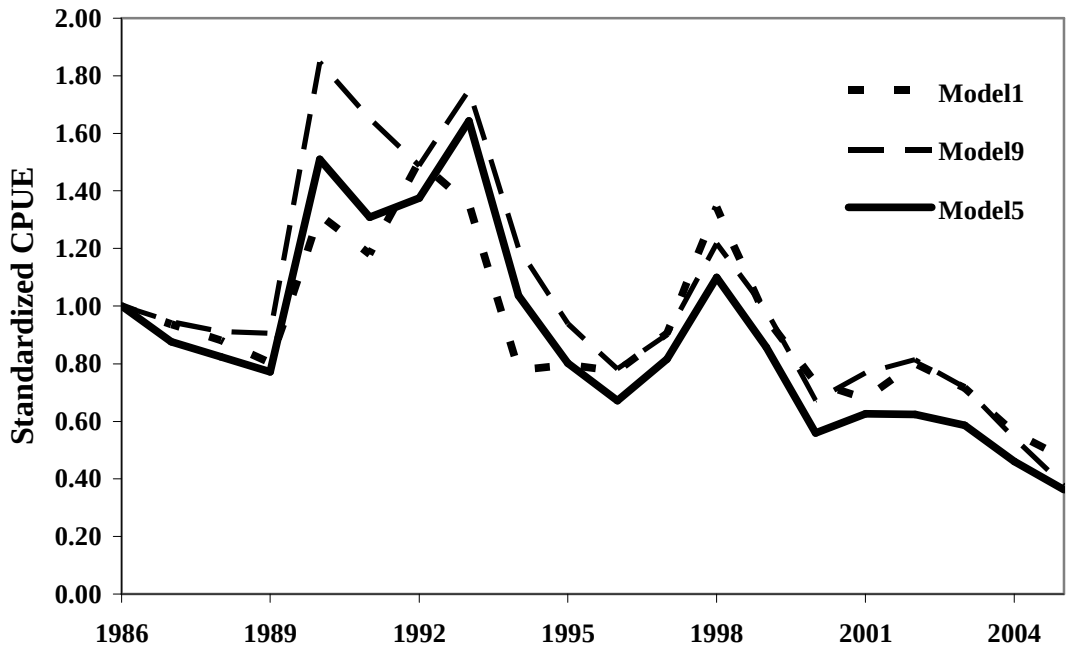


Figure 6.5. The standardized catch per unit of effort per year for Redfish taken by trawl vessels relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 5 – solid line), and with co-occurring species (model 9 - dashes) (see Table 6.9 for parameter values). The effect of the co-occurring species is not trivial in this case; in the last few years Model 9 is almost coincident with the geometric mean (Model 1).

6.3.5 RedFish Zone 21 Only

Zone 21 is everything on the east coast south of 36^0.
The data restrictions used in selecting the data for analysis were identical to those for zone 11:
Only data from zone 21 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records to some extent. With these two conditions (plus those above) there were 43,109 records available for analysis for Redfish taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 49,438 records. Thus, 87.2% of available records are used and these represent 92.7% of all catches (Table 6.13).

Table 6.13. Number of records used in the CPUE standardization in each year for Redfish from trawls only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 200m, and only zones 11. The geometric mean (Model 1) and the two optimum models (see Figure 6.6) are relative to 1986

Year	Records	Model1	Model5	Model10
1986	1504	1.0000	1.0000	1.0000
1987	1082	0.8757	0.7919	0.8021
1988	1727	1.1455	1.0944	1.0817
1989	1122	0.6627	0.6436	0.6501
1990	1406	0.8107	0.8848	0.8607
1991	2145	0.9518	1.1046	1.0483
1992	1728	0.9486	1.2364	1.1573
1993	1803	1.1731	1.4113	1.3514
1994	2814	1.1276	1.3330	1.2705
1995	2936	0.6982	0.7696	0.7775
1996	3192	0.6396	0.7005	0.6809
1997	2459	0.6973	0.7647	0.7403
1998	2345	0.7870	0.8738	0.8394
1999	2064	0.6510	0.7082	0.6808
2000	2484	0.4828	0.4805	0.4618
2001	2617	0.3552	0.4447	0.4195
2002	2901	0.3350	0.3988	0.3748
2003	2268	0.2703	0.3314	0.3177
2004	2165	0.2378	0.3102	0.3068
2005	2347	0.3255	0.3949	0.3864

Ten statistical models were considered for the Redfish data from trawl vessels in Zone 21 (Table 6.14). Model 1 represents the deviations from the overall geometric mean and Model 5 is the optimum model that does not include the effects of co-occurring species. Model 10 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects. For Redfish, co-occurring species can certainly influence the apparent trend (Table 6.13, Table 6.15, Figure 6.6).

Table 6.14. The factors involved in each of the ten statistical models trialled with Redfish from trawlers in Zone 21. The factor names are as listed in Section 6.2.

Model	Factors
model 1	Year
model 2	Year VesselID
model 3	Year VesselID DepCat
model 4	Year VesselID DepCat Month
model 5	Year VesselID DepCat Month Month*DepCat
model 6	add DumFH
model 7	add DumFH DumST
model 8	add DumFH DumST DumJM
model 9	add DumFH DumST DumJM Month*(DumFH DumST DumJM)
Model10	Year VesselID DepCat Month Month*DepCat VesselID*DepCat

Table 6.15. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model overall was Model 10 (without co-occurring species), which is bolded. Model 1 is the geometric average, the base case.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC	Deviance
Model1	**43246**	**0.09**	**19**	**43226**	**10494.6**	**106446.4**	**20**	**38993.3**	
Model2	43246	0.13	86	43159	15569.3	101371.7	87	37014.8	0.061596
Model3	43109	0.20	94	40.14	23316.4	93308.3	95	33477.8	0.222218
Model4	43109	0.21	105	43003	24135.3	92489.4	106	33119.8	0.006025
Model5	43109	0.22	191	42917	26046.6	90578.2	192	32391.6	0.005406
Model6	43109	0.23	195	42913	26472.2	90152.6	196	32196.6	0.008123
Model7	43109	0.23	199	42909	27255.8	89368.9	200	31828.2	0.003060
Model8	43109	0.23	203	42905	27355.7	89268.9	204	31788.0	0.000565
Model9	43109	0.24	335	42773	28106.2	88518.6	336	31688.1	0.001233
Model10	**43109**	**0.26**	**576**	**42532**	**29839.0**	**86785.7**	**577**	**31317.8**	**0.022628**

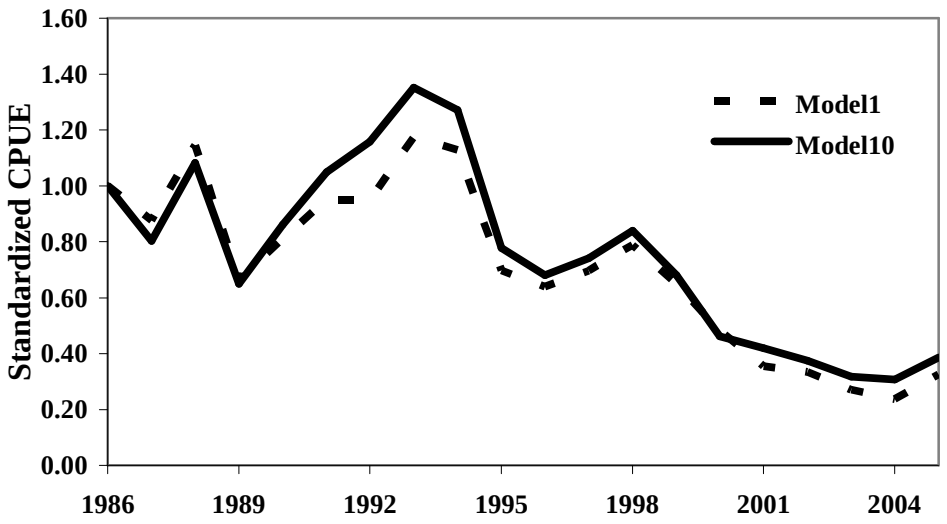


Figure 6.6. The standardized catch per unit of effort per year for Redfish taken by trawl vessels relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) and the optimal model (model 10 – solid line) (see Table 6.13 for parameter values). The optimal model involved two sets of interaction terms and no co-occurring species.

A comparison of the standardized CPUE trends from Zones 11 and 21 indicates that the trends in CPUE are similar in both areas.

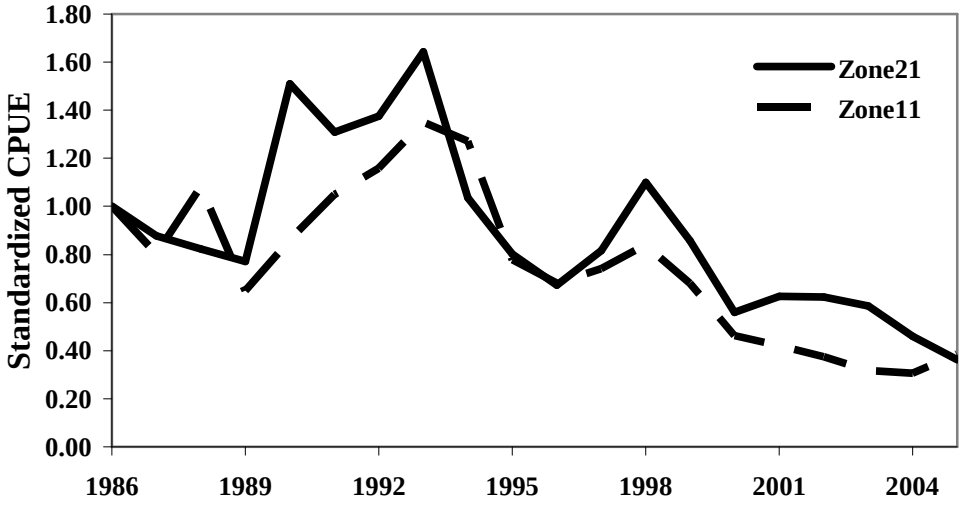


Figure 6.7. A comparison of the optimal statistical models for Redfish (without co-occurring species) taken in zones 11 and 21. Overall, there is little difference between the trends, although in the final year (2005) catch rates in zone 21 continue to trend down while those in 11 have turned upwards slightly.

6.3.6 Blue Warehou (East: Zones 10, 20 and 30). Calendar Year

The data restrictions used in selecting the data for analysis were:
Only data from zones 10, 20, and 30 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 22,189 records available for analysis for Blue Warehou taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 33,615 records. Thus, 66.00% of available records are used and these represent 76.96% of all catches (Table 6.16).

Table 6.16. Number of records used in the CPUE standardization in each calendar year for eastern Blue Warehou from trawls only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 10, 20, and 30. The geometric mean (Model 1) and the optimum model (Model 9) are relative to 1986 (see Figure 6.8).

Year	Records	Model1	Model9
1986	324	1.0000	1.0000
1987	274	0.9941	1.0877
1988	615	1.4634	1.3450
1989	893	1.9377	1.6936
1990	561	1.8893	1.6436
1991	1114	0.9273	0.9979
1992	1183	0.9559	0.7680
1993	1735	0.8156	0.5552
1994	2004	0.6773	0.5133
1995	2045	0.5444	0.4295
1996	2394	0.5843	0.4505
1997	1649	0.6519	0.5348
1998	1645	0.7022	0.5218
1999	1078	0.2752	0.2667
2000	1053	0.3082	0.2713
2001	752	0.1412	0.1469
2002	870	0.1100	0.1032
2003	759	0.0787	0.0938
2004	732	0.1356	0.1261
2005	509	0.0803	0.0815

Nine statistical models were considered for the eastern Blue Warehou calendar year data from trawl vessels (Table 6.17). Model 1 represents the overall geometric mean and Model 9 is the optimum model as determined by both variability described and AIC value (Table 6.18, Figure 6.8).

Table 6.17. The factors involved in each of the seven statistical models trialled with eastern Blue Warehou. The factor names are as listed in Section 6.2.

Model	Factors
Model 1	Year
Model 2	Year + VesselID
Model 3	Year + VesselID + DepCat
Model 4	Year + VesselID + DepCat + Month
Model 5	Year + VesselID + DepCat + Month + Zone
Model 6	Year + VesselID + DepCat + Zone*Month
Model 7	Year + VesselID + Zone*Month + DepCat*Zone
Model 8	Year + VesselID + Zone*Month + DepCat*Month
Model 9	Year + VesselID + Zone*Month + DepCat*Zone*Month

Table 6.18. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 9, is bolded. Model 1 is the base case; the geometric mean.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC	Deviance
Model1	**22275**	**19.62**	**19**	**22255**	**14899.1**	**61025.9**	**20**	**22489.49**	
Model2	22275	26.54	62	22212	20147.6	55777.4	63	20572.31	0.53309
Model3	22189	27.53	70	22118	20836.5	54859	71	20226.81	0.04859
Model4	22189	27.98	81	22107	21182.8	54512.7	82	20108.29	0.05673
Model5	22189	28.94	83	22105	21909.9	53785.6	84	19814.34	0.14415
Model6	22189	29.49	105	22083	22321.8	53373.7	106	19687.76	0.00414
Model7	22189	30.08	121	22067	22771.6	52923.9	122	19531.97	0.01347
Model8	22189	30.77	191	21997	23289.5	52405.9	192	19453.73	0.21452
Model9	**22189**	**31.84**	**290**	**21898**	**24103.1**	**51592.4**	**291**	**19304.58**	**0.03662**

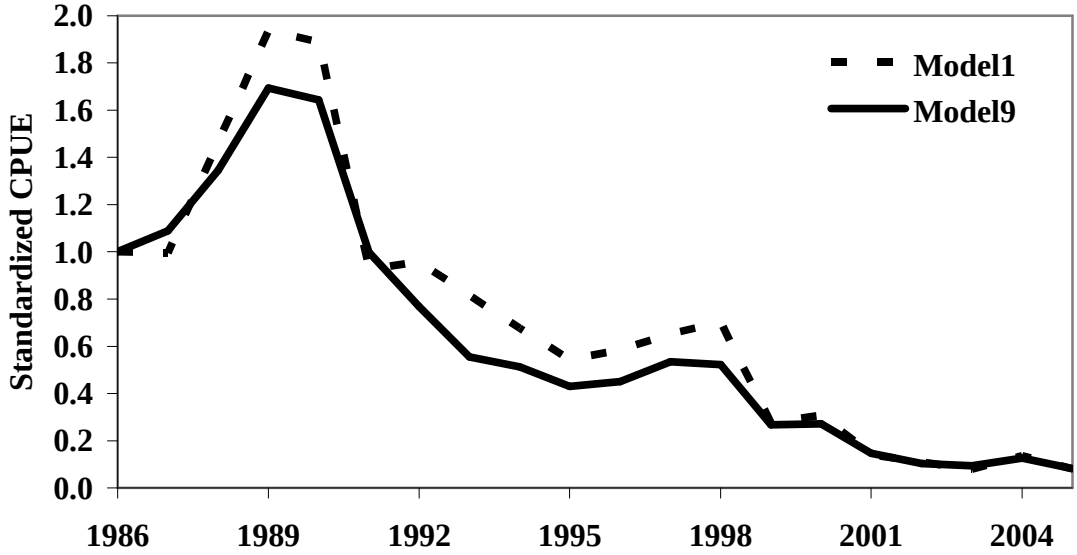


Figure 6.8. The standardized catch per unit of effort per year for Blue Warehou in the east for Calendar years, taken by trawl vessels relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 9 – solid line; see Table 6.16 for parameter values).

6.3.7 Blue Warehou (East: Zones 10, 20 and 30). Fishing Year (May 1st to Apr 30th)

The data restrictions used were the same for the calendar years:
Only data from zones 10, 20 , and 30 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986/1987 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years significantly reduced the number of records from those available. With these two conditions (plus those above) there were 21,794 records available for analysis for eastern Blue Warehou taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 32,963 records. Thus, 66.1% of available records are used and these represent 76.9% of all catches over the fishing years 1986/1987 to 2004/2005 (Table 6.19).

Table 6.19. Number of records used in the CPUE standardization in each fishing year period for eastern Blue Warehou from trawls only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 10, 20, and 30. The fishing year was from May 1st to April 30th. The geometric mean (Model 1) and the optimum model (Model 9) are relative to 1986/1987 (see Figure 6.9).

Fishing Year	Records	Model1	Model9
1986/1987	321	1.0000	1.0000
1987/1988	264	0.9319	1.1614
1988/1989	1039	1.6456	1.7555
1989/1990	478	1.9279	1.6667
1990/1991	672	1.5193	1.5258
1991/1992	1138	0.9083	1.1217
1992/1993	1457	0.8924	0.7234
1993/1994	1765	0.7261	0.5521
1994/1995	2081	0.6146	0.5201
1995/1996	2099	0.4935	0.4424
1996/1997	2256	0.5259	0.4623
1997/1998	1516	0.6625	0.5577
1998/1999	1499	0.6228	0.5087
1999/2000	1035	0.2426	0.2770
2000/2001	1124	0.2789	0.2650
2001/2002	696	0.1187	0.1453
2002/2003	976	0.0938	0.0982
2003/2004	885	0.1157	0.1432
2004/2005	493	0.0811	0.0849

The same nine statistical models were considered for the eastern Blue Warehou fishing year data as were used for calendar year data (Table 6.17). Model 1 represents the overall geometric mean and Model 9 is the optimum model as determined by both variability described and AIC value (Table 6.20; Figure 6.9).

Table 6.20. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 9, is bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	**21880**	**18.38**	**18**	**21861**	**13513**	**60005**	**19**	**22111.8**
Model2	21880	25.22	61	21818	18540	54978	62	20283.5
Model3	21794	26.23	69	21724	19224	54066	70	19941.6
Model4	21794	26.79	80	21713	19636	53655	81	19797.0
Model5	21794	27.82	82	21711	20392	52899	83	19491.6
Model6	21794	28.4	104	21689	20814	52476	105	19360.9
Model7	21794	29	120	21673	21261	52029	121	19206.4
Model8	21794	29.77	188	21605	21818	51471	189	19107.4
Model9	**21794**	**30.85**	**286**	**21507**	**22609**	**50681**	**287**	**18966.3**

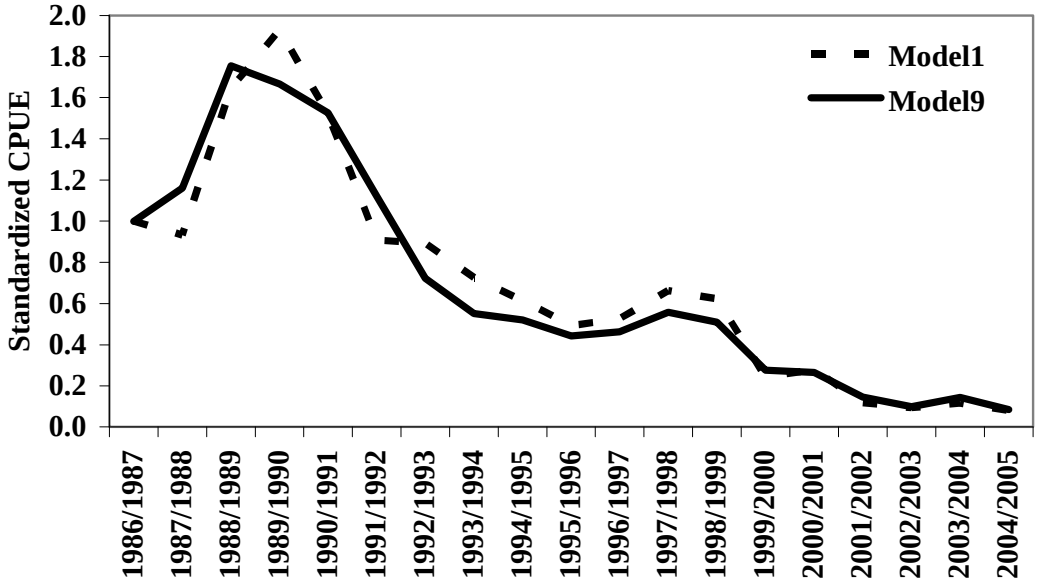


Figure 6.9. The standardized catch per unit of effort per year for Blue Warehou in the east for fishing years (May 1st to April 30th, relative to catch rates in 1986/1987, as represented by the geometric mean (model 1 - dots) the optimal model (model 9 – solid line, Table 6.19 for parameter values).

6.3.8 Blue Warehou (West: Zones 40 and 50). Calendar Year

The data restrictions used in selecting the data for analysis were:
Only data from zones 40 and 50 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 7,091 records available for analysis for western Blue Warehou taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 8,446 records. Thus, 83.96% of available records are used and these represent 85.99% of all catches (Table 6.21).

Table 6.21. Number of records used in the CPUE standardization in each calendar year period for western Blue Warehou from trawls only, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 40 or 50. The geometric mean (Model 1) and the optimum model (Model 8) are relative to 1986 (see Figure 6.10).

Year	Records	Model 1	Model 8
1986	32	1.0000	1.0000
1987	104	1.9556	0.5179
1988	77	0.9341	0.2664
1989	6	2.8828	0.8301
1990	248	0.8590	0.2751
1991	563	1.7397	0.3859
1992	463	0.9071	0.1717
1993	421	0.9440	0.1274
1994	681	0.6688	0.1416
1995	521	0.5065	0.0969
1996	428	0.2899	0.0592
1997	312	0.4787	0.0901
1998	375	0.8917	0.1261
1999	453	0.4546	0.0586
2000	457	0.3460	0.0548
2001	531	0.2838	0.0480
2002	428	0.3912	0.0594
2003	276	0.3748	0.0547
2004	337	0.3072	0.0803
2005	378	0.5607	0.1103

Nine statistical models were considered for the western Blue Warehou calendar year data (Table 6.21). Model 1 represents the overall geometric mean and Model 8 is the optimum model as determined by both variability described and AIC value (Table 6.23; Figure 6.10).

Table 6.22. The factors involved in each of the seven statistical models trialled with western Blue Warehou. The factor names are as listed in the Section 6.2.

Model	Factor
Model1	Year
Model2	Year + VesselID
Model3	Year + VesselID + Month
Model4	Year + VesselID + Month + DepCat
Model5	Year + VesselID + Month + DepCat + Zone
Model6	Year + Month + DepCat + Zone*VesselID
Model7	Year + Month + Zone*VesselID + Zone*DepCat
Model8	Year+ Zone*VesselID + Zone*DepCat +Zone*Month
Model9	Year + Zone*VesselID*Month*DepCat

Table 6.23. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 8, is bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	**7104**	**9.14**	**19**	**7084**	**2095**	**20825**	**20**	**7680.3**
Model2	7104	14.64	45	7058	3355	19565	46	7289.0
Model3	7104	23.5	56	7047	5385	17534	57	6532.3
Model4	7091	26.39	64	7026	6040	16850	65	6267.4
Model5	7091	26.46	65	7025	6055	16834	66	6262.7
Model6	7091	26.58	74	7016	6084	16805	75	6268.5
Model7	7091	26.67	80	7010	6103	16786	81	6272.4
Model8	**7091**	**27.61**	**90**	**7000**	**6318**	**16571**	**91**	**6201.0**
Model9	7091	37.98	779	6311	8692	14197	780	6482.6

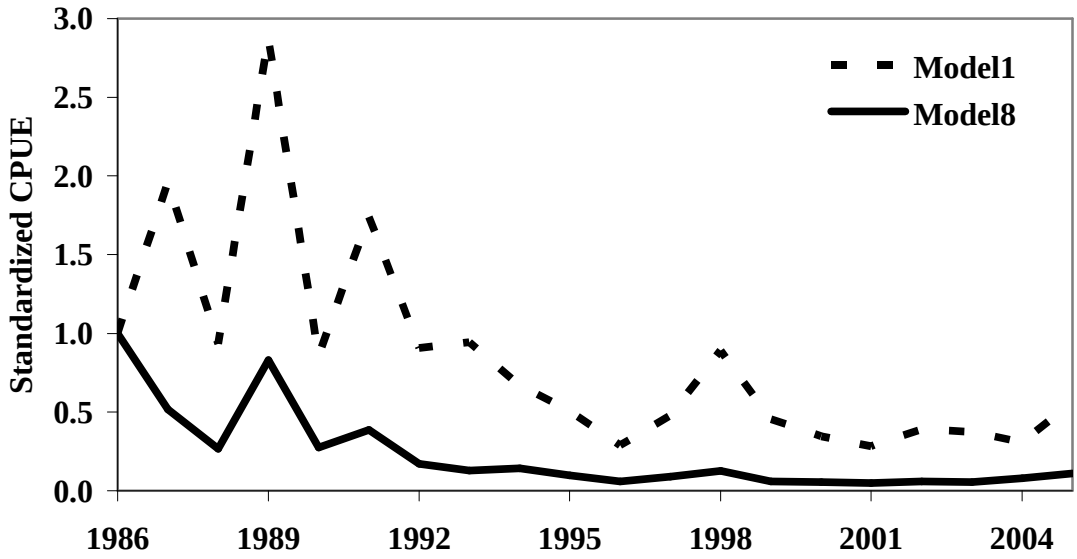


Figure 6.10. The standardized catch per unit of effort per year for Blue Warehou in the west for calendar years, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 8– solid line; see Table 6.21 for parameter values).

6.3.9 Blue Warehou (West: Zones 40 and 50). Fishing Year

The data restrictions used in selecting the data for analysis were:
Only data from zones 40 and 50 were used,
a median catch greater than 4 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986/1987 onwards until 2003/2004,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 6,726 records available for analysis for western Blue Warehou taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 7,889 records. Thus, 84.12% of available records are used and these represent 86.81% of all catches (Table 6.24).

Table 6.24. Number of records used in the CPUE standardization in each fishing year period (May 1st to April 30th for western Blue Warehou, years in the fishery >2, median catch per year > 4 t, CE >0, Average Depth < 400m, and only zones 40 or 50. The geometric mean (Model 1) and the optimum model (Model 8) are relative to 1986/1987 (see Figure 6.11).

Fishing Year	Records	Model1	Model8
1986/1987	30	1.0000	1.0000
1987/1988	109	1.7205	0.3910
1988/1989	73	1.1838	0.4248
1989/1990	20	0.1266	0.0807
1990/1991	239	1.0275	0.2689
1991/1992	579	1.6631	0.3365
1992/1993	466	0.9374	0.1517
1993/1994	561	0.8919	0.1344
1994/1995	564	0.6776	0.1119
1995/1996	531	0.5166	0.0870
1996/1997	393	0.2703	0.0459
1997/1998	322	0.6022	0.0957
1998/1999	344	0.9252	0.1060
1999/2000	458	0.4572	0.0527
2000/2001	470	0.3435	0.0480
2001/2002	520	0.2996	0.0436
2002/2003	438	0.3949	0.0523
2003/2004	298	0.3569	0.0489
2004/2005	311	0.3382	0.0716

Nine statistical models were considered for the western Blue Warehou fishing year data and these were the same as for the calendar year except that fishing year was used instead of Year (Table 6.22). Model 1 represents the overall geometric mean and Model 8 is the optimum model as determined by both variability described and AIC value (Table 6.25, Figure 6.11).

Table 6.25. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 8, is bolded. Model 1 is the base case.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	6739	9.61	18	6720	2089	19661	19	7253.6
Model2	6739	15.30	44	6694	3327	18423	45	6867.3
Model3	6739	25.06	55	6683	5451	16299	56	6063.8
Model4	6726	27.76	63	6662	6030	15690	64	5825.2
Model5	6726	27.83	64	6661	6045	15675	65	5820.8
Model6	6726	27.95	72	6653	6071	15650	73	5826.0
Model7	6726	28.02	78	6647	6087	15634	79	5831.2
Model8	6726	28.98	88	6637	6294	15427	89	5761.5
Model9	6726	39.40	755	5970	8558	16162	756	7408.6

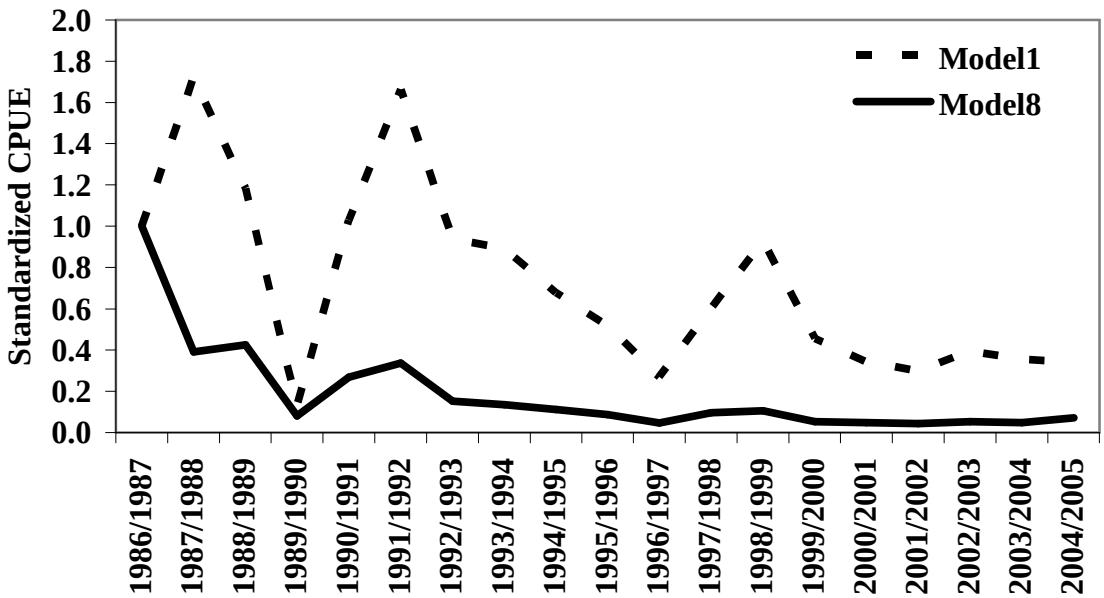


Figure 6.11. The standardized catch per unit of effort per year for Blue Warehou in the west for fishing years, relative to catch rates in 1986/1987, as represented by the geometric mean (model 1 - dots) the optimal model (model 8 – solid line; see Table 6.24 for parameter values).

6.3.10 Blue Grenadier Non-Spawning Calendar Year

The spawning fishery constitutes all records from zone 40 during the months of June, July, and August. All other records are taken as relating to the non-spawning fishery. The selection of data records was
Data from zones 10 to 60 except for 40 during June to August were used,
a median catch greater than 5 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards until 2004,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 2000 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 85,989 records available for analysis for non-spawning blue grenadier taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 105,707 records. Thus, 81.35% of available records are used and these represent 90.52% of all catches (Table 6.26).

Table 6.26. Number of records used in the CPUE standardization in each Calendar year period for non-spawning Blue Grenadier, years in the fishery >2, median catch per year > 5 t, CE >0, and Average Depth < 2000m. The geometric mean (Model 1) and the optimum model (Model 6) are relative to 1986 (see Figure 6.12).

Year	Records	Model 1	Model 5	Model 7
1986	1825	1.0000	1.0000	1.0000
1987	2296	1.2401	1.3928	1.4723
1988	2606	1.3046	1.4924	1.5725
1989	3022	1.3403	1.4468	1.4530
1990	2455	1.3325	1.4464	1.5121
1991	3541	1.3121	1.0751	1.1132
1992	3172	1.0418	0.9791	1.0046
1993	3724	0.8339	0.7490	0.7312
1994	4015	0.7378	0.6384	0.6402
1995	4541	0.4756	0.4398	0.4445
1996	4554	0.3990	0.3786	0.3836
1997	4758	0.3407	0.3817	0.3820
1998	4952	0.5008	0.6348	0.6616
1999	6437	0.6324	0.7115	0.7357
2000	6078	0.5032	0.6459	0.6633
2001	6277	0.3072	0.3043	0.3121
2002	5893	0.3424	0.3119	0.3138
2003	5341	0.2198	0.2257	0.2287
2004	5658	0.4006	0.4101	0.4192
2005	4844	0.4658	0.4629	0.4805

Seven statistical models were considered for the non-spawning Blue Grenadier calendar year data (Table 6.27). Model 1 represents the deviations from the overall geometric mean and Model 6 is the optimum model without a co-occurring species as determined by both variability described and AIC value, while Model 7, with Pink Ling was a slight improvement on Model 6 (Table 6.28, Figure 6.12).

Table 6.27. The factors involved in each of the six statistical models trialled with non-spawning Blue Grenadier by calendar year. The factor names are as listed in Section 6.2.

Model	Factors
Model 1	Year
Model 2	Year Zone
Model 3	Year Zone VesselID
Model 4	Year Zone VesselID DepCat
Model 5	Year Zone VesselID DepCat Month
Model 6	Year VesselID DepCat Month*Zone
Model 7	Year VesselID DepCat Month*Zone DumPL

Table 6.28. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 7, is bolded. Model 1 is the base case.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
1	**86206**	**10.16**	**19**	**86186**	**24014**	**212444**	**20**	**77792.5**
2	86189	14.95	28	86160	35351	201082	29	73074.8
3	86189	23.09	107	86081	54603	181831	108	64559.1
4	85972	29.88	142	85829	70379	165130	143	56400.9
5	85972	33.11	153	85818	77982	157527	154	52370.5
6	**85972**	**34.76**	**230**	**85741**	**81872**	**153637**	**231**	**50374.9**
7	**85972**	**34.80**	**234**	**85737**	**81948**	**153560**	**235**	**50339.8**

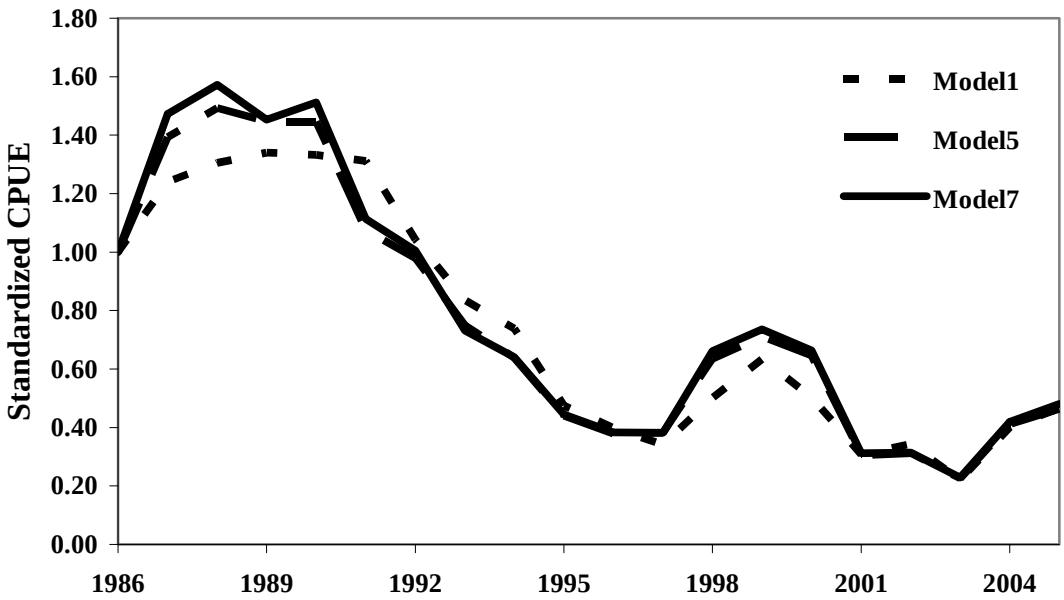


Figure 6.12. The standardized catch per unit of effort per year for non-spawning Blue Grenadier for calendar years, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (Model 6 – dashed lines) is very similar to the overall optimal model (model 7 – solid line; see Table 6.26 for parameter values).

6.3.11 Blue Grenadier Non-Spawning Fishery Fishing Year

The spawning fishery constitutes all records from zone 40 during the months of June, July, and August. All other records are taken as relating to the non-spawning fishery. The fishing year is taken as being from May 1st to April 30th. The selection of data records was
Data from zones 10 to 60 except for 40 during June to August were used,
a median catch greater than 5 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986/1987 onwards until 2004/2005,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 2000 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 82,683 records available for analysis for non-spawning blue grenadier taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 101,611 records. Thus, 81.37% of available records are used and these represent 90.99% of all catches (Table 6.29).

Table 6.29. Number of records used in the CPUE standardization in each fishing year (May 1st to April 30th) for non-spawning Blue Grenadier, years in the fishery >2, median catch per year > 5 t, CE >0, and Average Depth < 2000m. The geometric mean (Model 1) and the optimum model (Model 7) are relative to 1986 (see Figure 6.13). Model 6 is the optimum model without co-occurring species and is almost coincident with Model 7

Fishing Year	Records	Model 1	Model6	Model 7
1986/1987	1823	1.0000	1.0000	1.0000
1987/1988	2580	1.1154	1.2317	1.2331
1988/1989	3078	1.1861	1.2506	1.2482
1989/1990	2444	0.9887	1.2087	1.2066
1990/1991	3393	1.4003	1.1731	1.1722
1991/1992	3132	0.9934	0.8869	0.8878
1992/1993	3445	0.7445	0.6061	0.6047
1993/1994	3941	0.7225	0.5869	0.5862
1994/1995	4237	0.5624	0.4645	0.4654
1995/1996	4615	0.3467	0.3025	0.3046
1996/1997	4418	0.2920	0.2759	0.2782
1997/1998	4597	0.3326	0.3854	0.3879
1998/1999	5562	0.5549	0.6188	0.6221
1999/2000	6425	0.5764	0.7168	0.7222
2000/2001	6120	0.2813	0.2734	0.2748
2001/2002	6491	0.3235	0.2835	0.2842
2002/2003	5553	0.2246	0.2029	0.2033
2003/2004	5306	0.2555	0.2437	0.2446
2004/2005	5523	0.3591	0.3498	0.3499

The seven statistical models were considered for the non-spawning Blue Grenadier fishing year data were the same as for the calendar year (Table 6.30). Model 1 represents the overall geometric mean and Model 6 is the optimum model without a co-occurring species as determined by both variability described and AIC value, while Model 7, with Pink Ling was only trivially different from Model 6 (Table 6.31, Figure 6.13).

Table 6.30. The factors involved in each of the six statistical models trialled with non-spawning Blue Grenadier by fishing year. The factor names are as listed in Section 6.2.

Model	Factors
Model 1	Year
Model 2	Year Zone
Model 3	Year Zone DepCat
Model 4	Year Zone DepCat VesselID
Model 5	Year Zone DepCat VesselID Month
Model 6	Year Zone DepCat VesselID Month Month*Zone
Model 7	Year Zone DepCat VesselID Month Month*Zone DumPL

Table 6.31. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Param is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum model – Model 7, is bolded. Model 1 is the base case.

Model	N	Var%	df Param	df Resids	Model SS	Resid SS	# Param	AIC
1	**82899**	**10.89**	**18**	**82880**	**24773**	**202692**	**19**	**74155.1**
2	82882	15.65	27	82854	35603	191837	28	69612.9
3	82882	23.66	106	82775	53804	173637	107	61509.3
4	82666	30.7	141	82524	69538	156982	142	53299.6
5	82882	33.65	152	82513	76224	150296	153	49636.4
6	**82882**	**35.19**	**228**	**82437**	**79707**	**146812**	**229**	**47844.5**
7	**82882**	**35.22**	**232**	**82433**	**79779**	**146741**	**233**	**47812.4**

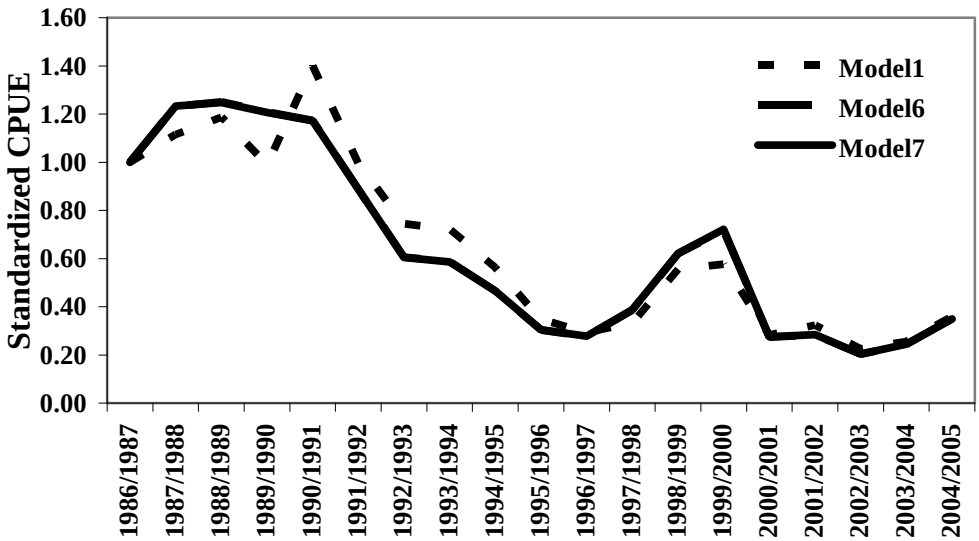


Figure 6.13. The standardized catch per unit of effort per year for non-spawning Blue Grenadier for fishing years, relative to catch rates in 1986/1987 (represented as 1986), as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (Model 6) is effectively coincident with the overall optimal model (model 7 – solid line; see Table 6.28 for parameter values).

6.3.12 Blue Grenadier Spawning Fishery, Calendar Year

The spawning fishery constitutes all records from zone 40 during the months of June, July, and August. Because the spawning fishery only runs from June to August the fishing year is the same as the calendar year. The selection of data records was
Data from zone 40 during June to August,
a median catch greater than 5 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards until 2004,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 2000 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 9,238 records available for analysis for non-spawning blue grenadier taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 9,969 records. Thus, 88.28% of available records are used and these represent 92.67% of all catches (Table 6.32).

Table 6.32. Number of records used in the CPUE standardization in each year for the spawning fishery for Blue Grenadier, years in the fishery >2, median catch per year > 5 t, CE >0, and Average Depth < 2000m. The geometric mean (Model 1) and the optimum model (Model 6) are relative to 1986 (see Figure 6.14). Model 5 is the optimum model without co-occurring species and this time is not almost coincident with overall optimum Model 6.

Year	Records	Model1	Model5	Model6
1986	65	1.0000	1.0000	1.0000
1987	196	1.6746	1.1600	1.0760
1988	92	1.1750	2.8295	2.3455
1989	31	0.4029	0.5833	0.6336
1990	141	0.9338	0.6822	0.8684
1991	129	1.9275	2.9344	3.2640
1992	168	1.3311	0.9966	1.1381
1993	148	1.5828	2.3344	2.8738
1994	318	1.0263	1.2360	1.6451
1995	476	0.2107	0.4965	0.8028
1996	493	0.2319	0.7174	1.0612
1997	421	0.1608	0.5904	0.8342
1998	578	0.4047	0.7412	0.9468
1999	857	0.8231	0.5880	0.7896
2000	950	1.0645	0.5975	0.8878
2001	1112	1.6543	1.0681	1.4750
2002	1047	1.1994	0.7753	1.0217
2003	1014	2.1856	0.6500	0.7726
2004	735	0.8245	0.5096	0.6077
2005	267	0.2414	0.6020	0.7570

Six statistical models were considered for the spawning Blue Grenadier fishery data (Table 6.33). Model 1 represents the deviations from the overall geometric mean and Model 5 is the optimum model without a co-occurring species as determined by both variability described and AIC value, while Model 6, with Pink Ling was an improvement on Model 5 (Table 6.34; Figure 6.14).

Table 6.33. The factors involved in each of the six statistical models trialled with spawning fishery Blue Grenadier. The factor names are as listed in Section 6.2.

Model	**Factors**
Model 1	Year
Model 2	Year Vess
Model 3	Year Vess DepCat
Model 4	Year Vess DepCat weeknum
Model 5	Year Vess DepCat weeknum weeknum*DepCat
Model 6	Year Vess DepCat weeknum weeknum*DepCat DumPL

Table 6.34. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Param is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 6, is bolded. Model 1 is the base case.

Model	**N**	**Var%**	**df Param**	**df Resids**	**Model SS**	**Resid SS**	**# Param**	**AIC**
1	**9278**	**6.01**	**19**	**9258**	**5570**	**87049**	**20**	**20811.8**
2	9278	53.51	70	9207	49564	43055	71	14382.2
3	9238	59.58	97	9140	55045	37344	98	13100.1
4	9238	61.74	111	9126	57041	35349	112	12620.9
5	**9238**	**63.99**	**343**	**8894**	**59127**	**33262**	**344**	**12522.7**
6	**9238**	**65.96**	**347**	**8890**	**60945**	**31445**	**348**	**12011.8**

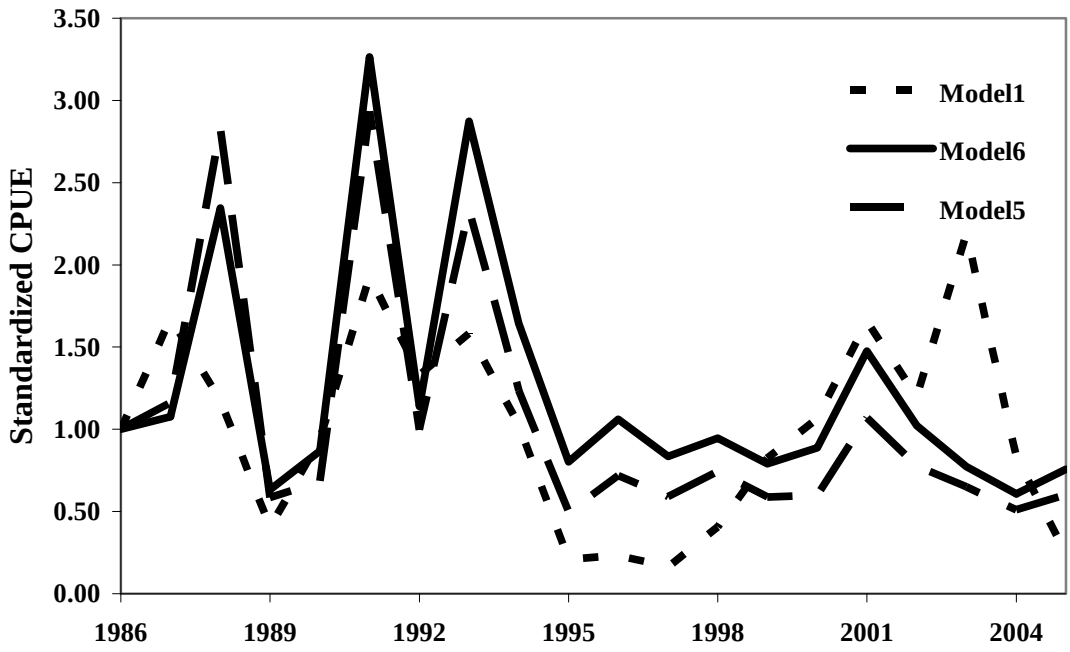


Figure 6.14. The standardized catch per unit of effort per year for the spawning fishery for Blue Grenadier, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (Model 5 – dashed line) is somewhat different from the overall optimal model (model 6 – solid line; see Table 6.32 for parameter values).

6.3.13 Alternative Spawning Blue Grenadier Analyses

Questions have once again been asked about the validity of the CPUE standardizations when the fleet is made up of such disparate vessels. Apart from the wet-boat fleet since 1997 there have been one or more large factory vessels fishing in the winter spawning fishery. These vessels are far more effective at catching fish than the rest of the fleet. Requests were made for three alternative analyses:

1. Completely exclude the large factory boats to determine the trend without them.
2. Included all the large boats (one was only present in a single year and another only present for two years so the data selection would exclude them).
3. Present an analysis only of the large vessels. A formal standardization would not be possible but any trends in catch rates could be considered (though rules about confidentiality will prevent a direct printing of the results they can still be discussed in general terms.

While the geometric mean catch rates are obviously affected by the inclusion or otherwise of the bog boats (Figure 6.15a), the impact on the optimum standardized model is less marked (Figure 6.15b). The inclusion of all big boats has only a minor impact on the standardization. The exclusion of the factory vessels only flattens the final four years of the catch rate series; the overall trend, except in 1999, remains approximately the same.

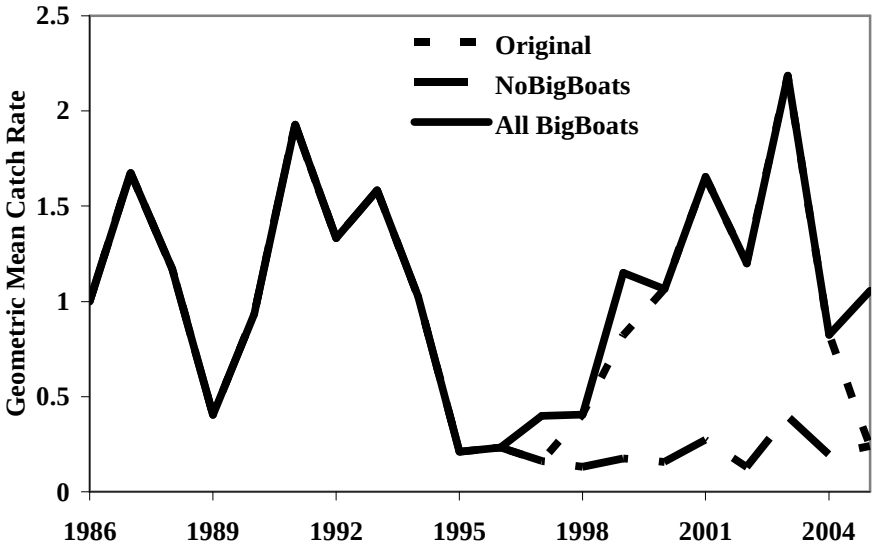


Figure 6.15a. The Geometric mean catch rate standardized to 1986 (Table 6.35). The impact of the factory vessels and the inclusion of the large vessels only present for one or two years is clear.

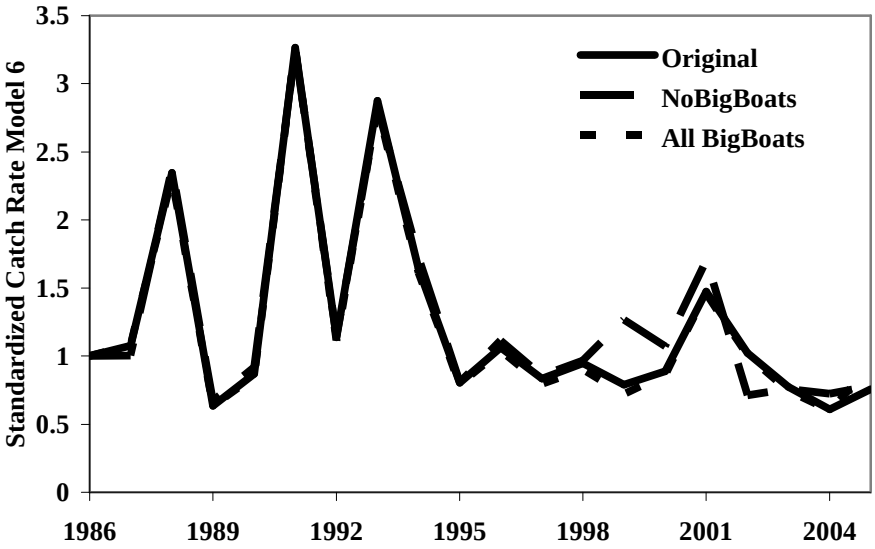


Figure 6.15b. The standardized catch rates as per Model 6 for the three alternative treatments (Table 6.35).

Table 6.35. Alternative analyses for the Blue Grenadier spawning fishery. The Original is a repeat of the parameters in Table 6.32 above, No Bog Boats shows the same parameters but excluding the catches of the factory vessels, finally, All Big Boats includes the factory vessels that were only present for one and two years (See Figure 6.15a and Figure 6.15b).

Year	Original Model1	No Big Boats Model1	All Big Boats Model1	Original Model 6	No Big Boats Model 6	All Big Boats Model 6
1986	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
1987	1.6746	1.6746	1.6746	1.0760	1.0025	1.0791
1988	1.1750	1.1750	1.1750	2.3455	2.3761	2.3073
1989	0.4029	0.4029	0.4029	0.6336	0.6680	0.6320
1990	0.9338	0.9338	0.9338	0.8684	0.9157	0.8507
1991	1.9275	1.9275	1.9275	3.2640	3.2501	3.2578
1992	1.3311	1.3311	1.3311	1.1381	1.1466	1.1148
1993	1.5828	1.5828	1.5828	2.8738	2.8210	2.8211
1994	1.0263	1.0263	1.0263	1.6451	1.7258	1.6139
1995	0.2107	0.2107	0.2107	0.8028	0.8064	0.7884
1996	0.2319	0.2319	0.2319	1.0612	1.1132	1.0395
1997	0.1608	0.1608	0.3994	0.8342	0.8555	0.7948
1998	0.4047	0.1315	0.4047	0.9468	0.9652	0.9028
1999	0.8231	0.1745	1.1500	0.7896	1.2676	0.7208
2000	1.0645	0.1560	1.0645	0.8878	1.0727	0.8618
2001	1.6543	0.2723	1.6543	1.4750	1.7064	1.4611
2002	1.1994	0.1292	1.1994	1.0217	0.7107	1.0033
2003	2.1856	0.3978	2.1856	0.7726	0.7581	0.7461
2004	0.8245	0.1946	0.8245	0.6077	0.7233	0.5985
2005	0.2414	0.2414	1.0563	0.7570	0.7804	0.9162

While it is not possible, for reasons of confidentiality to illustrate the catch rates only of the factory vessels if is possible to say that the catch rates in 2005 were almost three times the average of all previous years. It is not surprising that Industry perceptions reflect such large changes, which are not apparent in the standardization.

In summary, the alternative analyses do not demonstrate that there would be any advantages to removing the large factory vessels from consideration. They certainly have an effect of the time series but apart from in 1999 this is not large. This suggests that the standardization is performing relatively well.

6.3.14 Blue Eye, Eastern Fishery (Zones 20 and 30), Calendar Year

There were only an average of about 6 records a year from Zone 10 so this was omitted from consideration as constituting only noise. The data from the South East Non-Trawl and Gill, Hook, and Trap fishery was not considered, even though this makes up 10 times as much catch than trawl caught fish since 1999.
Data from zones 20 and 30,
a median catch greater than 1 tonne,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards until 2004,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 2000 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years significantly reduced the number of records (indicating there were a large number of small catches). With these two conditions (plus those above) there were 4,704 records available for analysis for non-spawning blue grenadier taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 10,490 records. Thus, only 44.8% of available records are used and these represent 60.6% of all catches (Table 6.36).

Table 6.36. Number of records used in the CPUE standardization in each calendar year for the eastern fishery for Blue Eye, years in the fishery >2, median catch per year > 1 t, CE >0, and Average Depth < 2000m. The geometric mean (Model 1) and the optimum model (Model 9) are relative to 1986 (see Figure 6.16).

Year	Records	Model 1	Model 9
1986	30	1.0000	1.0000
1987	95	1.8957	2.0259
1988	186	1.9904	2.2938
1989	96	2.8918	2.3088
1990	108	4.4091	3.1905
1991	246	1.3375	1.4659
1992	211	1.0655	1.1304
1993	434	1.4259	1.1580
1994	580	1.3274	1.1075
1995	229	1.0976	0.8010
1996	402	0.8078	0.7110
1997	362	0.6022	0.7394
1998	269	0.6395	0.7974
1999	351	0.5370	0.7981
2000	187	0.8378	0.7430
2001	164	0.6739	0.7460
2002	176	0.6536	0.5447
2003	225	0.3842	0.6304
2004	191	0.4130	0.4501
2005	162	0.4389	0.4146

Nine statistical models were considered for the eastern Blue Eye fishery data (Table 6.37). Model 1 represents the deviations from the overall geometric mean and Model 8 is the optimum model as determined by both variability described and AIC value (Table 6.38; Figure 6.16).

Table 6.37. The factors involved in each of the eight statistical models trialled with eastern fishery for Blue Eye. The factor names are as listed in Section 6.2.

Model	Factors
1	Year
2	Year+Vess
3	Year+Vess + DepCat
4	Year+Vess + DepCat + Month
5	Year+Vess + DepCat + Month + Zone
6	Year+Vess + DepCat + Zone*Month
7	Year+Vess + Zone*Month + DepCat*Month
8	Year+Vess + Zone*Month + DepCat*Month Zone*DepCat
9	Year + Vess + DepCat*Zone*Month

Table 6.38. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Param is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The deviance is the sum of the squared residual difference between sequential models. The optimum model – Model 9, is bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
1	**4711**	**13.51**	**19**	**4691**	**1391**	**8907**	**20**	**3040.6**
2	4711	33.48	40	4670	3448	6850	41	1845.6
3	4704	34.59	62	4641	3560	6731	63	1811.5
4	4704	35.85	73	4630	3689	6602	74	1742.5
5	4704	38.82	74	4629	3994	6296	75	1521.2
6	4704	39.47	85	4618	4061	6229	86	1492.9
7	4704	43.60	248	4455	4487	5804	249	1486.5
8	4704	44.13	264	4439	4542	5749	265	1473.7
9	**4704**	**46.00**	**340**	**4363**	**4734**	**5556**	**341**	**1465.1**

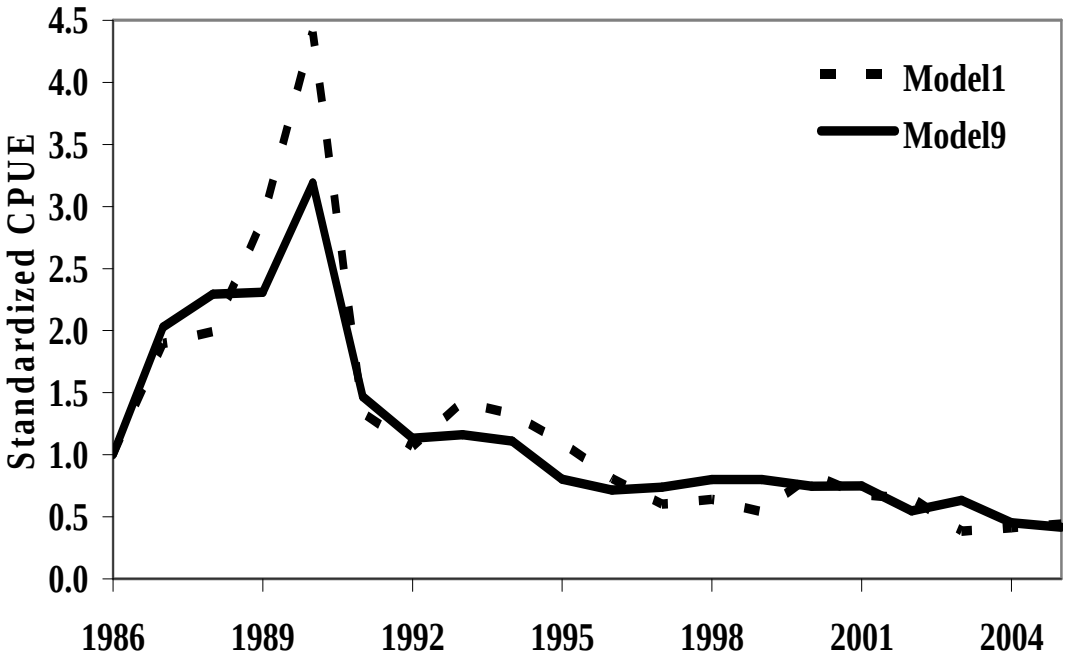


Figure 6.16. The standardized catch per unit of effort per year for the eastern fishery for Blue Eye, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model was Model 9 (solid line; see Table 6.36 for parameter values).

6.3.15 Blue Eye, Western Fishery (Zones 40 and 50), Calendar Year

VesselID=114 designates a vessel that was in the fishery for four years and reported some very large catches early in the history of the fishery. This single vessel has a disproportionate effect in 1988 that appears atypical and was therefore removed. For this reason extra columns are provided in the parameter table to include the vessel.
Data from zones 40 and 50,
a median catch greater than 1 tonne,
three or more years in the fishery,
catch rates greater than zero,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 2000 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records. With these two conditions (plus those above) there were 6,909 records available taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 9,761 records. Thus, only 70.78% of available records are used and these represent 71.1% of all catches (Table 6.39).

Table 6.39. Number of records used in the CPUE standardization in each year for the western fishery for Blue Eye, years in the fishery >2, median catch per year > 1 t, CE >0, and Average Depth < 2000m. The geometric mean (Model 1) and the optimum model (Model 6) are relative to 1986 (see Figure 6.17). Alt_6 is the same time series based on the same model structure but with the only difference being the inclusion of a single vessel in the years 1986 to 1989. This vessel reported only 385kg in 1986 and 550kg in 1987, but then reported 43.52 tonnes of Blue Eye in 1988 and 6.15 tonnes in 1989.

Year	Records	Model1	Alt_6	Model 6
1986	48	1.0000	1.0000	1.0000
1987	8	1.2105	0.4371	1.5043
1988	79	4.7934	3.8011	1.4586
1989	186	1.7452	2.9192	2.2309
1990	63	1.5636	3.0259	2.1622
1991	111	1.0881	1.5436	1.1250
1992	97	1.5291	2.1783	1.6356
1993	209	0.5859	0.8772	0.6523
1994	255	0.5490	0.9602	0.7164
1995	376	0.3729	0.8730	0.6549
1996	338	0.4715	0.9465	0.7039
1997	508	0.3048	0.8724	0.6493
1998	613	0.2631	1.0107	0.7537
1999	657	0.2991	0.9913	0.7347
2000	835	0.2741	0.8792	0.6609
2001	689	0.3142	0.8908	0.6525
2002	630	0.3073	0.7597	0.5632
2003	279	0.1473	0.5983	0.4466
2004	543	0.2330	0.5743	0.4294
2005	385	0.2020	0.5069	0.3787

The same nine statistical models were considered for the western Blue Eye fishery data as for the eastern fishery (Table 6.37). Model 1 represents the deviations from the overall geometric mean and Model 6 is the optimum model as determined by both variability described and AIC value (Table 6.40; Figure 6.17). In addition, the alternative standardization which excludes the effect of VesselID 114 (an arbitrary name) is presented also (Figure 6.17).

Table 6.40. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Param is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum model – Model 6, is bolded. Model 1 is the base case geometric mean catch rate (excludes Vessel 114).

Model	N	Var%	df Params	df Resids	Model SS	Resid SS	# Param	AIC
1	**6867**	**11.91**	**19**	**6847**	**1730**	**12793**	**20**	**4312.4**
2	6867	40.97	41	6825	5949	8574	42	1608.5
3	6854	43.32	67	6786	6277	8215	68	1377.5
4	6854	43.76	78	6775	6342	8150	79	1345.0
5	6854	44.05	79	6774	6383	8109	80	1312.4
6	**6854**	**44.34**	**90**	**6763**	**6426**	**8066**	**91**	**1298.0**
7	6854	46.54	261	6592	6744	7747	262	1363.4
8	6854	47.07	276	6577	6821	7671	277	1325.9
9	6854	48.16	353	6500	6979	7513	354	1337.2

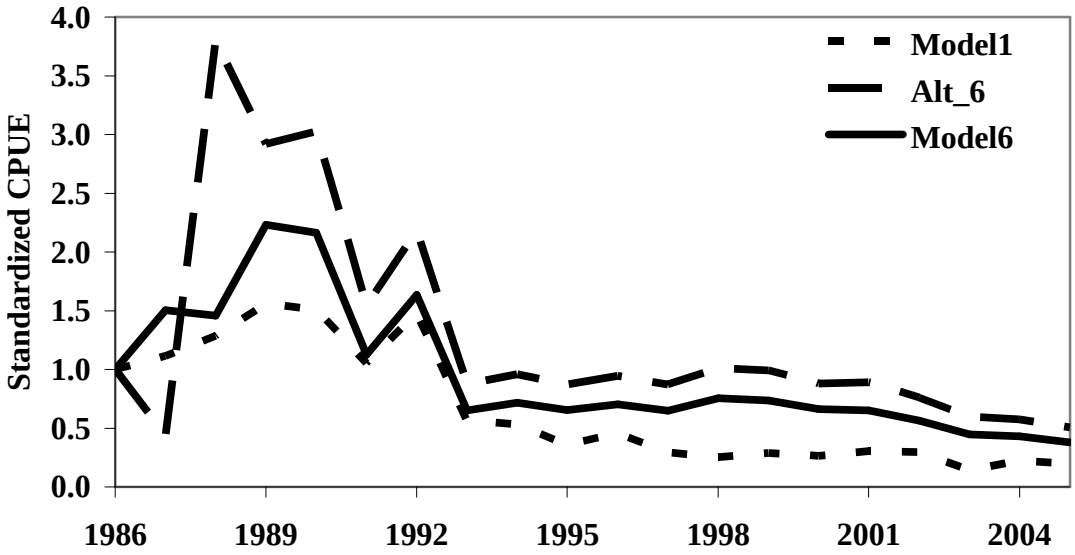


Figure 6.17. The standardized catch per unit of effort per year for the western fishery for Blue Eye, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model was Model 6 (solid line; see Table 6.40 for parameter values). Alt_6 represents the same model but with the inclusion of data from vessel 114.

6.3.16 Jackass Morwong Zone 10 & 20 Otter Trawl

Three standardizations were made to match the assessment; 1) Zones 10 and 20 for otter trawl, Zone 30 for otter trawl, and zones 10 and 20 for Danish Seine.
The data restrictions used in selecting the data for analysis were:
Only data from zone 10 and 20 were used,
a median catch greater than 2 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records available by about 16%. With these two conditions (plus those above) there were 87,538 records available for analysis for Jackass Morwong taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 104,280 records. Thus, 83.95% of available records are used and these represent 93.85% of all catches (Table 6.41).

Table 6.41. Number of records used in the CPUE standardization in each year for Jackass Morwong from trawls only, years in the fishery >2, median catch per year >2 t, CE >0, Average Depth < 400m, and only zones 10 and 20. The geometric mean (Model 1) and the two optimum models (see Figure 6.18) are relative to 1986.

Year	Records	Model1	Model6	Model7
1986	3788	1.0000	1.0000	1.0000
1987	3681	1.2087	1.1733	1.1984
1988	4687	1.1936	1.1017	1.1199
1989	4042	1.2267	1.0663	1.0834
1990	3703	0.9518	0.8659	0.9050
1991	3827	0.8505	0.7724	0.7927
1992	3160	0.7011	0.6237	0.6291
1993	3670	0.6941	0.6352	0.6451
1994	5065	0.6028	0.5566	0.5585
1995	4590	0.5826	0.5582	0.5606
1996	5457	0.5387	0.4820	0.4781
1997	5601	0.6075	0.5225	0.5222
1998	4302	0.4630	0.4214	0.4227
1999	4153	0.4463	0.4206	0.4264
2000	4937	0.3545	0.3446	0.3611
2001	4538	0.2346	0.2364	0.2452
2002	5127	0.2517	0.2674	0.2833
2003	4273	0.2125	0.2019	0.2126
2004	4140	0.2139	0.2044	0.2098
2005	4797	0.2757	0.2510	0.2554

Seven statistical models were considered for the Jackass Morwong data from trawl vessels in Zones 10 and 20 (Table 6.42). Model 1 represents the overall geometric mean and Model 6 is the optimum model that does not include the effects of co-occurring species. Model 7 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects. For Jackass Morwong, co-occurring species appear to have almost no effect on the apparent trend (Table 6.41, Table 6.43; Figure 6.18).

Table 6.42. The factors involved in each of the seven statistical models trialled with Jackass MOrwong from trawlers in Zones 10 and 20. The factor names are as listed in Section 6.2.

Model	Factors
model 1	Year
model 2	Year VesselID
model 3	Year VesselID DepCat
model 4	Year VesselID DepCat Month
model 5	Year VesselID DepCat Month Zone
model 6	Year VesselID Zone DepCat*Month
model 7	add DumFH

Table 6.43. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum models (one with co-occurring species – Model 7 - and one without – Model 6, are bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var %	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	**87908**	**13.94**	**19**	**87888**	**28778**	**177728**	**20**	**61924.0**
Model2	87908	21.71	101	87806	44836	161670	102	53763.4
Model3	87538	22.77	109	87428	46846	158904	110	52412.5
Model4	87538	24.63	120	87417	50678	155072	121	50297.7
Model5	87538	25.80	121	87416	53093	152657	122	48925.7
Model6	**87538**	**26.73**	**209**	**87328**	**54988**	**150762**	**210**	**48008.2**
Model7	**87538**	**27.29**	**213**	**87324**	**56157**	**149593**	**214**	**47334.8**

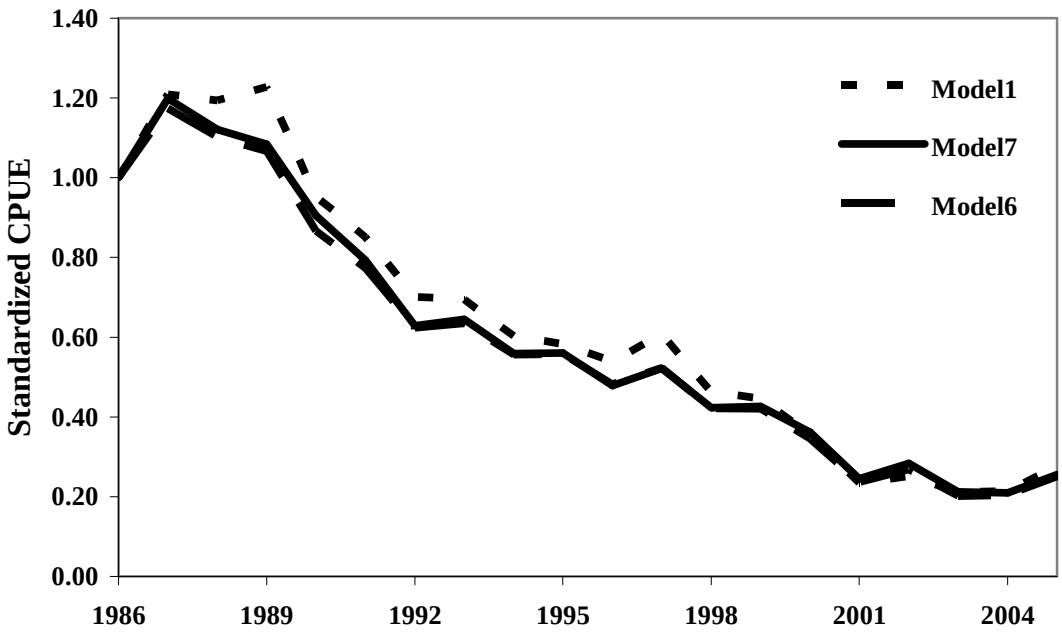


Figure 6.18. The standardized catch per unit of effort per year for Jackass Morwong taken by trawl vessels in Zones 10 and 20, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 6 – dashed), and with co-occurring species (model 7 – solid line) (see Table 6.9 for parameter values). The effect of the co-occurring species is trivial in this case; in the last few years Model 7 is almost coincident with the geometric mean (Model 1).

6.3.17 Jackass Morwong Zone 30 Otter Trawl

Three standardizations were made to match the assessment; 1) Zones 10 and 20 for otter trawl, 2) Zone 30 for otter trawl, and 3) zones 10 and 20 for Danish Seine.
The data restrictions used in selecting the data for analysis were:
Only data from zone 30 were used,
a median catch greater than 2 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for trawl vessels only (i.e. exclude Danish Seine vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records available by about 10%. With these two conditions (plus those above) there were 13,618 records available for analysis for Jackass Morwong taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 15,056 records. Thus, 90.45% of available records are used and these represent 90.9% of all catches (Table 6.44).

Table 6.44. Number of records used in the CPUE standardization in each year for Jackass Morwong from trawls only, years in the fishery >2, median catch per year >2 t, CE >0, Average Depth < 400m, and only zone 30. The geometric mean (Model 1) and the two optimum models (see Figure 6.19) are relative to 1986.

Year	Records	Model1	Model5	Model6
1986	64	1.0000	1.0000	1.0000
1987	152	0.8482	0.8972	0.9242
1988	250	1.6919	1.2021	1.2289
1989	543	2.8094	1.7107	1.7677
1990	286	1.4902	1.2466	1.2949
1991	342	1.3781	0.9383	0.9736
1992	377	1.0608	0.9784	1.0171
1993	845	1.0729	0.7612	0.7712
1994	713	0.8835	0.5245	0.5344
1995	789	0.7529	0.4988	0.5121
1996	827	0.6443	0.4998	0.5159
1997	850	0.7239	0.6014	0.6041
1998	683	0.7848	0.5703	0.5624
1999	849	0.9485	0.6598	0.6515
2000	495	0.6772	0.5145	0.5022
2001	755	0.3679	0.2992	0.3041
2002	1052	0.2974	0.2490	0.2404
2003	1100	0.4341	0.3527	0.3401
2004	1448	0.3597	0.2366	0.2244
2005	1198	0.2604	0.1753	0.1663

Six statistical models were considered for the Jackass Morwong data from trawl vessels in Zone 30 (Table 6.45). Model 1 represents the overall geometric mean and Model 6 is the optimum model that does not include the effects of co-occurring species. Model 7 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects. For Jackass Morwong, co-occurring species appear to have almost no effect on the apparent trend (Table 6.44, Table 6.46, Figure 6.19).

Table 6.45. The factors involved in each of the six statistical models trialled with Jackass Morwong from trawlers in Zone 30. The factor names are as listed in Section 6.2. These models differ from the previous Jackass Morwong analysis only by omitting the factor Zone.

Model	Factors
model 1	Year
model 2	Year VesselID
model 3	Year VesselID DepCat
model 4	Year VesselID DepCat Month
model 5	Year VesselID DepCat*Month
model 6	add DumFH

Table 6.46. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum models (one with co-occurring species – Model 6 - and one without – Model 5, are bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var %	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	**13676**	**18.14**	**19**	**13656**	**4922**	**22221**	**20**	**6678.3**
Model2	13676	25.07	72	13603	6806	20338	73	5573.3
Model3	13618	26.92	80	13537	7281	19766	81	5235.7
Model4	13618	33.59	91	13526	9084	17963	92	3955.1
Model5	**13618**	**35.12**	**169**	**13448**	**9498**	**17549**	**170**	**3793.6**
Model6	**13618**	**35.37**	**173**	**13444**	**9566**	**17481**	**174**	**3748.7**

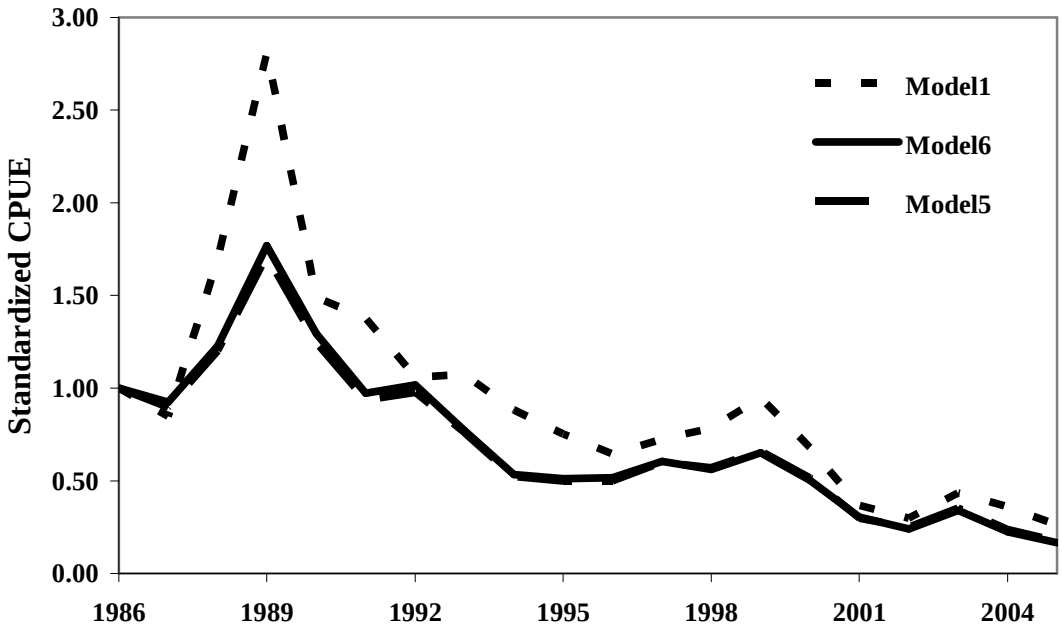


Figure 6.19. The standardized catch per unit of effort per year for Jackass Morwong taken by trawl vessels in Zone 30, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 5 – dashed), and with co-occurring species (model 6 – solid line) (see Table 6.44 for parameter values). The effect of the co-occurring species is trivial in this case.

6.3.18 Jackass Morwong Zone 10 & 20 Danish Seine

Three standardizations were made to match the assessment; 1) Zones 10 and 20 for otter trawl, 2) Zone 30 for otter trawl, and 3) zones 10 and 20 for Danish Seine.
The data restrictions used in selecting the data for analysis were:
Only data from zone 10 and 20 were used,
a median catch greater than 0.75 tonnes,
three or more years in the fishery,
catch rates greater than zero,
from 1986 onwards,
for Danish Seine vessels only (i.e. exclude Trawl vessels), and
depths less than 400 m.

The limits on a minimum median catch for the years each vessel had been in the fishery and the requirement that the vessel be in the fishery for at least three years reduced the number of records available by about 4%. With these two conditions (plus those above) there were 9,107 records available for analysis for Jackass Morwong taken by trawl. If no restrictions are placed on the median catch and years in the fishery there would be 9,499 records. Thus, 95.87% of available records are used and these represent 95.3% of all catches (Table 6.47).

Table 6.47. Number of records used in the CPUE standardization in each year for Jackass Morwong from Danish Seiners only, years in the fishery >2, median catch per year >0.75 t, CE >0, Average Depth < 400m, and only zones 10 and 20. The geometric mean (Model 1) and the two optimum models (see Figure 6.20) are relative to 1986.

Year	Records	Model1	Model6	Model7
1986	39	1.0000	1.0000	1.0000
1987	198	1.4124	1.2471	1.1971
1988	227	2.1350	1.3335	1.2876
1989	212	1.5877	1.4230	1.3912
1990	176	4.0069	3.2252	2.9105
1991	140	1.2931	1.0117	0.9627
1992	265	1.2810	0.8601	0.8239
1993	77	0.5820	0.4086	0.3817
1994	138	0.3052	0.2927	0.2674
1995	86	0.3333	0.2194	0.2101
1996	343	0.9881	0.4350	0.4077
1997	802	0.9928	0.4629	0.4354
1998	938	0.9519	0.4570	0.4285
1999	631	0.6780	0.3303	0.3187
2000	734	1.0244	0.5933	0.5568
2001	913	1.7753	0.9183	0.8673
2002	961	1.4652	0.6889	0.6469
2003	773	0.9525	0.6192	0.5771
2004	654	0.6079	0.4252	0.4004
2005	800	0.6612	0.4359	0.4072

Seven statistical models were considered for the Jackass Morwong data from trawl vessels in Zones 10 and 20 (Table 6.48). Model 1 represents the overall geometric mean and Model 6 is the optimum model that does not include the effects of co-occurring species. Model 7 is the overall statistically optimum model but the use of co-occurring species may be having unexpected and undesirable effects. For Jackass Morwong, co-occurring species appear to have almost no effect on the apparent trend (Table 6.47, Table 6.49; Figure 6.20).

Table 6.48. The factors involved in each of the seven statistical models trialled with Jackass Morwong from Danish Seiners in Zones 10 and 20. The factor names are as listed in Section 6.2.

Model	Factors
model 1	Year
model 2	Year VesselID
model 3	Year VesselID DepCat
model 4	Year VesselID DepCat Month
model 5	Year VesselID DepCat Month Zone
model 6	Year VesselID Zone DepCat*Month
model 7	add DumFH

Table 6.49. Outcomes for each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Params is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum models (one with co-occurring species – Model 7 - and one without – Model 6, are bolded. Model 1 is the base case geometric mean catch rate.

Model	N	Var %	df Params	df Resids	Model SS	Resid SS	# Param	AIC
Model1	**9138**	**7.25**	**19**	**9118**	**1735**	**22199**	**20**	**8150.9**
Model2	9138	19	32	9105	4549	19385	33	6938.3
Model3	9107	21.27	37	9069	5067	18759	38	6657.0
Model4	9107	24.94	48	9058	5943	17883	49	6243.5
Model5	9107	25	49	9057	5958	17868	50	6237.8
Model6	**9107**	**26.93**	**91**	**9015**	**6415**	**17411**	**92**	**6085.9**
Model7	**9107**	**27.23**	**95**	**9011**	**6488**	**17338**	**96**	**6055.6**

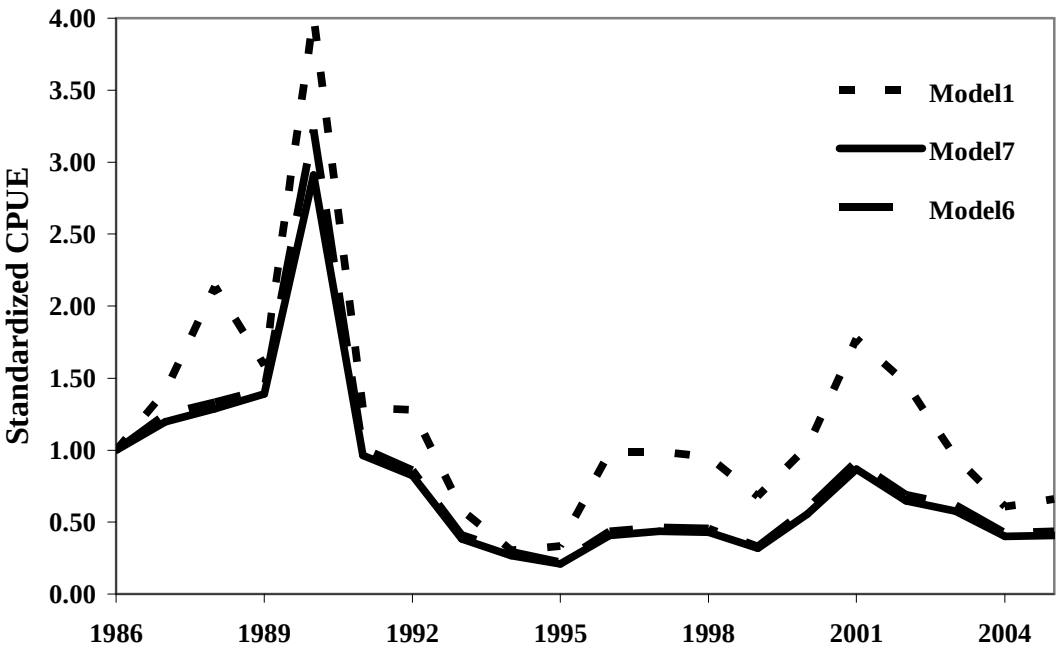


Figure 6.20. The standardized catch per unit of effort per year for Jackass Morwong taken by Danish Seine vessels in Zones 10 and 20, relative to catch rates in 1986, as represented by the geometric mean (model 1 - dots) the optimal model without co-occurring species (model 6 – dashed), and with co-occurring species (model 7 – solid line) (see Table 6.47 for parameter values). The effect of the co-occurring species is trivial in this case.

6.3.19 Spotted Warehou (Zones 10 to 50)

To match the ageing data a fishing year, defined as running from May 1st through to April 30th, was used instead of calendar year.

The data restrictions used in selecting the data for analysis were:
Only data from zones 10 and 50 were used,
a median catch greater than 4.0 tonnes,
three or more years in the fishery,
catch rates greater than zero,
excluding 1985/1986 and 2005/2006 (which are only partial years),
for Trawl vessels only, and
depths > 0m.

The data restrictions reduced the number of records available by about 16.3%. With these conditions there were 78,096 records available for analysis for Spotted Warehou taken by trawl. If no restrictions are placed on the records there would be 93,325 records. Thus, 83.68% of available records are used and these represent 90.65% of all catches (Table 6.50).

Table 6.50. Number of records used in the CPUE standardization in each year for Spotted Warehou, years in the fishery >2, median catch per year >4.0 t, CE >0, Average Depth > 0m, and only zones 10 to 50. The geometric mean (Model 1) and the two optimum models (see Figure 6.21) are relative to 1986/1987.

Year	Records	Model1	Model7
1986/1987	1398	1.0000	1.0000
1987/1988	1159	1.0407	1.0820
1988/1989	1887	1.1607	1.3006
1989/1990	1346	0.7026	1.0027
1990/1991	1497	0.9708	0.6085
1991/1992	1667	0.6384	0.6781
1992/1993	2493	0.6126	0.6632
1993/1994	3821	0.6929	0.6404
1994/1995	3868	0.7642	0.6325
1995/1996	4934	0.6439	0.6026
1996/1997	5164	0.6065	0.5720
1997/1998	4788	0.6143	0.4883
1998/1999	4484	0.6054	0.4872
1999/2000	4977	0.6111	0.4862
2000/2001	6787	0.5991	0.4549
2001/2002	7055	0.6423	0.4862
2002/2003	7386	0.5721	0.4549
2003/2004	6887	0.5543	0.5150
2004/2005	6498	0.4874	0.4586

Seven statistical models were considered for the Spotted Warehou data from trawl vessels in Zones 10 to 50 (Table 6.51). Model 1 represents the overall geometric mean and Model 7 is the optimum statistical model (Table 6.51,Table 6.52; Figure 6.21).

Table 6.51. The factors involved in each of the seven statistical models trialled with Spotted Warehou in Zones 10 to50 from trawlers. Fyear is fishing year – May 1st to April 30th. VesselID is a unique identifier for each vessel that has fished Spotted Warehou, Month is simply month, DepCat is a series of 50 metre depth categories, Zone is the zone from 10 to 50. When interaction terms are used the primary terms are omitted as redundant.

Model	Factors
Model 1	LnCE= Fyear
Model 2	LnCE= Fyear + VesselID
Model 3	LnCE= Fyear + VesselID + Month
Model 4	LnCE= Fyear + VesselID + Month + DepCat
Model 5	LnCE= Fyear + VesselID + Month + DepCat + Zone
Model 6	LnCE= Fyear + VesselID + DepCat + Zone*Month
Model 7	LnCE= Fyear + VesselID + Zone*Month*DepCat

Table 6.52. Properties of each statistical model. N is the total number of observations used, Var% is the percent variation in the data accounted for by the model, df Param is the degrees of freedom associated with the model, df Resids are the degrees of freedom associated with the rest of the data, Model SS is the sum of squared residuals for the model, Resid SS is the residual sum of squared not accounted for by the model, # Param is the number of parameters and AIC is Akaike's Information Criterion as defined in the General Methods. The optimum model – Model 7 is bolded. Model 1 is the base case geometric mean catch rate.

Model	**N**	**Var%**	df Param	df Resids	Model SS	Resid SS	# Param	AIC
Model 1	**78096**	**0.88**	**18**	**78077**	**2426**	**272461**	**19**	**97623.4**
Model 2	78096	15.94	96	77999	43808	231079	97	84914.1
Model 3	78096	21.12	107	77988	58066	216821	108	79962.3
Model 4	78096	21.99	138	77957	60472	214415	139	79152.8
Model 5	78096	23.38	142	77953	64261	210626	143	77768.6
Model 6	78096	24.63	186	77909	67691	207196	187	76574.3
Model 7	**78096**	**27.48**	**1026**	**77069**	**75547**	**199340**	**1027**	**75235.8**

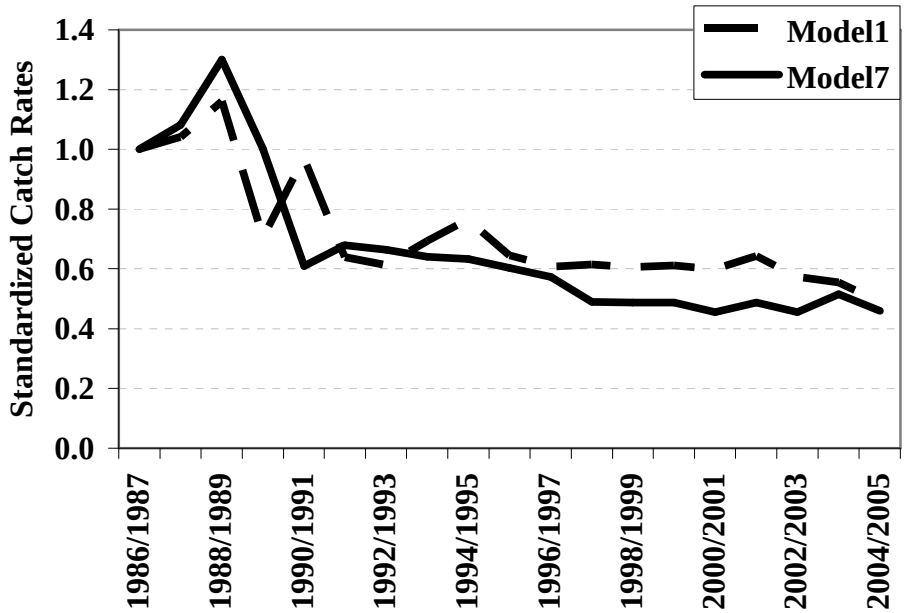


Figure 6.21. The standardized catch per unit of effort per year for Spotted Warehou taken by trawlers in Zones 10 to 50, relative to catch rates in 1986/1987. The geometric mean catch rate (model 1 - dashes) and the optimal model (model 7 – solid line) (see Table 6.50 for parameter values). The fishery has exhibited relative stability since 1997/1998.

6.4 Discussion

There are a number of issues that the RAG needs to consider with respect to the commercial catch and effort data.

- The move to asking skippers to use estimated processed weights instead of estimated whole weights. On advice from the AFMA data section we have implemented the analyses above on the assumption that all years up to and including 2003 were reported as whole weights while 2004 and 2005 was reported as processed weights. This means that the landed weights were converted back to whole weights by multiplying each processed weight by the required conversion factor. This is especially important for Blue Grenadier, Pink Ling, Jackass Morwong, Gemfish, BlueEye (just), and Spotted Warehou. The question to be answered is whether this approach is acceptable and should be continued or whether we need a different strategy to deal with this database change. If we were to ignore this change the catch rates will be systematically underestimated to different extents by species.
- Once again much of the time involved in these analyses was spent adding the 2005 year's data to the database. A process of developing an internally consistent database containing all required species that can be regularly updated as new data arrives *and which can be properly documented*, must be made a high priority if future analyses are required.
- With the expansion in the number of species requiring analysis, details regarding such things as fishing years and fishing zones need to be formally documented *and agreed by the RAG* for each species.

6.5 References

Burnham, K.P. & D.R. Anderson (1998) *Model Selection and Inference. A practical Information-Theoretic approach.* Springer-Verlag, New York Ltd. 353p.

Kimura, D.K. (1981) Standardized measures of relative abundance based on modelling log(c.p.u.e.), and their application to pacific ocean perch (*Sebastes alutus*). *Journal du Conseil International pour l'Exploration de la Mer. 39*: 211-218.

Klaer, N.L. (1994) Methods for standardisation of catch/effort and data requirements. 86-90 *In*: Hancock, D.A (*ed*) *Population Dynamics for Fisheries Management*. Australian Society for Fish Biology Workshop Proceedings, Perth 24-25 August 1993. Australian Society for Fish Biology, Perth.

Venables, W.N. & C.M. Dichmont (2004) GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research* **70**: 319-337.

Vignaux, M. (1992) Catch per unit effort (CPUE) analysis of the hoki fishery. *New Zealand Fisheries Assessment Research Document 92/14* 31 p.

Vignaux, M. (1993) Catch per unit od effort (CPUE) analysis of the Hoki fishery 1987-1992. *New Zealand Fisheries Assessment Research Document 93/14* 15 p.

7. Natural Mortality Values used for SESSF Species

Jemery Day[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

7.1 Natural mortality values

Values for natural mortality are used directly in the Tier 3 harvest control rule in the harvest strategy framework which was applied to the SESSF in 2005 (Smith and Shoulder 2005). The Tier 3 harvest control rule applies to species and/or stocks where there are robust estimates of natural mortality rate, *M*, and current fishing mortality rate F_{CUR}, but no direct estimates of current biomass B_{CUR}.

For the tier 3 rule to be applied consistently, it is important to have robust estimates of M for the full range of SESSF species. Values of natural mortality were collected by Klaer and Thomson (2006) for the report "Yield, and total mortality values and Tier 3 estimates for selected shelf and slope species in the South East Fishery" and these values are listed in Table 7.1.

Table 7.1 Population parameters used in 2005 Tier 3 analysis, from Klaer and Thomson (2006).

Species	*M*
Flathead	0.2
Redfish	0.1
Morwong	0.11
Silver trevally	0.1
Spotted warehou	0.25
Blue warehou	0.45
John dory	0.36
School whiting	0.5
Mirror dory	0.3
Pink ling	0.2
Blue grenadier	0.2

The natural mortality values of Klaer and Thomson (2006) listed in Table 7.1 were obtained from Smith and Wayte (2002) or by calculating the median of the figures presented by Bax and Knuckey (2001). The value of *M* for John dory was updated by the Shelf Research Assessment Group in 2005 based on an additional meta-analysis performed by Matt Koopman.

It appears that recent updates to some of these parameters have not been incorporated in the Tier 3 analysis, and there are also some other discrepancies. To get a broader picture of values and estimates of natural mortality from a range of sources, Table 7.2 was constructed, using data from: Fishery Assessment Reports (Smith and Wayte 2002,

Smith and Wayte 2004, Smith and Wayte 2005); Bax and Knuckey (2001); Klaer and Thomson (2006); Punt *et al*. (2005)

Table 7.2 Mortality parameters collected from a range of sources and Fishery Assessment Reports (Smith and Wayte 2002, Smith and Wayte 2004, Smith and Wayte 2005); Bax and Knuckey (2001); Klaer and Thomson (2006); Punt *et al*. (2005). Also included are mortality parameters used in recent assessments, with the range of values explored in sensitivity analyses, the primary author of the assessment and a reference for the most recent available assessment.

Species	***M* from FAR**	***M* Hoenig 5% (m, f)**	**2005 Tier 3 (catch curves)**	**Robin Hood**	**Assessment values (m, f)**	**Primary Author**	**Mortality values explored**	**Most recent source**
Alfonsino				0.23 (NZ)				
Bight redfish					0.1	Neil Klaer	0.05 0.1 0.15	Tuck (2006)
Blue eye trevalla	0.1	0.08 0.07		0.28	0.08	Gavin Fay (fitted)		
Blue grenadier	0.2	0.12 0.14	0.2	0.2	0.24 0.20	Geoff Tuck (females est'd)		Tuck (2006)
Blue warehou	0.45 (too high 0.3-0.35)	0.37	0.45	0.58	0.45	André Punt (fixed)	0.3 0.4 0.5	Tuck (2006)
Deepwater flathead					0.2	Neil Klaer	0.15 0.2 0.25	Tuck (2006)
Flathead	0.2	0.21 0.18	0.2	0.27	0.21 0.23	André Punt (fixed)	0.1 to 0.3 in steps of 0.025	Tuck (2006)
Gemfish east	0.25	0.25 0.18		0.27				
Gemfish west	0.25	0.25 0.18		0.27				
Jackass Morwong	0.15	0.10 0.08	0.11	0.45	0.15	Gavin Fay (fixed)		Tuck (2006)
John dory	0.1	0.25	0.36	0.38				
Mirror dory	0.3	0.25	0.3	0.38				
Ocean perch	0.1?	0.05		0.1				
Orange roughy eastern zone	0.04	0.02		0.04	0.04	Sally Wayte (est'd)		Tuck (2006)
Orange roughy	0.04	0.02		0.04	0.048	Sally Wayte		Tuck (2006)

Species	*M* from FAR	*M* Hoenig 5% (m, f)	2005 Tier 3 (catch curves)	Robin Hood	Assessment values (m, f)	Primary Author	Mortality values explored	Most recent source
southern zone						(fixed)		
Orange roughy western zone	0.04	0.02		0.04	0.04	Sally Wayte (fixed)		Tuck (2006)
Orange roughy Cascade zone	0.02	0.02		0.04	0.02	Sally Wayte (est'd)	0.02 0.04	Tuck (2006)
Oreo smooth, Cascade				0.063 (NZ)				
Oreo smooth, other				0.063 (NZ)				
Oreo basket, other								
Pink ling	0.2	0.12 0.11	0.2	0.16	0.2	Neil Klaer (fixed)		Tuck (2004)
Redfish	0.1	0.07	0.1	0.12	0.1	Neil Klaer (fixed)	0.05 0.10 0.15	Tuck (2006)
Ribaldo								
Royal red prawn	?							
School whiting	0.5	0.37	0.5	0.9	0.9-1.1	Gurong Cui		Tuck (2006)
Silver trevally	0.1	0.12	0.1	0.1	0.1	Jemery Day (fixed)	0.05 0.10 0.15	Tuck (2006)
Spotted (silver) warehou	0.3	0.21	0.25	0.33				
Deepwater shark basket east								
Deepwater shark basket west								
Elephant fish					0.2	André Punt (fixed)		

Species	***M* from FAR**	***M* Hoenig 5% (m, f)**	**2005 Tier 3 (catch curves)**	**Robin Hood**	**Assessment values (m, f)**	**Primary Author**	**Mortality values explored**	**Most recent source**
Gummy shark					0.2 or 0.231 for M (age>=2) 95% probability interval: [0.202, 0.272]	André Punt est'd? density dep't mortality? Age dep't mortality		Tuck (2004)
Saw shark					0.2	André Punt (fixed)		
School shark					0.1	André Punt	0.08 0.1	Punt (2001)

When two values are listed for natural mortality in Table 7.2, these are sex specific mortalities with the values for males listed before the mortality for females.

In addition to these values, Matt Koopman (PIRVic – pers. comm.) also collected some figures on natural mortality estimates using a range of methods for four species. The values obtained using each of these methods are listed in Table 7.3.

Table 7.3 Mortality values from meta-analysis done by Matt Koopman (PIRVic – pers. comm.).

Species	Pauly	Sparre & Venema (1992)	Rikhter & Efanov (1976)	Hoenig (1983)
Flathead	0.254	0.219	0.406	0.212
John dory	0.353	0.384	0.360	0.368
Ribaldo	0.235	0.0853	0.0840	
Redfish	0.138	0.105	0.264	0.103

7.2 References

Bax, N.J., and Knuckey, I.A. 2002. Draft. Evaluation of selectivity in the South-East fishery to determine its sustainable yield. Final Report to the Fisheries Research and Development Corporation. FRDC Project 96/140.

Klaer, N. and Thomson, R. 2006. Yield, total mortality and Tier 3 estimates for selected shelf and slope species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2006.

Punt A.E., Smith D.C. and Koopman M.T. 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report to Fisheries Research and Development Corporation. FRDC Project 2002/094. Primary Industries Research Victoria, Queenscliff.

Punt A.E., Pribac F., Walker T.I. and Taylor B.L. 2001. Population Modelling and Harvest Evaluation for School and Gummy Shark. Final report to Fisheries Research and Development Corporation. FRDC Project 99/102. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart.

Smith, A.D.M. and Wayte, S.E. (eds) 2002. The South East Fishery 2002. Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra, 271pp.

Smith, A.D.M. and S.E. Wayte (eds) 2004. The South East Fishery 2003, Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Smith, A.D.M. and S.E. Wayte (eds) 2005. The Southern and Eastern Scalefish and Shark Fishery 2004, Fishery Assessment Report compiled by the Southern and Eastern Scalefish and Shark Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Smith, A.D.M. and Shoulder P. 2005. A harvest strategy framework for the SESSF. Presented to the Shelf and Slope and Deepwater Assessment Groups, 2005.

Tuck, G.N. and Smith, A.D.M. 2004. Stock assessment for south east and southern shark fishery species. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart. 412 p.

Tuck, G.N. (ed.) 2006. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2004-2005. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Tuck, G.N. (ed.) 2006. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. (in press).

8. Updated Stock Assessment for Blue Grenadier (*Macruronus novaezelandiae)* in the Southern and Eastern Scalefish and Shark Fishery Based on Data up to 2005: July 2006[1]

Geoffrey N. Tuck[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

8.1 Introduction

An integrated analysis model has been applied to the blue grenadier stock of the Southern and Eastern Scalefish and Shark Fishery (SESSF) with data updated by inclusion of the 2005 calendar year data and additional information from acoustic surveys of spawning biomass. The same assessment model that has been used in previous years (eg Punt et al. 2001, Tuck and Punt, 2005) was used again this year. While initial progress is promising, an application of Stock Synthesis 2 (SS2) to blue grenadier was deferred until next year due its current inability to model density dependent growth appropriately. This unique aspect of the blue grenadier model will be addressed within SS2 over subsequent months.

This paper considers a number of assessment sensitivities based upon the use or otherwise of data inputs. These inputs include:

1) acoustic survey estimates
2) egg survey estimates
3) the application of the acoustic survey estimates to total (male and female) spawning biomass
4) aging error

Due to time and the extensive number of diagnostic plots that are usually given for a single assessment, not all diagnostics could be produced in this paper. However, the main management related indices of interest are provided for each scenario.

8.2 The fishery

Blue grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Data support the hypothesis of a single breeding population in Australian waters. Blue grenadier is a moderately long-lived species with a maximum age of about 25 years and an age at maturity of 4-5 years. Spawning occurs off western Tasmania between late May and early September. Adults migrate to the spawning area from throughout southeastern Australia, with large fish arriving earlier in the spawning season.

[1] Paper presented to the Slope Resource Assessment Group on 24-25 July, 2006

Blue grenadier are caught by demersal trawling. The global agreed TAC in 2005 was 5000 tonnes (with a voluntary industry reduction to 4200t), down from 7000 t in 2004, 9000 t in 2003 and 10000 t which it had been since 1994. There are two defined sub-fisheries: the spawning and non-spawning fisheries. The non-spawning fishery catches have been relatively consistent over the last few years (at just under 2000t), whereas the spawning fishery catches showed a marked increase during the mid-1990s before decreasing from 2003. The spawning and non-spawning fishery catches are currently at similar levels.

8.3 Data

The model has been updated by the inclusion of the 2005 catch- and discard-at-age from the spawning and non-spawning fisheries; updated cpue series (Haddon, 2006), the total mass landed and discarded, mean length- and weight-at-age; updated acoustic estimates of spawning biomass (T. Ryan, pers. comm.) and estimates of the female spawning biomass in 1994 and 1995 from egg surveys (Bulman et al., 1999). Data were formulated by calendar year (i.e. 1 Jan to 31 Dec).

8.3.1 Catch

The landings from the SEF1 logbook data were used to apportion catches to the spawning and non-spawning fisheries. The SEF1 landings have been adjusted upwards to take account of differences between logbook and landings data (multiple of 1.4 for the non-spawning fishery since 1986; 1.2 for the spawning fishery from 1986 up to and including 1996). These figures were then scaled up to the SEF2 data. As SEF2 data were only available from 1993, for years prior to this the average scaling factor from 1993 to 1998 was used to scale the data. The landings data are provided in Table 8.1.

8.3.2 Catch rates

Haddon (2006) provides the updated catch rate series for blue grenadier (Table 8.2, Figure 8.1). Models 7 and 6 of Haddon (2006) were used for the non-spawning and spawning fisheries respectively in the assessment models. The series show recent increases in cpue for both sub-fisheries.

8.3.3 Catch-at-age

Although length frequency information is collected at several ports around Australia, traditionally only those collected in Portland and Beachport (for 2002 to 2004) have been used for the non-spawning length-frequency. This was done because BGAG had agreed to only use Portland data - earlier investigations by BGAG members indicated that data from all ports showed the same trend. However, 2005 length frequencies show large differences in length frequency, with Eden showing a marked increase in small fish compared to the other ports. As such, a catch-weighted length frequency was applied to produce the 2005 length frequency, utilizing data from Beachport, Portland

and Eden (Figure 8.2). Future work will examine the sensitivity of the model results to using all available data, in particular those from the east coast.

Table 8.1. Landed and discarded catches for the winter spawning and non-spawning sub-fisheries by calendar year. These estimates have been adjusted to account for reporting of headed and gutted catches, and scaled up to the sef2 data (see text).

Year	**Landings**		**Discards**	
	Spawning	**Non-spawning**	**Spawning**	**Non-spawning**
1979	245	245		
1980	410	410		
1981	225	225		
1982	390	390		
1983	450	450		
1984	675	675		
1985	600	600		
1986	321	1840		
1987	1019	2214		
1988	415	2279		
1989	47	2816		
1990	743	2604		
1991	1158	4193		
1992	931	2669		
1993	990	2359		
1994	1194	1916		
1995	1196	1558		80
1996	1464	1504		975
1997	2952	1581		3716
1998	3267	2469		1329
1999	6087	3214		123
2000	6056	2592		69
2001	7613	1496		10
2002	7428	1731		2
2003	7572	900		4
2004	5065	1399		21
2005	2973	1283		431

Table 8.2. Standardised CPUE (Haddon, 2006) for the spawning and non-spawning sub-fisheries by calendar year.

Year	Spawning		Non-spawning	
	CPUE	Records	CPUE	Records
1986	1.00	65	1.00	1825
1987	1.08	196	1.47	2296
1988	2.35	92	1.57	2606
1989	0.63	31	1.45	3022
1990	0.87	141	1.51	2455
1991	3.26	129	1.11	3541
1992	1.14	168	1.00	3172
1993	2.87	148	0.73	3724
1994	1.65	318	0.64	4015
1995	0.80	476	0.44	4541
1996	1.06	493	0.38	4554
1997	0.83	421	0.38	4758
1998	0.95	578	0.66	4952
1999	0.79	857	0.74	6437
2000	0.89	950	0.66	6078
2001	1.48	1112	0.31	6277
2002	1.02	1047	0.31	5893
2003	0.77	1014	0.23	5341
2004	0.61	735	0.42	5658
2005	0.76	267	0.48	4844

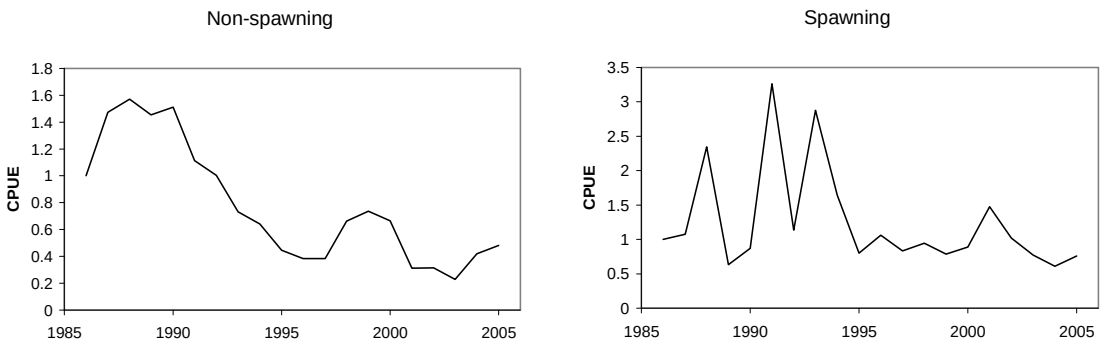


Figure 8.1. The calendar year catch rate indices for the non-spawning and spawning blue grenadier fishery.

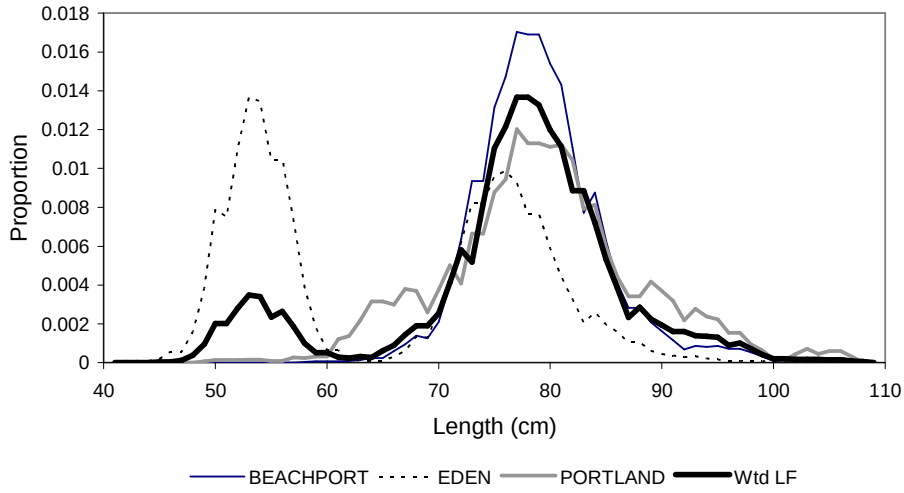


Figure 8.2. The port-based blue grenadier length frequencies for 2005. The Wtd LF line is the catch-weighted length frequency used for the non-spawning sub-fishery.

Spawning sub-fishery length frequencies were obtained from AFMA on-board observations. To obtain the overall length-frequency, length records were catch-weighted by the weight of catch from the haul and the sample weight of the fish (Figure 8.3).

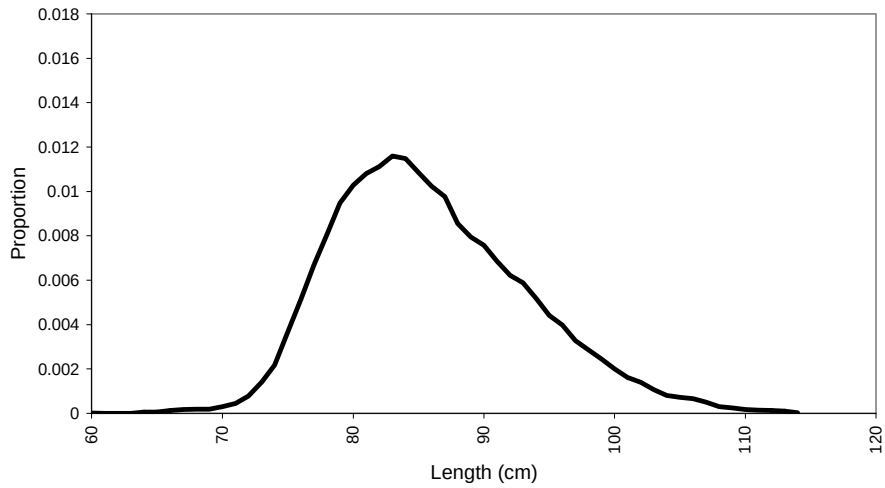


Figure 8.3. The catch-weighted length frequency for blue grenadier of the spawning sub-fishery in 2005.

The catch-at-age for 2005 for each of the two sub-fisheries is shown in Figure 8.4. As expected, the non-spawning age composition shows the presence of a recent year class progressing into the available biomass. This year class has not entered the spawning fishery.

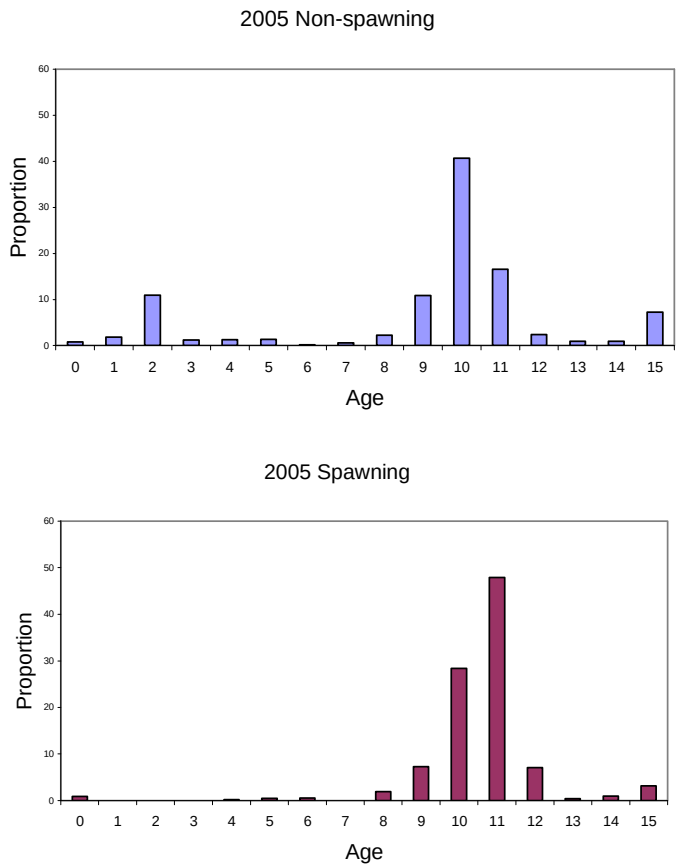


Figure 8.4. The observed proportion caught–at-age for the non-spawning (top) and spawning (bottom) sub-fisheries.

8.3.4 Acoustic survey estimates

Following instruction from Slope RAG (May 2006), several scenarios were considered relating to the acoustic and egg survey biomass estimates. For the acoustic estimates, five models of spawning biomass were provided by Tim Ryan (pers. comm.). These models differed according to the target strength used. Based on expert judgement, two of these models were taken into the assessment, namely Macauley (2004) and Cordue (2000). Table 8.3 shows the spawning biomass estimates for each of these models. The model of Macauley (2004) produces markedly higher estimates of spawning biomass (with a lower estimate of target strength) than Cordue (2000) (with a correspondingly higher estimate of target strength). The assumption of two times turnover was maintained through all assessment models. Following previous methodology, as the acoustic estimates relate to total spawning biomass and the model had been written to accept survey estimates as females only, a 1:1 sex ratio has been assumed. However, the acoustic estimates can now be included as total (males and females) spawning biomasses. This is considered further as a sensitivity.

Table 8.3. The estimated spawning biomass of blue grenadier in years 2003 to 2005 according to the models of Macauley (2004) and Cordue (2000) (T. Ryan, pers. comm.).

Model	Name	2003	2004	2005
Macauley (2004)	High	131991	87852	116390
Cordue (2000)	Low	23798	13544	16670
c.v. used in assessment model		0.3	0.46	0.3

8.3.5 Egg survey estimates

Egg survey estimates of female spawning biomass are available for years 1994 and 1995 (Bulman et al., 1999). Three scenarios for the egg estimates were considered: a base-case level, double and no egg estimates. The egg-estimates (cv) for 1994 and 1995 respectively are: 57772 (0.18) and 41409 (0.29).

8.3.6 Parameters of breeding biology

Previous models, including base-case models, have assumed that the proportion of females that spawn is 0.77 and the length at maturity is 70cm (Punt et al., 2001). These values were taken from research on hoki in New Zealand (Livingston et al., 1997). Recent studies have provided more up-to-date values for these parameters that are specific to the Australian stock of blue grenadier (S. Russell and D. Smith, pers. comm.), namely 0.84 for the proportion of females that are not on the spawning grounds, and lengths at 50% maturity of 63.7cm for females and 56.8 for males. As no information was available on the proportion of non-spawning male blue grenadier, it was assumed that the proportion was the same as that of the females. In the results that follow, the updated parameters have been used only in sensitivity tests, i.e. unless specifically stated, the traditional values have been used.

8.3.7 Age-reading error

Standard deviations for aging error have been estimated, producing the age-reading error matrix of Table 8.5.

8.3.8 Base-case and sensitivity tests

The 25-26 August 2005 meeting of Slope RAG provided a new base-case model description, namely 'lower acoustic estimates, base-case values for the egg-survey and two-times turnover'. Although the actual values of the acoustic estimates have changed in 2005, this definition will be maintained in this report, and presentation of figures will assume this scenario unless stated explicitly otherwise in the text. The non-estimated parameters of the base-case model are provided in Table 8.6. In addition to the base-case model, numerous other sensitivities are explored – these are listed below in Table 8.4.

Table 8.4. The various sensitivities considered for the assessment models. When the new breeding parameters are used, the acoustic estimates are fit to male and female spawning biomasses.

Name	Acoustic Survey	Egg Survey	Age-reading error	New Breeding Parameters
(base-case) 1	Low	Base-case	No	No
2	Low	Double	No	No
3	Low	None	No	No
4	High	Base-case	No	No
5	High	Double	No	No
6	High	None	No	No
7	Low	Base-case	Yes	No
8	Low	Base-case	No	Yes
9	High	Double	Yes	No
10	High	Double	No	Yes
11	Low	Base-case	Yes	Yes
12	High	Double	Yes	Yes

Table 8.5. The age-reading error matrix, shown as the proportion of records found to be a certain age by a reader (columns) that were assigned to an age by another reader (rows). Source: A.E. Punt and Central Aging Facility (CAF, PIRVic, Queenscliff, Victoria).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	94.7	11.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0
2	5.3	77.7	14.8	0.2	0	0	0	0	0	0	0	0	0	0	0
3	0	11.1	70.2	16.6	0.3	0	0	0	0	0	0	0	0	0	0
4	0	0	14.8	66.4	17.8	0.4	0	0	0	0	0	0	0	0	0
5	0	0	0.1	16.6	63.7	18.2	0.4	0	0	0	0	0	0	0	0
6	0	0	0	0.2	17.8	62.8	18.2	0.4	0	0	0	0	0	0	0
7	0	0	0	0	0.3	18.2	62.8	18.2	0.4	0	0	0	0	0	0
8	0	0	0	0	0	0.4	18.2	62.8	18.2	0.4	0	0	0	0	0
9	0	0	0	0	0	0	0.4	18.2	62.8	18.2	0.5	0	0	0	0
10	0	0	0	0	0	0	0	0.4	18.2	62.8	18.9	0.7	0	0	0
11	0	0	0	0	0	0	0	0	0.4	18.2	61.1	19.9	1.2	0	0
12	0	0	0	0	0	0	0	0	0	0.4	18.9	58.8	21.5	2.2	0.2
13	0	0	0	0	0	0	0	0	0	0	0.5	19.9	54.4	23.0	4.0
14	0	0	0	0	0	0	0	0	0	0	0	0.7	21.5	49.5	24.0
15	0	0	0	0	0	0	0	0	0	0	0	0	1.3	25.2	71.7

Table 8.6. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
N	Weight for the catch- and discard-at-age data	50
σ_r	c.v. for the recruitment residuals	1.0
σ_c	c.v. for the landings data	0.05
σ_d	c.v. for the discard data	0.3
σ_q	c.v. for the CPUE data	0.3
h	"steepness" for the Beverton-Holt stock-recruit curve	0.9
x	age of plus group	15 years
μ	fraction of mature population that spawn each year	0.77
l_∞	von Bertalanffy parameter (maximum length)	102.76 cm
κ	von Bertalanffy parameter (growth rate)	0.16 y^{-1}
t_0	von Bertalanffy parameter	-2.209 y
aa	allometric length-weight equations	0.00375 g^{-1}.cm
bb	allometric length-weight equations	3.013
l_m	length at maturity (knife-edged)	70 cm

8.4 Results and discussion

8.4.1 Stock assessment – base case

Figure 8.5 shows the observed and predicted fits to the landings and discards from each sub-fishery. The model is forced to fit the recorded landings because of the very low c.v. that is used (σ_c = 0.05, Table 8.6). It is able to fit the recent drop in the mass of discards however the large discard measured in 1997 is not well estimated despite the ability of the model to allow for density-dependant discarding.

The estimated natural mortality figure for females is approximately 0.20 and consequently that for males is 0.24 (as male natural mortality is assumed to be a multiple of 1.2 times that of females).

The model is not able to fit the early fluctuations in the CPUE for the winter spawning sub-fishery but it is able to achieve a reasonably good fit to the CPUE for recent years (Figure 8.6). The fit to the CPUE for the non-spawning sub-fishery is reasonably good although the increase in the CPUE after 1998 is not as well estimated as might be expected. The drop in CPUE for 2000 is not predicted by the model which actually predicts an increase, consistent with the growth of a large cohort of grenadier spawned in 1994. Attempts to provide better fits to the non-spawning fishery cpue have not been fruitful (such as forcing fits to the cpue by lowering the cv). This issue will be explored further as a high priority. Changes to the form of the selectivity function may prove successful.

The estimated vulnerability of fish of a given length class to being caught (but not necessarily landed) by either sub-fishery is shown in Figure 8.7 (top plot). The probability that a fish will be discarded once it has been caught is shown in the bottom plot.

The fits to the catch-at-age and the discard-at-age data for both sub-fisheries are reasonably good (Figure 8.8 to Figure 8.10). Figure 8.11, which shows the estimated annual recruitment multipliers, illustrates a long period of poor recruitment following the strong recruitments of 1994 and 1995. While an increase in recruitment is estimated by the model for years 2003 and 2004, these will not have been well estimated (as these fish have mostly not moved into the available population) and the real strength of these cohorts will need to be determined over the next few years.

Figure 8.12 shows the estimated annual fishing mortalities for both sub-fisheries. The fishing mortality for the non-spawning sub-fishery has remained relatively stable. The spawning fishery mortality increased rapidly from the mid-1990s, however following the reduction in quota, the most recent spawning fishery mortality reduced considerably.

Figure 8.13 shows the estimated abundance (in millions of fish) by age and year for the base-case model. This figure illustrates the broad number of ages in the population in the early years of the fishery and that the recent age-structure has reduced so that it is now dominated by 10 and 11 year old fish spawned in 1994 and 1995. While a small increase in recruitment can be observed in 2003 and 2004, clearly a strong recruitment since those of the mid-1990s is not evident.

Table 8.7 shows the results against various quantities of interest for the base case model. The quantities of interest shown are the estimated pristine female spawning biomass (B_0); the reference biomass (B_{ref}) which is the average female spawning biomass over the 1979 to 1988 period; the spawning biomass in 1979 ($\tilde{B}_{79}$) and in 2005 ($\tilde{B}_{2005}$) and its size in 1986, 1993, and 2004 relative to the reference level (depletion, $\tilde{B}_y / B_{ref}$); the estimated fishing mortality rate for the spawning (F^1_{curr}) and non-spawning (F^2_{curr}) sub-fisheries for 2005 (=curr); the estimated recruitment residual for the strong 1994 cohort, and the 2003 cohort, and the negative log likelihood (-ln L) value from the model. Also shown are the base-case results for the previous three year's assessments. Note that the final year of biomass estimation (curr) is one year less than the year the assessment is produced.

The base-case model concludes that the reference female biomass is nearly 41000 t and that current female spawner biomass (in the middle of 2005) is approximately 38% of the reference biomass. Figure 8.14 shows the female spawning biomass trajectory for the base-case model as a function of the reference biomass (intervals on survey estimates are 2 standard deviations). Figure 8.15 shows the female spawning biomass trajectory relative to the reference biomass.

Table 8.7. Estimated values for several parameters of interest. The base case model is shown as well as sensitivity tests. Results are shown for base-case runs in the previous 3 years for comparison with the 2005 assessment. 'Curr' refers to the current or final year of the estimation. The base case model includes the base case estimates from the egg survey, the lower acoustic survey estimates and 2 times turnover.

Specification	B_0	B_{ref}	$\tilde{B}_{79}$	$\tilde{B}_{curr}$	$\tilde{B}_{86} / B_{ref}$	$\tilde{B}_{93} / B_{ref}$	$\tilde{B}_{curr} / B_{ref}$	F^1_{curr}	F^2_{curr}	R_{94}	R_{03}	-ln L
Previous assessment results												
Base-case, *curr*=2002	33026	52605	51685	31241	98.04%	81.94%	59.39%	0.175	0.027	6.00	-	352.42
Base-case, *curr*=2003	26877	42082	41441	18066	97.85%	81.86%	42.93%	0.278	0.026	6.19	-	362.06
Base-case, *curr*=2004	30241	48612	47311	21283	98.97%	86.11%	43.78%	0.139	0.036	6.86	0.71	396.00
2006 assessment results, curr=2005												
base-case	27557	40972	39177	15618	99.90%	90.42%	38.12%	0.099	0.054	7.80	1.1	418.69

8.4.2 Stock assessment – sensitivity tests

The various sensitivities outlined in Table 8.4 are summarized in Figure 8.16 to Figure 8.19. In general similar trends in both relative spawning biomass and recruitment multiplies can be seen. The magnitude of the spawning biomass, not surprisingly, is larger for models with the higher acoustic estimates. Also, the models (high acoustic, base case egg, i.e Model 4) and (low acoustic, double egg, i.e. Model 2) do not appear to fit the survey data as well as the other models (Figure 8.16). The objective function values for each of the six models of Figure 8.16 are:

1. Acoustic low, Egg base case = 418.7
2. Acoustic low, Egg double = 425.3
3. Acoustic low, no egg = 416.3
4. Acoustic high Egg base case = 425.2
5. Acoustic high, Egg double = 423.5
6. Acoustic high, no egg = 422.1

As previously estimated, the spawning biomass shows a peak in 2001 following the influx of the recruitments in the mid-1990s and a substantial decline since then. The models utilizing the high acoustic estimates show a mid-year 2005 depletion (relative to the reference biomass) of approximately 45%, whereas the lower acoustic estimates are around 38%.

Figure 8.18 and Figure 8.19 show the spawning female biomass relative to the reference level, and the estimated recruitment multipliers for models where the age-reading error matrix is included, and where the acoustic estimates have been fit to total (male and female) spawning biomass (rather than females only). In general, similar trends are shown.

8.4.3 Harvest control rule application

For an application of the Tier 1 rules, two models were chosen as representative of the six either ‘high’ or ‘low’ models. These were: (high acoustic, double egg, i.e. Model 5) and (low acoustic, base-case egg, i.e. Model 1 the base-case model). In order to apply the Tier 1 harvest control rule, the mid-year depletion in 2007 must be estimated. The 2007 depletion for these two models under each of two biomass target reference points is shown in Table 8.8. This depletion then determines the fishing mortality to apply to the 2007 available biomass (according to the rules specified in Smith and Shoulder (2005)). The ensuing landed and total recommended biological catches (RBC) are given in Table 8.8. These RBCs reflect the large estimated differences in magnitude of the biomass of the two acoustic models.

Table 8.8. The estimated 2007 mid-year depletion and RBCs (landed and total) for two resource models and two Tier rules with target biomass depletion of either 48% or 40%.

Model	High acoustic, double egg			low acoustic, base-case egg		
Tier rule	2007 Depletion	Landed RBC	Total RBC	2007 Depletion	Landed RBC	Total RBC
40-20	0.38	17103	17784	0.31	2520	2630
48-20	0.39	10154	10559	0.31	1455	1518

8.5 Acknowledgements

Many thanks are due to Andre Punt, Tony Smith, Gavin Fay, Rick Methot and all of the SS2-WG for their assistance with the SS2 model development (even if we did not use it for BG… next year). Malcolm Haddon is thanked for providing catch rate indices, and Matt Koopman, Mike Fuller and Neil Klaer for their advice on data matters. The Central Aging Facility and the AFMA observer section are thanked for providing the aging data and spawning length frequency data respectively.

8.6 References

Bulman, C. M., Koslow, J. A., and Haskard, K. A. 1999. Estimation of the spawning stock biomass of blue grenadier (*Macruronus novaezelandiae*) off western Tasmania based upon the annual egg production method. Marine and Freshwater Research. 50:197-207.

Livingston, M.E., Vignaux, M. and Schofield, K.A. 1997. Estimating the annual proportion of non-spawning adults in New Zealand hoki, *Macruronus novaezelandiae.* Fishery Bulletin (US) 95:99-113.

Punt, A.E., Smith, D.C., Thomson, R.B., Haddon, M., He. X and Lyle, J.M. 2001. Stock assessment of the blue grenadier Macruronus novaezelandiae resource off south eastern Australia. Marine and Freshwater Resources. 52:701-717.

Haddon, M. 2006. Standardized Commercial Catch-Effort data for selected Shelf and Slope Assessment Group Species for 1986 - 2005. Prepared for the Slope Resource Assessment Group. July 24-25, 2006.

Tuck, G.N., Koopman, M. 2005. Updated stock assessment for blue grenadier in the South East Fishery, August 2005. Report to the Slope Resource Assessment Group. 25-26 August 2005.

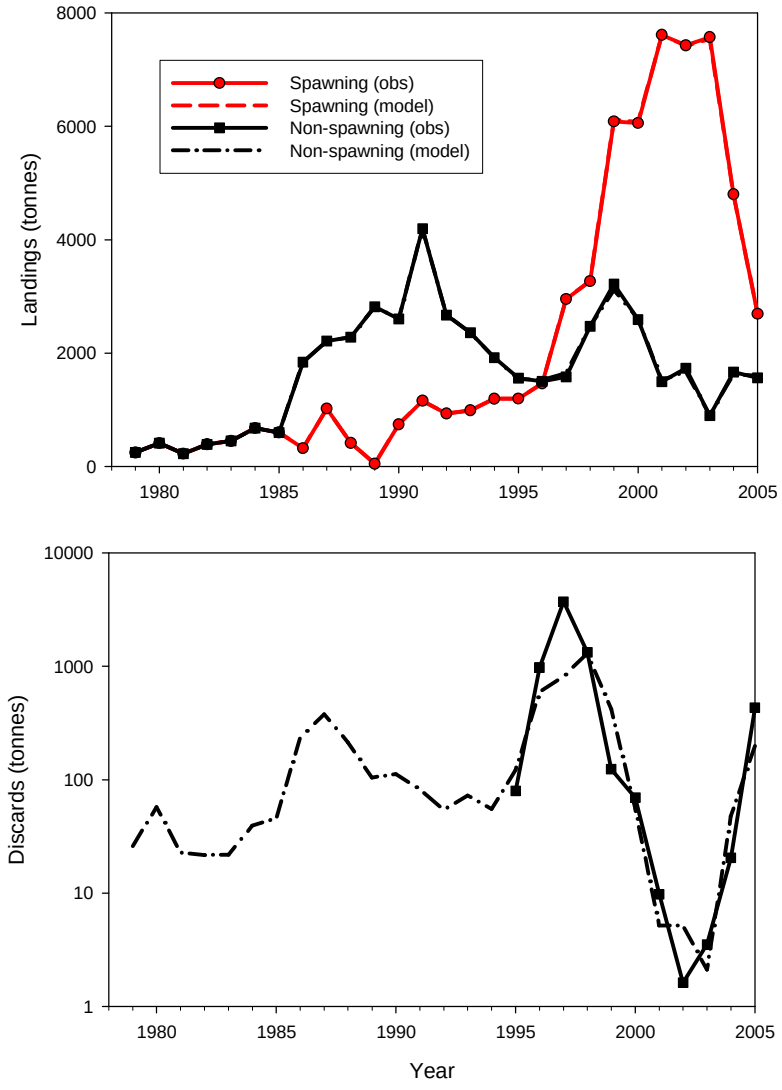


Figure 8.5. Top plot: Annual estimated landings of blue grenadier (obs; scaled to account for headed and gutted fish and to sef2) and estimated by the base case model (model). Bottom plot: Discards estimated from the ISMP (obs) and model estimated (model). The spawning and non-spawning sub-fisheries are shown.

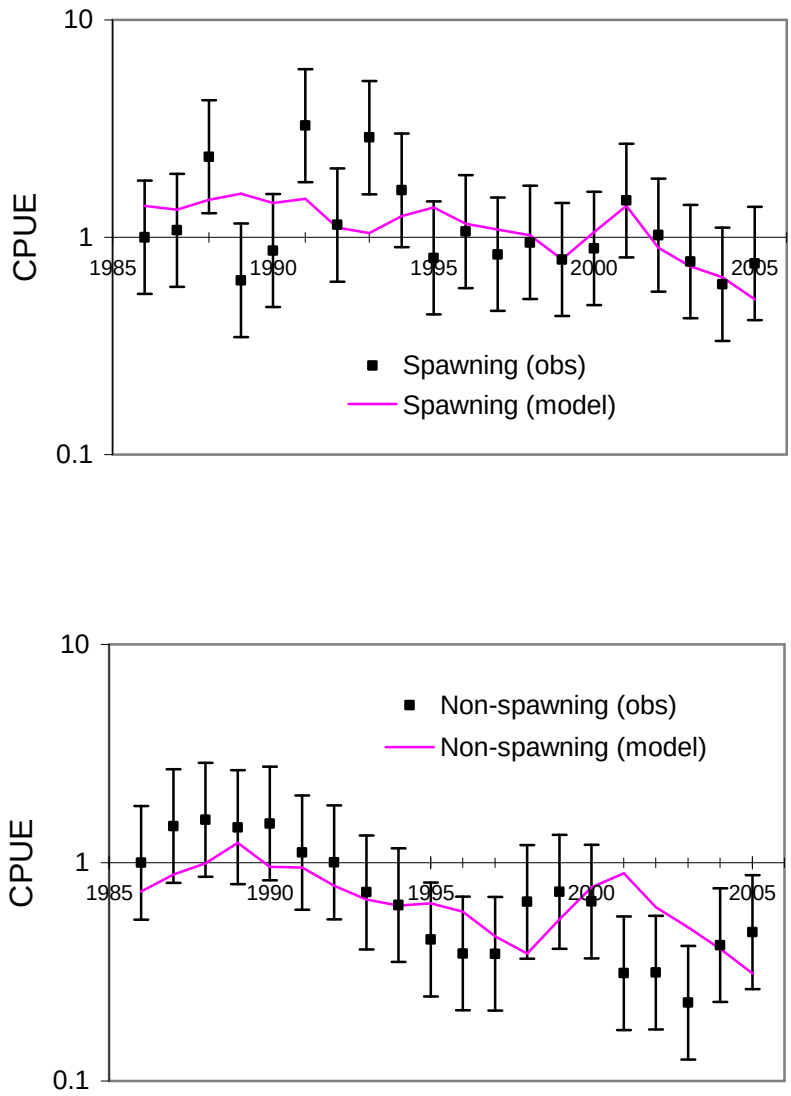


Figure 8.6. Catch-per-unit-effort (CPUE) calculated using a GLM to standardise CPUE from log-books (obs) and the base-case model estimated CPUE (model) for the spawning fishery (top) and the non-spawning fishery (bottom).

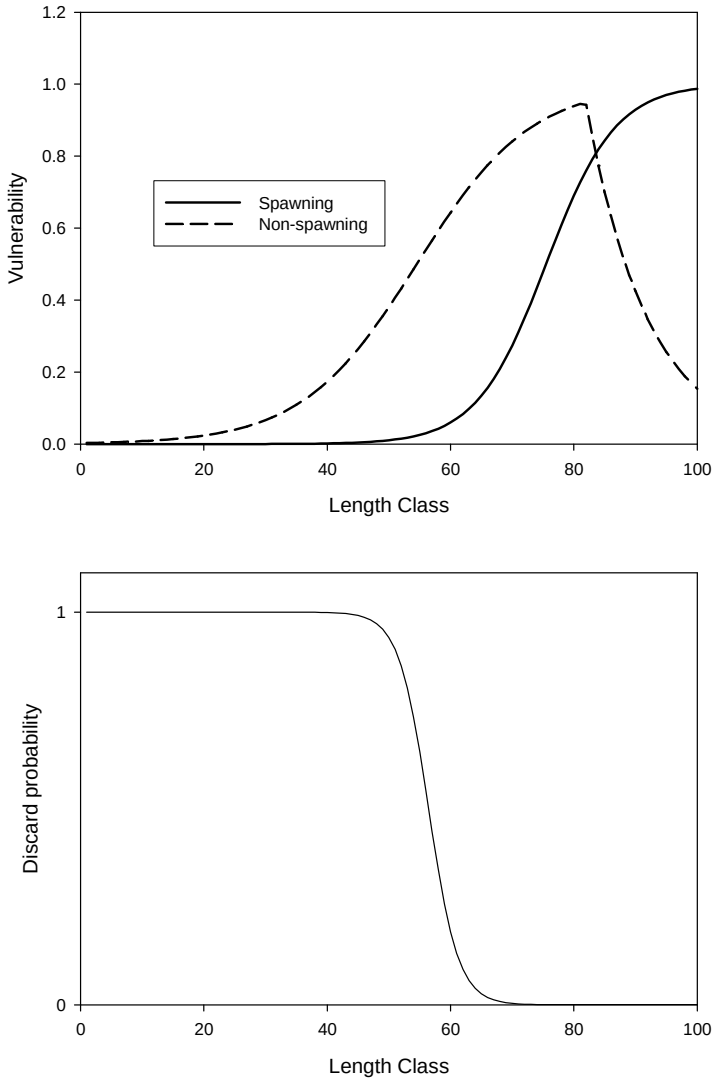


Figure 8.7. Vulnerability of blue grenadier to being caught (but not necessarily landed) by the two sub-fisheries (top) and the probability of being discarded if caught (bottom) as a function of length class.

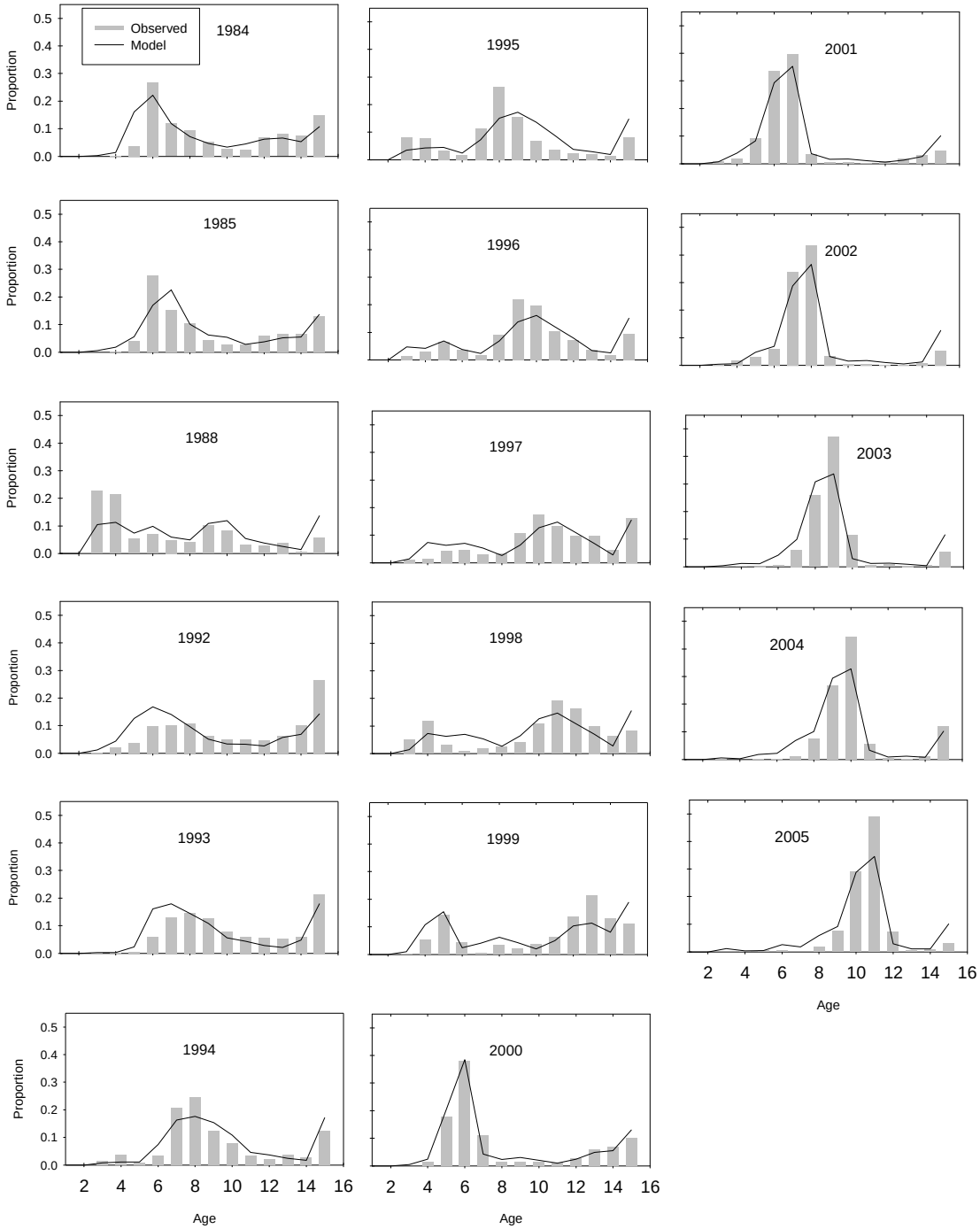


Figure 8.8. Observed (bars) and model estimated (lines) proportion caught at age for the spawning sub-fishery and base-case model.

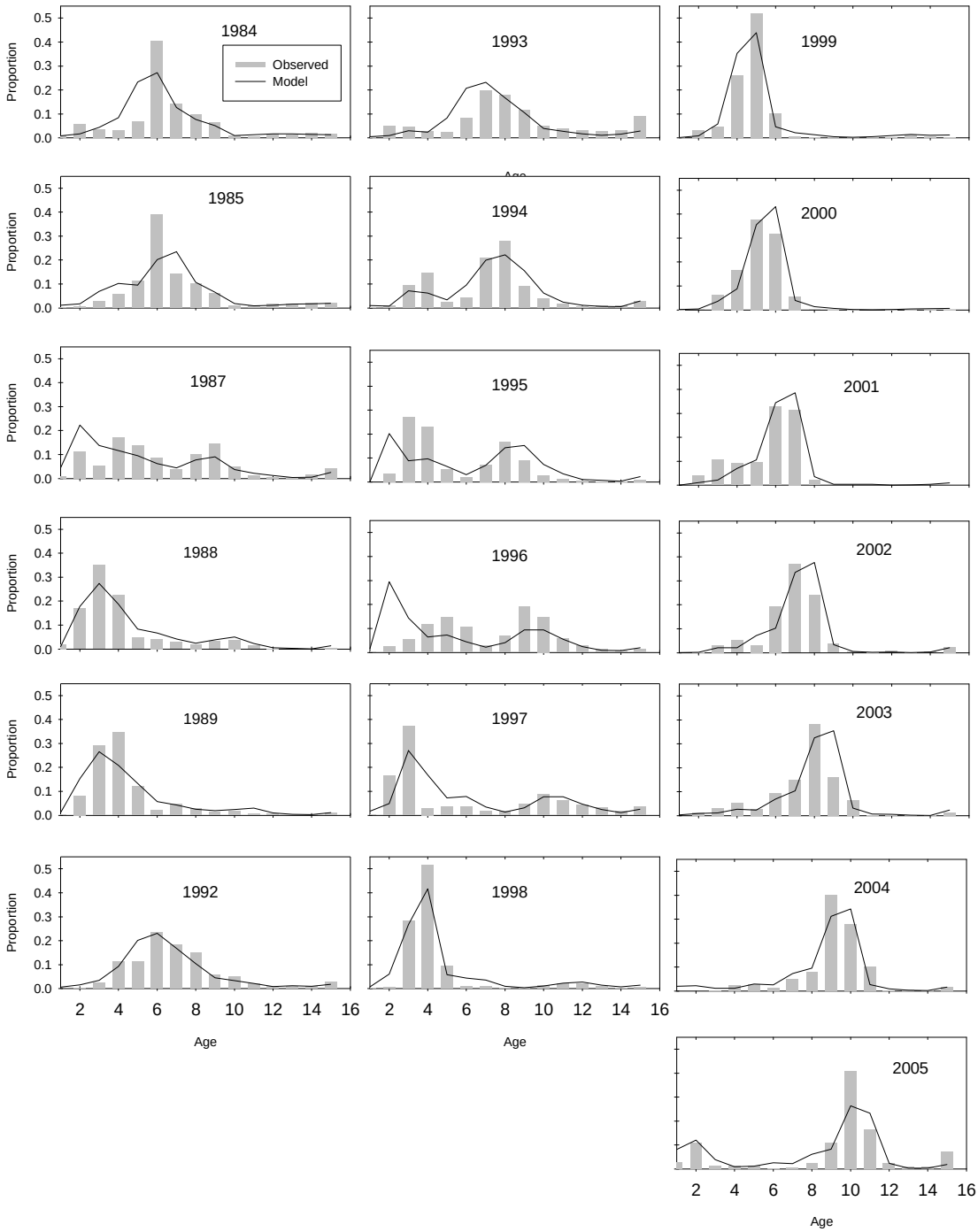


Figure 8.9. Observed (bars) and model estimated (lines) proportion caught at age for the non-spawning sub-fishery and base-case model.

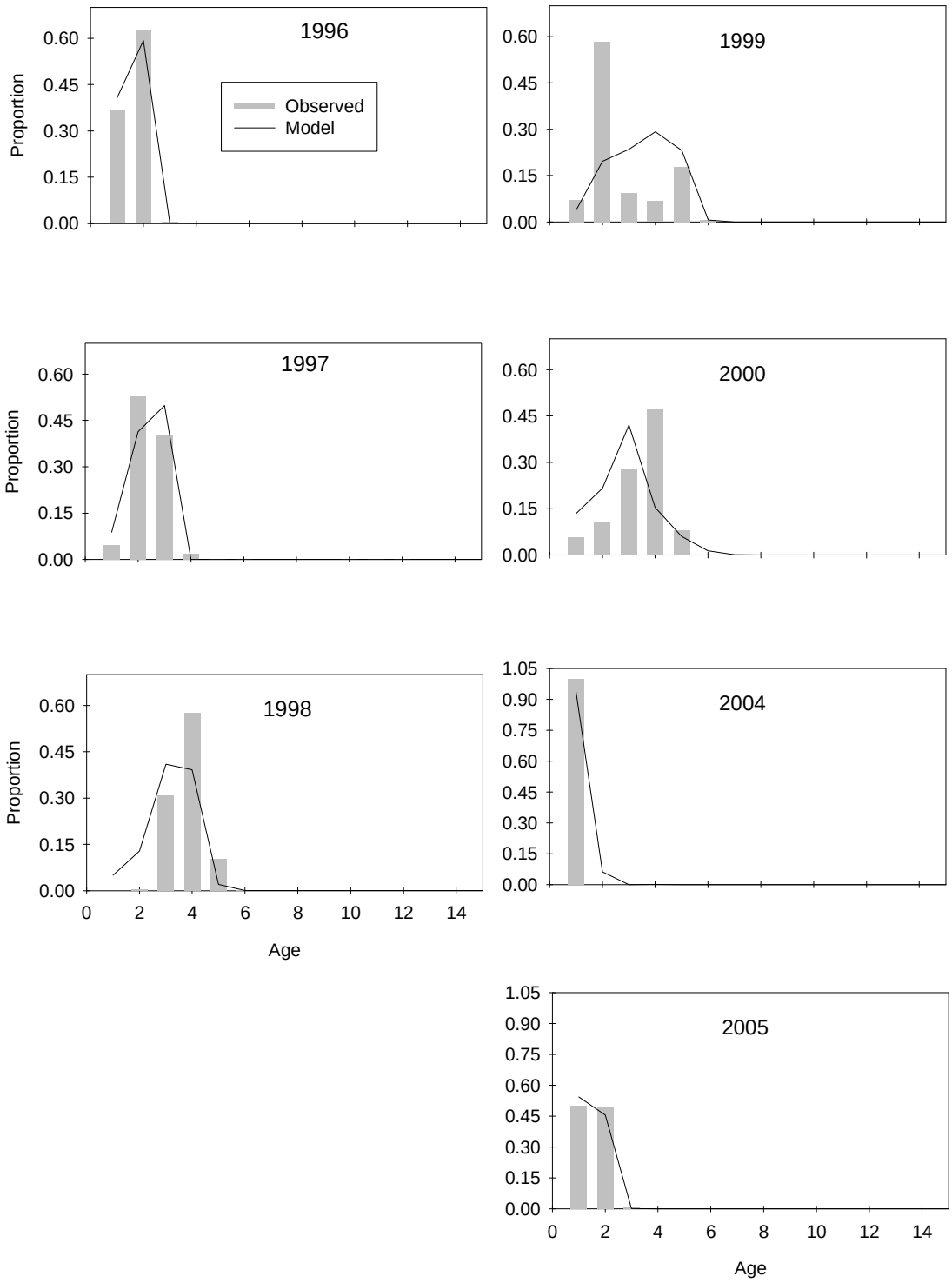


Figure 8.10. Observed (bars) and model estimated (lines) proportion discarded-at-age for the non-spawning sub-fishery.

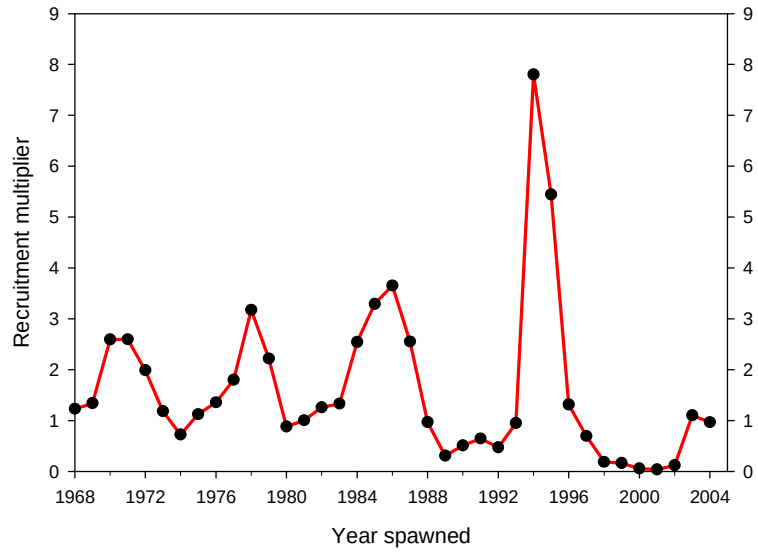


Figure 8.11. Estimated recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning from the base-case model from 1968.

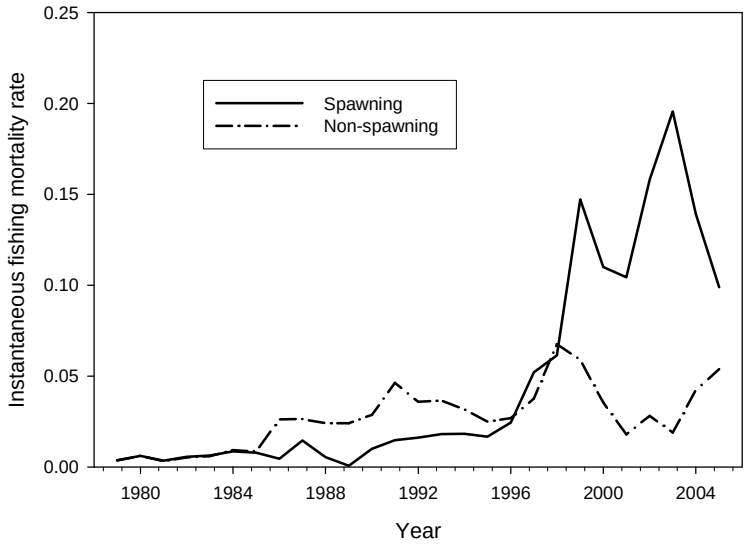


Figure 8.12. The estimated instantaneous fishing mortality rate by sub-fishery from an application of the base case model.

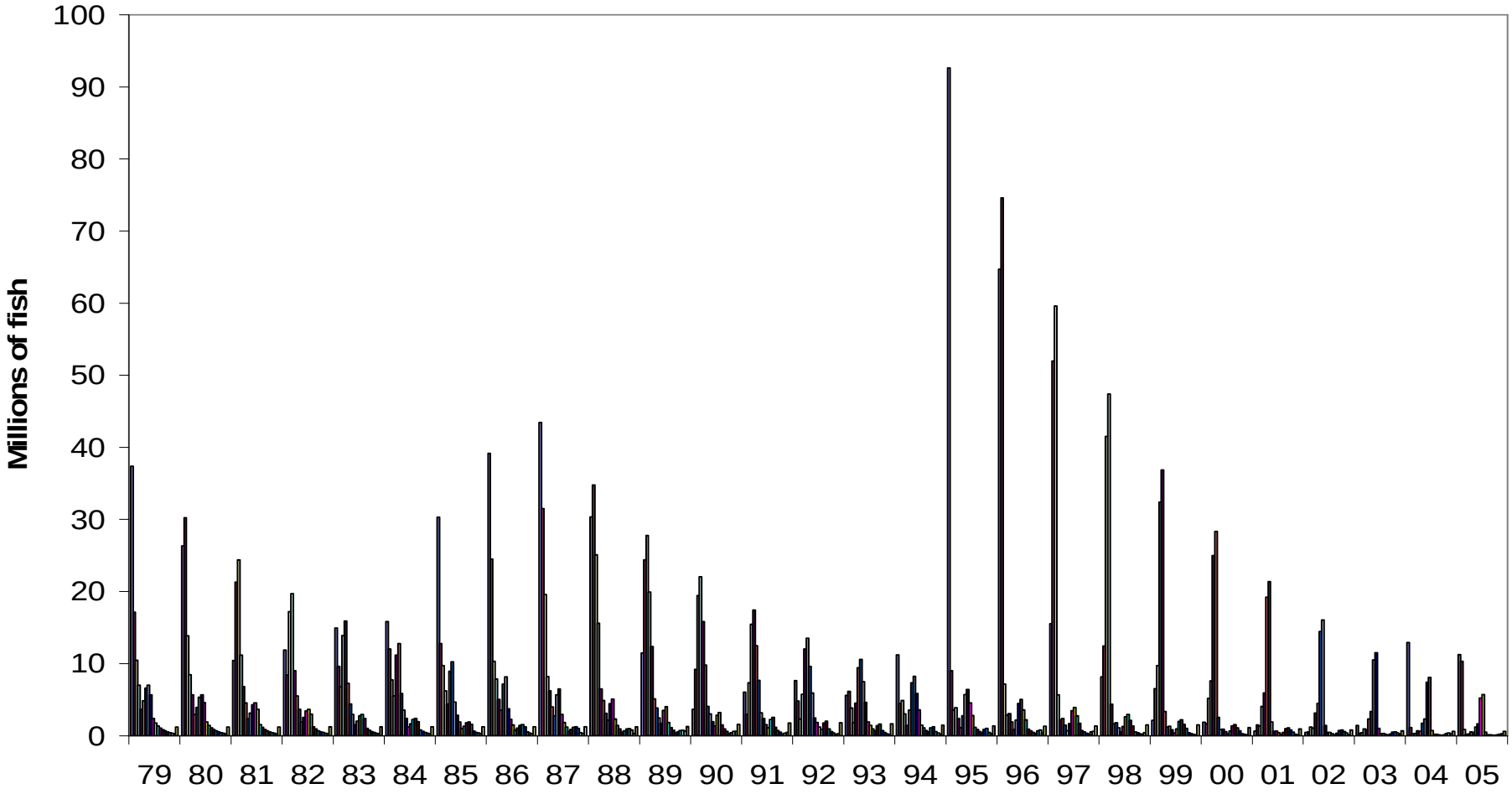


Figure 8.13. The estimated numbers-at-age of blue grenadier by year for the base case model.

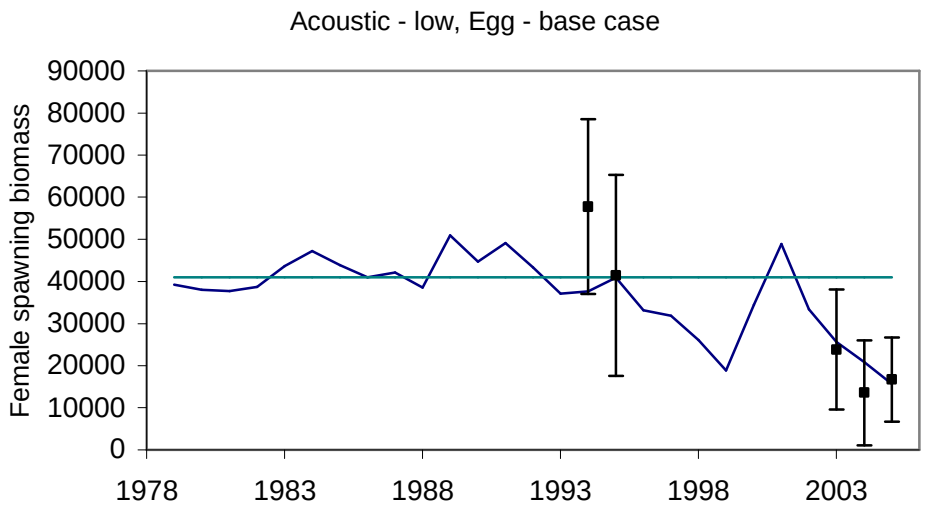


Figure 8.14. The trajectory of female spawning biomass for the base case model. The vertical lines show the estimates of spawning biomass derived from surveys of egg abundance in 1994 and 1995 and acoustic surveys from 2003 to 2005. The horizontal line shows B_{ref}, which is defined as the average female spawning biomass over the period 1978 to 1988.

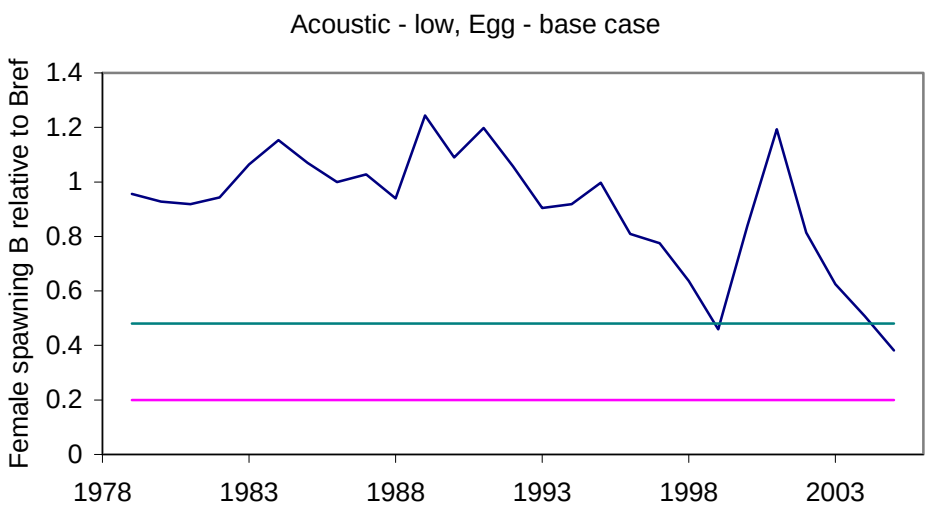


Figure 8.15. The trajectory of female spawning biomass relative to the reference biomass, B_{ref} for the base case model. The horizontal lines show the 0.48 and 0.20 levels.

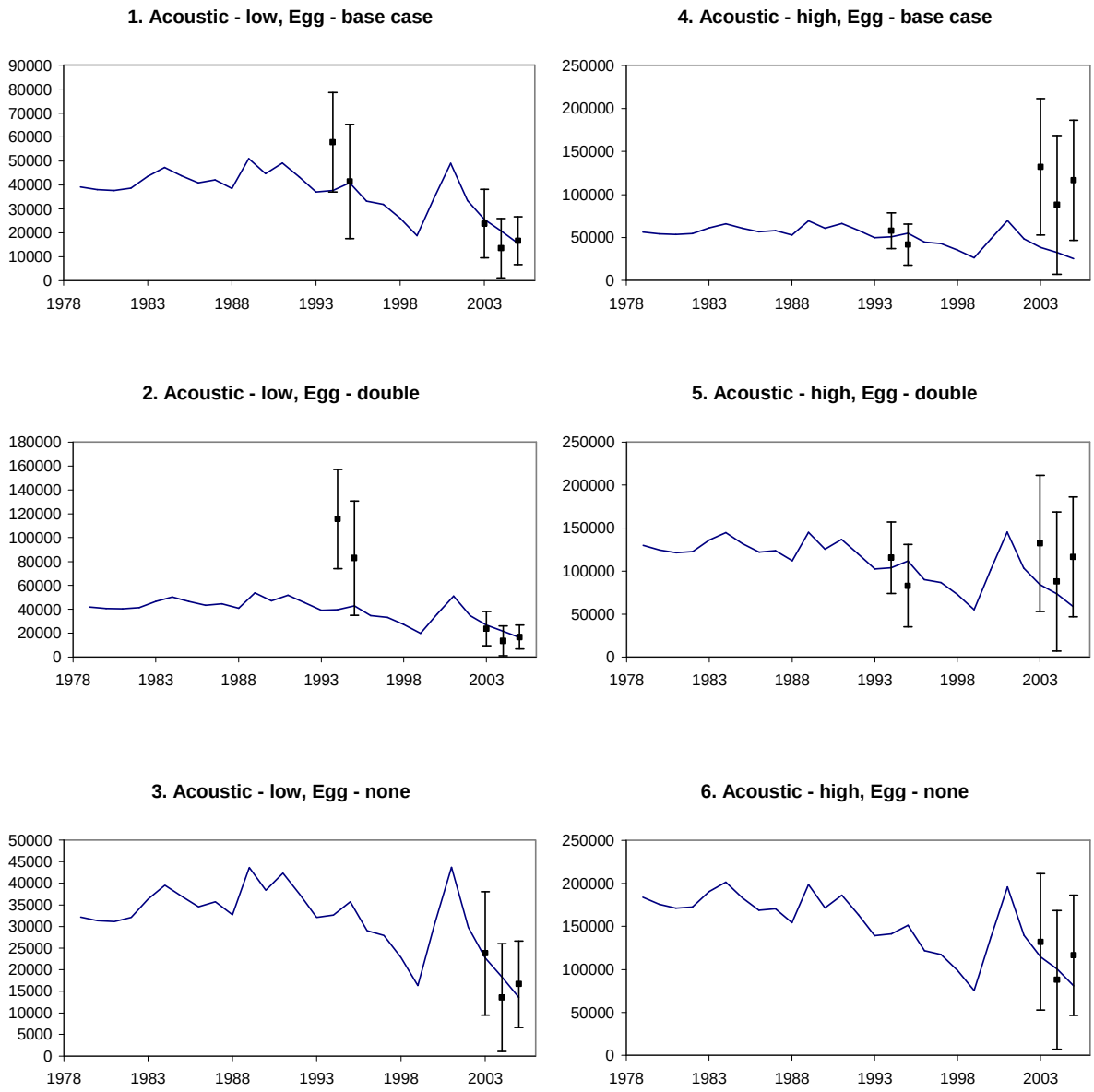
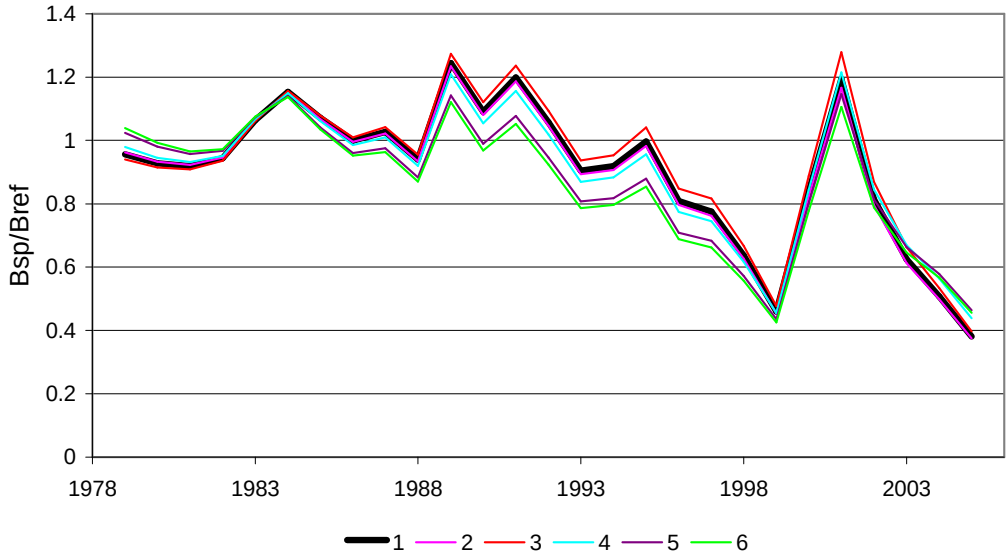


Figure 8.16. The estimated trajectory of female spawning biomass for each of six models that have different assumptions regarding the acoustic and egg surveys (see text). Vertical lines show the acoustic surveys from 2003 to 2005 (±2 s.d.) and the egg surveys (1994, 1995).



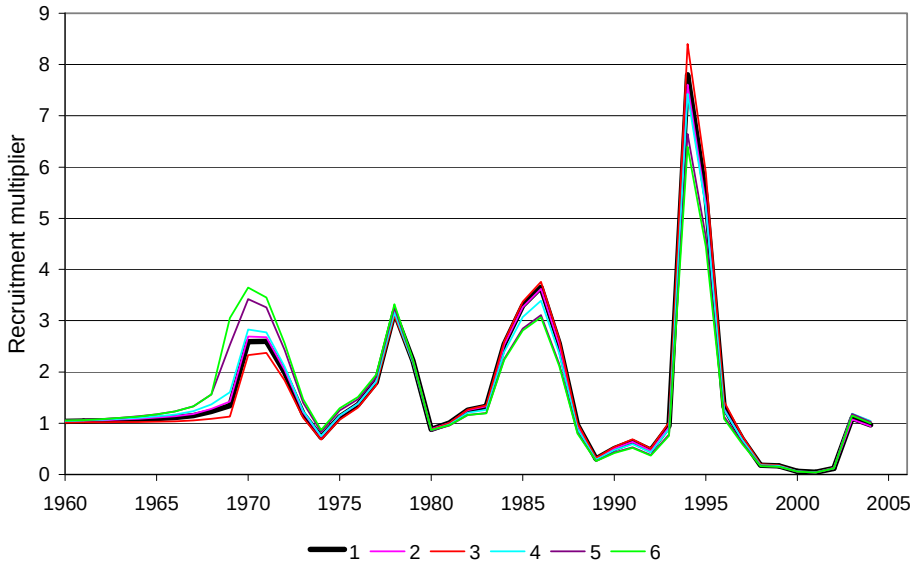
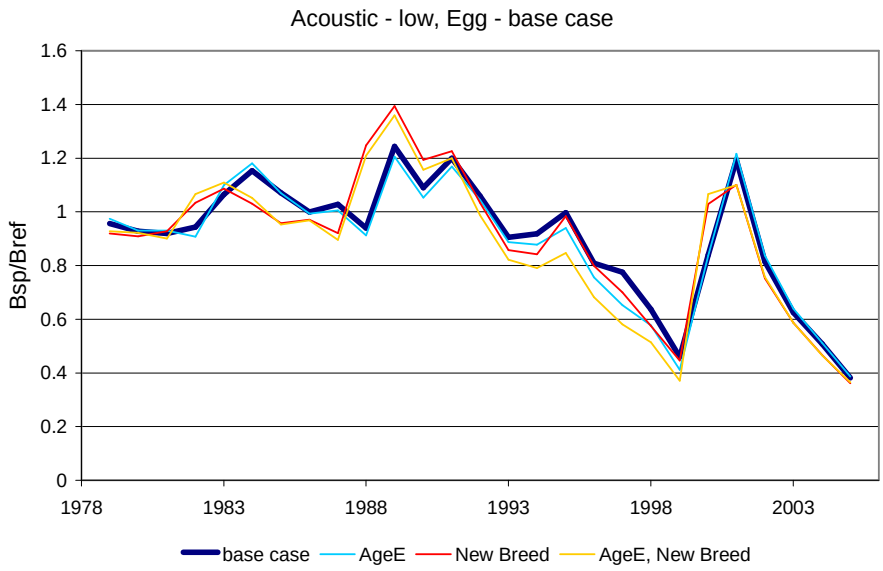


Figure 8.17. The female spawning biomass relative to the reference level and the recruitment multipliers for all sensitivity models 1 through 6 (model 1 is the base case model).



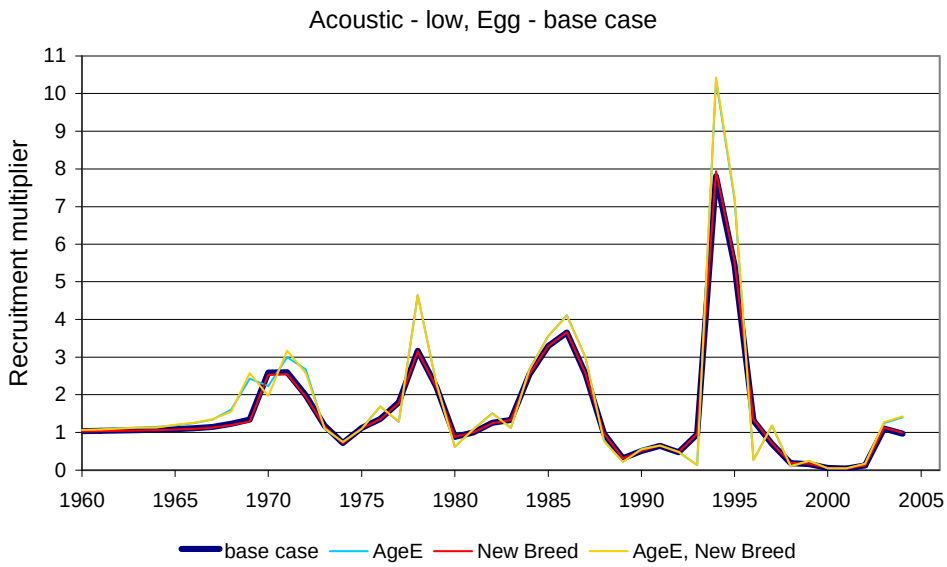
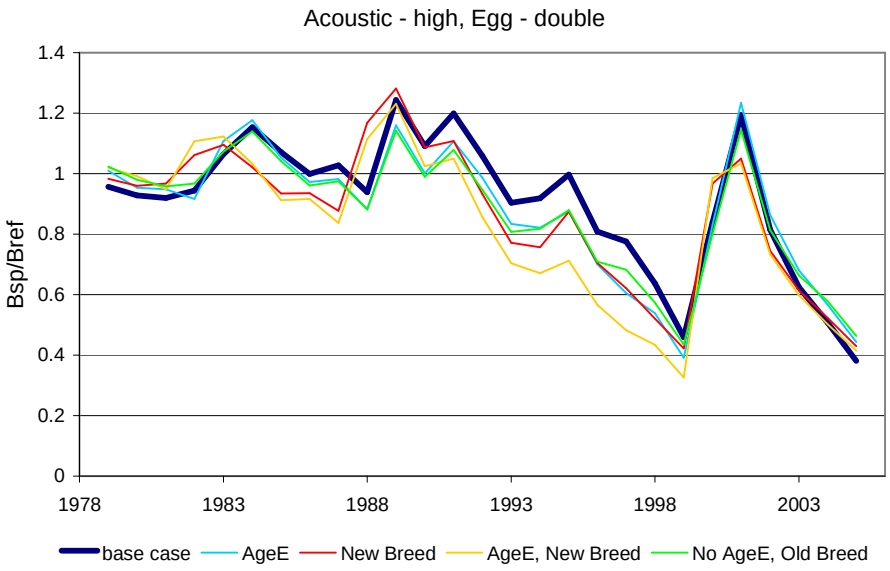


Figure 8.18. The female spawning biomass relative to the reference level and the recruitment multipliers for sensitivity models with low acoustic estimates and base case egg values. From Table 8.6, the models are ageE=7, New Breed=8, Age, New Breed=11.



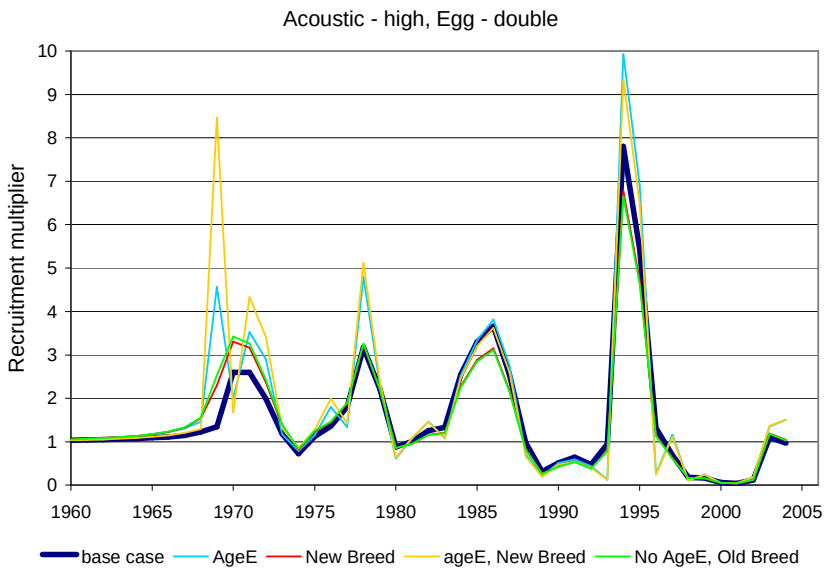


Figure 8.19. The female spawning biomass relative to the reference level and the recruitment multipliers for sensitivity models with high acoustic estimates and double egg values (except for the base case plot). From Table 8.6, the models are ageE=9, New Breed=10, Age, New Breed=12, No AgeE, Old Breed=5.

9. Updated Stock Assessment of Blue Grenadier (*Macruronus novaezelandiae)* Based on Data up to 2005: Application of New Base-Case Models, Harvest Control Rules and Decision Analysis[2]

Geoffrey N. Tuck[1] and André E. Punt[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

9.1 Summary

The 2006 assessment of blue grenadier *Macruronus novaezelandiae* used the age-structured integrated assessment method developed by Punt et al. (2001). The assessment has been updated by the inclusion of data from the 2005 calendar year. In addition, new biological parameters relating to the proportion spawning and the length at maturity have been used. Due to the large differences in magnitude of the estimates of spawning biomass from the acoustic surveys, two models of biological status were explored. These models apply

1) the higher estimates of spawning biomass from the acoustic surveys (Macauley, 2004) and double the egg survey estimates. This model is referred to as the High model.

2) the lower estimates of spawning biomass from the acoustic surveys (Cordue, 2000) and the base-case egg survey estimates of female spawning biomass. This model is referred to as the Low model.

Results imply that the female spawning biomass in 2005 is around 40% of the reference biomass. However, not surprisingly, the magnitude of the biomass differs substantially between the two models. This is reflected in the application of the harvest control rules, where the Recommended Biological Catches (RBCs) for 2007 are between 11,000 t and 18,000 t for the High model and between 2,000 t and 3,300 t for the Low model. The long-term RBCs also differ markedly; with RBCs of 20,000 t for the High model and 5,500 t for the Low model.

An exploration of the consequences of each of the models and their estimated RBC catch series was undertaken. Each RBC catch series was applied to the Low and High models and the subsequent depletions over 20 years recorded. The results illustrated that, while the 2007 depletion is not greatly affected, over a fairly short period of time (5 years) the impact on the stock can be substantial (collapse) if the high RBC catch series is applied when the Low model is the better representation of the state of the stock. In

[2] Paper presented to the Slope Resource Assessment Group on 24-25 July, 2006

contrast, the stock gradually increases in biomass if the lower catch series are used and the High model is the actual biological state of the stock.

9.2 Introduction

An integrated analysis model has been applied to the blue grenadier stock of the Southern and Eastern Scalefish and Shark Fishery (SESSF), with data updated by inclusion of the 2005 calendar year data and additional information from acoustic surveys of spawning biomass. The same assessment model that has been used in previous years (e.g. Punt et al. 2001, Tuck and Punt, 2005) was used again this year.

This document is supplementary to Tuck (2006; 24-25 July 2006), where a number of stock assessment sensitivities were considered. These sensitivities included (a) various acoustic estimates of 2003-2005 spawning biomass that depended upon assumptions of target strength (b) egg survey estimates for 1994-1995 (c) the use of an age-reading error matrix, and (d) updated biological parameters relating to the proportion spawning and the length at maturity. Following instruction from the Slope Resource Assessment Group (Slope RAG, 24-25 July 2006), this document presents (a) diagnostic plots from two resource models, (b) corresponding recommended biological catches (RBCs) and (c) a management decision table. These are described in more detail below.

The two alternative base-case models considered here both include age-reading error, the updated biological parameters for the proportion spawning and length at maturity (for males and females), and an assumption of 2-times turnover on the spawning ground. The acoustic estimates are assumed to pertain to total (male and female) spawning biomass. In previous models (including previous base-case models) a 1:1 sex ratio has been assumed, with the acoustic estimates then being halved in order to fit to female spawning biomass. The two models differ according to the applied target strength used to produce the absolute estimates of spawning biomass from the acoustic surveys and assumptions about the egg survey estimates. The ‘High’ model assumes the target strength of Macauley (2004) and doubles the egg survey estimates. The survey estimates of absolute abundance used when fitting this model are higher than those used when fitting the ‘Low’ model which uses the Cordue (2000) target strength and the base-case egg survey estimates of spawning biomass.

9.3 The fishery

Blue grenadier are found from New South Wales around southern Australia to Western Australia, including the coast of Tasmania. Data support the hypothesis of a single breeding population in Australian waters. Blue grenadier is a moderately long-lived species with a maximum age of about 25 years and an age at maturity of 4-5 years. Spawning occurs off western Tasmania between late May and early September. Adults migrate to the spawning area from throughout southeastern Australia, with large fish arriving earlier in the spawning season.

Blue grenadier are caught by demersal trawling. The global agreed TAC in 2005 was 5000 tonnes (with a voluntary industry reduction to 4200t), down from 7000 t in 2004,

9000 t in 2003 and 10000 t which it had been since 1994. There are two defined sub-fisheries: the spawning and non-spawning fisheries. The non-spawning fishery catches have been relatively consistent over the last few years (at just under 2000t), whereas the spawning fishery catches showed a marked increase during the mid-1990s before decreasing from 2003. The spawning and non-spawning fishery catches are currently at similar levels.

9.4 Data

The model has been updated by the inclusion of the 2005 catch- and discard-at-age from the spawning and non-spawning fisheries; updated cpue series (Haddon, 2006), the total mass landed and discarded, mean length- and weight-at-age; updated acoustic estimates of spawning biomass (T. Ryan, pers. comm.) and estimates of the female spawning biomass in 1994 and 1995 from egg surveys (Bulman et al., 1999). Data were formulated by calendar year (i.e. 1 Jan to 31 Dec).

9.4.1 Catch

The landings from the SEF1 logbook data were used to apportion catches to the spawning and non-spawning fisheries. The SEF1 landings have been adjusted upwards to take account of differences between logbook and landings data (multiple of 1.4 for the non-spawning fishery since 1986; 1.2 for the spawning fishery from 1986 up to and including 1996). These figures were then scaled up to the SEF2 data. The average scaling factor from 1993 to 1998 was used to scale the data as SEF2 data were only available from 1993. The landings data are provided in Table 9.1.

Table 9.1. Landed and discarded catches for the winter spawning and non-spawning sub-fisheries by calendar year. These estimates have been adjusted to account for reporting of headed and gutted catches, and scaled up to the SEF2 data (see text).

Year	**Landings**		**Discards**	
	Spawning	**Non-spawning**	**Spawning**	**Non-spawning**
1979	245	245		
1980	410	410		
1981	225	225		
1982	390	390		
1983	450	450		
1984	675	675		
1985	600	600		
1986	321	1840		
1987	1019	2214		
1988	415	2279		
1989	47	2816		
1990	743	2604		
1991	1158	4193		
1992	931	2669		
1993	990	2359		
1994	1194	1916		
1995	1196	1558		80
1996	1464	1504		975
1997	2952	1581		3716
1998	3267	2469		1329
1999	6087	3214		123
2000	6056	2592		69
2001	7613	1496		10
2002	7428	1731		2
2003	7572	900		4
2004	5065	1399		21
2005	2973	1283		431

9.4.2 Catch rates

Haddon (2006) provides the updated catch rate series for blue grenadier (Table 9.2, Figure 9.1). Models 7 and 6 of Haddon (2006) were used for the non-spawning and spawning fisheries respectively in the assessment models. The series show recent increases in cpue for both sub-fisheries.

Table 9.2. Standardised CPUE (Haddon, 2006) for the spawning and non-spawning sub-fisheries by calendar year.

Year	Spawning		Non-spawning	
	CPUE	Records	CPUE	Records
1986	1.00	65	1.00	1825
1987	1.08	196	1.47	2296
1988	2.35	92	1.57	2606
1989	0.63	31	1.45	3022
1990	0.87	141	1.51	2455
1991	3.26	129	1.11	3541
1992	1.14	168	1.00	3172
1993	2.87	148	0.73	3724
1994	1.65	318	0.64	4015
1995	0.80	476	0.44	4541
1996	1.06	493	0.38	4554
1997	0.83	421	0.38	4758
1998	0.95	578	0.66	4952
1999	0.79	857	0.74	6437
2000	0.89	950	0.66	6078
2001	1.48	1112	0.31	6277
2002	1.02	1047	0.31	5893
2003	0.77	1014	0.23	5341
2004	0.61	735	0.42	5658
2005	0.76	267	0.48	4844

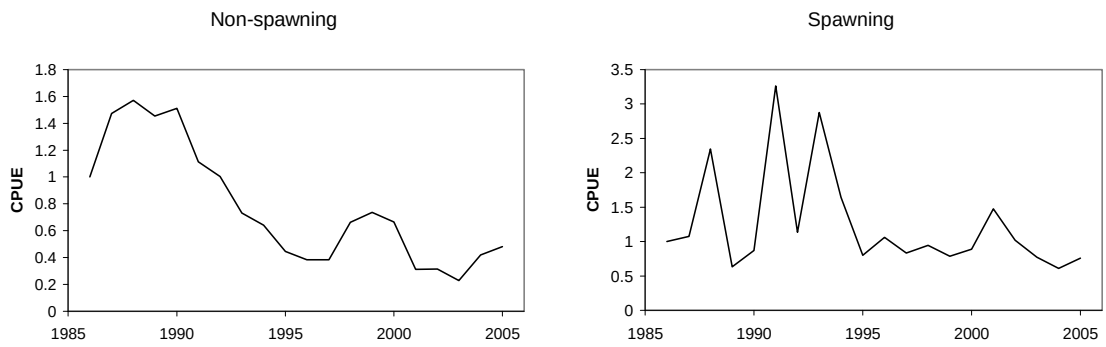


Figure 9.1 The calendar year catch-rate indices for the non-spawning and spawning blue grenadier fisheries (Haddon, 2006).

9.4.3 Catch-at-age

Although length frequency information is collected at several ports around Australia, traditionally only the data collected in Portland and Beachport (for 2002 to 2004) have been used when constructing a length-frequency distribution for the non-spawning fishery. This was done because BGAG had agreed to only use Portland data - earlier investigations by BGAG members indicated that the data from all ports showed the same trend. However, 2005 length frequencies show large differences in length frequency among ports, with Eden showing a marked increase in small fish compared to the other ports. As such, a catch-weighted length frequency was used to produce the 2005 length frequency, utilizing data from Beachport, Portland and Eden (Figure 9.2). Following instruction from Slope RAG (24-25 July 2006), the age-compositions were recalculated using a single age-length key (not by sub-fishery) based on all the port data for the non-spawning fishery (for years 2002-2005). The age-compositions over all years are shown in Figure 9.9 to Figure 9.14.

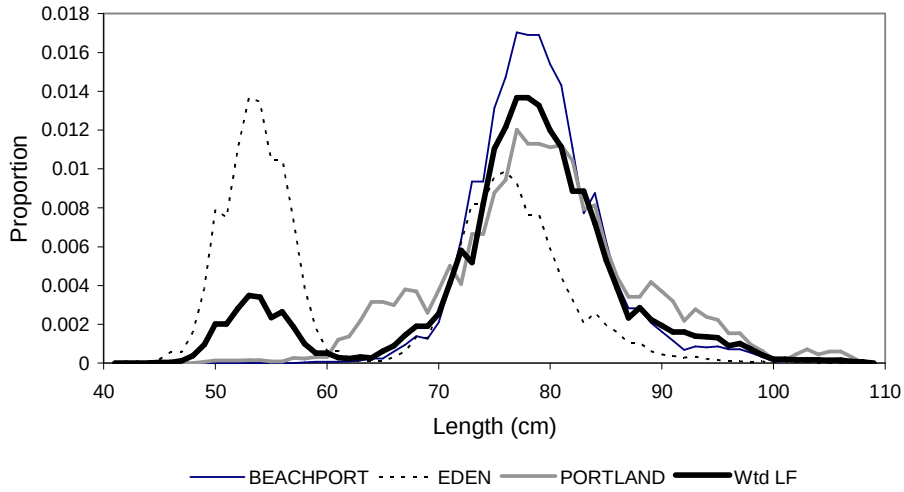


Figure 9.2. The port-based blue grenadier length frequencies for 2005. The Wtd LF line is the catch-weighted length frequency used for the non-spawning sub-fishery.

Spawning sub-fishery length frequencies were obtained from AFMA on-board observations. To obtain the overall length-frequency, length records were catch-weighted by the weight of catch from the haul and the sample weight of the fish (Figure 9.3).

The catch-at-age for 2005 for each of the two sub-fisheries is shown in Figure 9.4. As expected, the non-spawning age composition shows the presence of a recent year-class progressing into the available biomass. This year-class has not yet entered the spawning fishery.

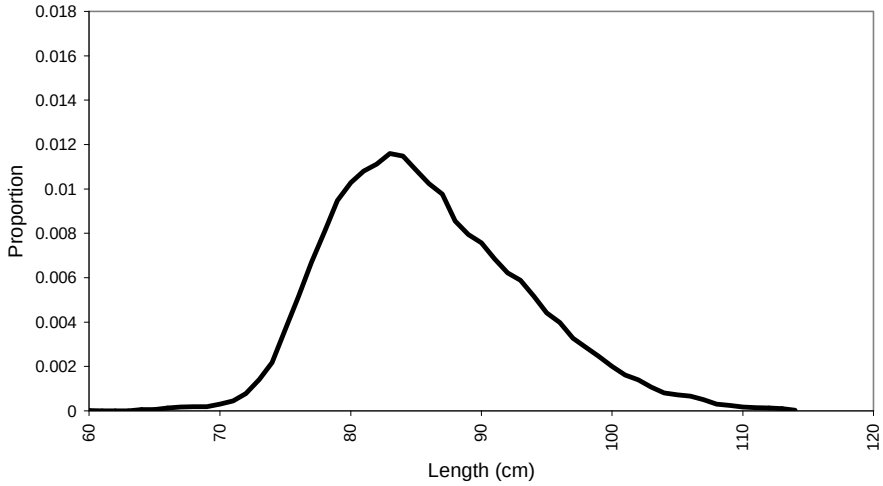


Figure 9.3. The catch-weighted length frequency for blue grenadier of the spawning sub-fishery in 2005.

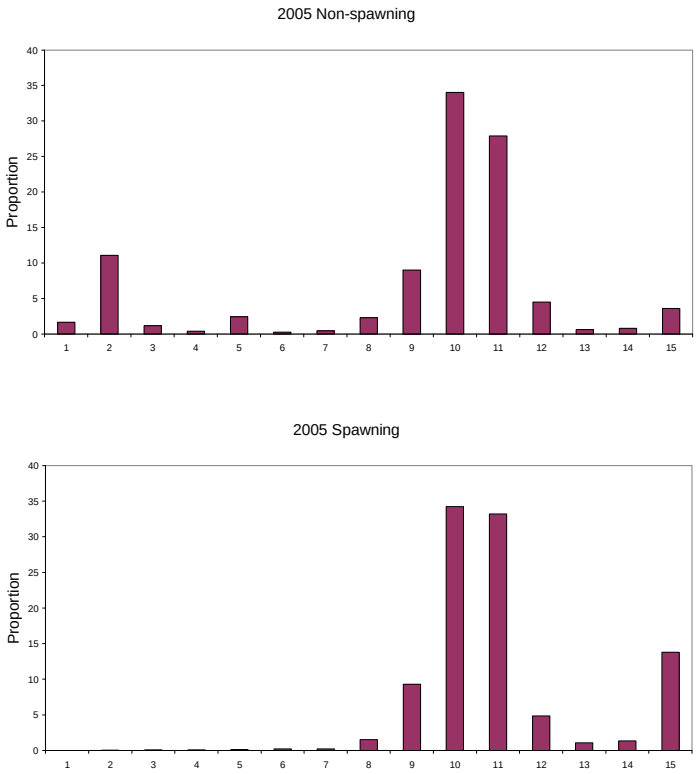


Figure 9.4. The observed proportion caught–at-age data for the non-spawning (top) and spawning (bottom) sub-fisheries in 2005.

9.4.4 Age reading error

Standard deviations for aging error have been estimated, producing the age-reading error matrix of Table 9.4.

9.4.5 Acoustic survey estimates

Following instruction from SlopeRAG (May 2006), several scenarios were considered relating to the acoustic and egg survey biomass estimates in the paper in Tuck (2006; Slope RAG 24-25 July 2006). For the acoustic estimates, five models of biomass were provided by Tim Ryan (pers. comm.). These models differed according to the target strength used. Based on expert judgement, two of these models were used in the assessments of Tuck (2006), namely Macauley (2004) and Cordue (2000). Table 9.3 shows the biomass estimates for each of these models. The model of Macauley (2004) produces markedly higher estimates of biomass (with a lower estimate of target strength) than that of Cordue (2000) (with a correspondingly higher estimate of target strength).

Table 9.3. The estimated biomass of blue grenadier on the spawning grounds in years 2003 to 2005 according to the models of Macauley (2004) and Cordue (2000) (T. Ryan, pers. comm.).

Model	Name	2003	2004	2005
Macauley (2004)	High	131,991	87,852	116,390
Cordue (2000)	Low	23,798	13,544	16,670
c.v. used in assessment model		0.3	0.46	0.3

This paper considers two resource models that differ in terms of the assumptions regarding target strength. These models have been named ‘High’ and ‘Low’ with the name reflecting the relative magnitude of the biomass estimate (and not the target strength value).

9.4.6 Egg survey estimates

Egg survey estimates of female spawning biomass are available for 1994 and 1995 (Bulman et al., 1999). The egg-estimates (cv) for 1994 and 1995 respectively are: 57,772 (0.18) and 41,409 (0.29). For the ‘High’ resource model, the egg estimates were doubled. For the ‘Low’ resource model, the base-case egg estimates were used.

Table 9.4. The age-reading error matrix, shown as the percentage of times an animal with true age given by the column header is aged to be of the age given by the rows. Source: A.E. Punt and Central Aging Facility (CAF, PIRVic, Queenscliff, Victoria).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	94.7	11.1	0.1	0	0	0	0	0	0	0	0	0	0	0	0
2	5.3	77.7	14.8	0.2	0	0	0	0	0	0	0	0	0	0	0
3	0	11.1	70.2	16.6	0.3	0	0	0	0	0	0	0	0	0	0
4	0	0	14.8	66.4	17.8	0.4	0	0	0	0	0	0	0	0	0
5	0	0	0.1	16.6	63.7	18.2	0.4	0	0	0	0	0	0	0	0
6	0	0	0	0.2	17.8	62.8	18.2	0.4	0	0	0	0	0	0	0
7	0	0	0	0	0.3	18.2	62.8	18.2	0.4	0	0	0	0	0	0
8	0	0	0	0	0	0.4	18.2	62.8	18.2	0.4	0	0	0	0	0
9	0	0	0	0	0	0	0.4	18.2	62.8	18.2	0.5	0	0	0	0
10	0	0	0	0	0	0	0	0.4	18.2	62.8	18.9	0.7	0	0	0
11	0	0	0	0	0	0	0	0	0.4	18.2	61.1	19.9	1.2	0	0
12	0	0	0	0	0	0	0	0	0	0.4	18.9	58.8	21.5	2.2	0.2
13	0	0	0	0	0	0	0	0	0	0	0.5	19.9	54.4	23.0	4.0
14	0	0	0	0	0	0	0	0	0	0	0	0.7	21.5	49.5	24.0
15	0	0	0	0	0	0	0	0	0	0	0	0	1.3	25.2	71.7

9.4.7 Parameters of breeding biology

Previous models, including base-case models, have assumed that the proportion of females that spawn is 0.77 and that the length at maturity is 70cm (Punt et al., 2001). These values were taken from research on hoki in New Zealand (Livingston et al., 1997). Recent studies have provided more up-to-date values for these parameters that are specific to the Australian stock of blue grenadier (S. Russell and D. Smith, pers. comm.), namely 0.84 for the proportion of females that are on the spawning grounds, and lengths at 50% maturity of 63.7cm for females and 56.8cm for males. As no information was available on the proportion of non-spawning male blue grenadier, it was assumed that this proportion was the same as that for females. In the results that follow, the updated parameters have been used and not the traditional values.

9.5 Analytic approach

9.5.1 The population dynamics model

The population and likelihood models applied in 2006 are the same as those used in the 2005 assessment and are based upon the integrated analysis model developed for blue grenadier in the South East Fishery by Punt et al. (2001; Appendix; see also Tuck and Koopman, 2005). The 2006 model is updated and extended by including the following data:

- the total mass landed and discarded during 2005; the catch- and discard-at-age during 2005 and the estimated mean length and weight of each age-class present during 2005,
- revised standardised CPUE series,
- an updated age-reading error matrix,
- updated biological parameters for the proportion spawning and the length at maturity, and
- an acoustic estimate of the 2005 spawning biomass off western Tasmania.

Two alternative base-case models are considered in this document. Both include age-reading error, the updated biological parameters for the proportion spawning and the length at maturity (for males and females) and an assumption of 2-times turnover on the spawning ground. The acoustic estimates are assumed to relate to the total (male and female) spawning biomass. In previous models (including previous base-case models) a 1:1 sex ratio has been assumed, with the acoustic estimates then being halved in order to fit to female spawning biomass. The two models differ according to the target strength used to produce the absolute estimates of spawning biomass from the acoustic surveys, and assumptions about the egg survey estimates. The ‘High’ model assumes the target strength of Macauley (2004) and doubles the egg survey estimates. The survey estimates of absolute abundance for this model are higher than those for the ‘Low’ model which uses the Cordue (2000) target strength and the base-case egg survey estimates of spawning biomass.

Two sub-fisheries are included in the model – the spawning sub-fishery that operates during winter (June – August inclusive) off western Tasmania, and the non-spawning sub-fishery that operates during other times of the year and in other areas throughout the year. The model is sex dis-aggregated. However male and female fish are assumed to grow at the same rate.

Parameter uncertainty is examined through the use of sensitivity tests and by applying the Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman et al., 1995).

9.5.2 The objective function

The negative of the logarithm of the likelihood function includes five components. These relate to minimizing the sizes of the recruitment residuals, fitting the observed catches and discards by fleet, fitting the observed age-compositions by fleet, fitting the catch rate information, and fitting the estimates of spawner biomass from the egg and acoustic surveys. The Appendix (Section 9.10) has details of the likelihood formulations (see also Punt et al. (2001)).

9.5.3 Parameter estimation

The values assumed for some of the (non-estimated) parameters of the base case models are shown in Table 9.5. The model has 112 estimated parameters: 2 catchability coefficients; 1 female natural mortality, 1 B_0, 27 annual fishing mortality rates for each of the two sub-fisheries; recruitment residuals for 26 years and 19 age classes in the first year; 2 selectivity parameters for the spawning sub-fishery and 3 for the non-spawning; and 4 parameters for the probability of discarding-at-length.

The values for the parameters that maximize the objective function are determined using the AD Model Builder package[3]. This assessment quantifies the uncertainty of the estimates of the model parameters and of the other quantities of interest using Bayesian methods. The Markov Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gelman et al., 1995) was used to sample 2000 equally likely parameter vectors from the joint posterior density function. The samples on which inference is based were generated by running 2,000,000 cycles of the MCMC algorithm, discarding the first 1,000,000 as a burn-in period and retaining every 500th parameter vector thereafter.

[3] Copyright 1991, 1992 Otter Software Ltd.

Table 9.5. Parameter values assumed for some of the non-estimated parameters of the base-case model.

Parameter	Description	Value
N	Weight for the catch- and discard-at-age data	50
σ_r	c.v. for the recruitment residuals	1.0
σ_c	c.v. for the landings data	0.05
σ_d	c.v. for the discard data	0.3
σ_q	c.v. for the CPUE data	0.3
h	"steepness" of the Beverton-Holt stock-recruit curve	0.9
x	age of plus group	15 years
μ	fraction of mature population that spawn each year	0.84
l_∞	von Bertalanffy parameter (maximum length)	102.76 cm
κ	von Bertalanffy parameter (growth rate)	0.16 y^{-1}
t_0	von Bertalanffy parameter	-2.209 y
aa	allometric length-weight equations	0.00375 g^{-1}.cm
bb	allometric length-weight equations	3.013
l_m	length at maturity (knife-edged) (M, F)	63.7, 56.8cm

9.6 Results and discussion

9.6.1 Stock assessment – 'Low' and 'High' models

Figure 9.5 and Figure 9.6 show the observed and predicted fits to the landings and discards from each sub-fishery for each model. The model is forced to fit the recorded landings very well because of the very low c.v. that is assumed for these data (σ_c = 0.05, Table 9.5). The fits to the landings data from the High model are not shown as they do not differ appreciably from those for the Low model. The model is able to fit the recent drop in the mass of discards and the recent increase; however the large discard measured in 1997 is not well estimated despite the ability of the model to allow for density-dependant discarding.

For the Low model the estimated natural mortality figure for females is approximately 0.18 and consequently that for males is 0.21 (as male natural mortality is assumed to be 1.2 times that of females). For the High model, female natural mortality was estimated to be 0.21, with that of males then being 0.25.

Figure 9.7 shows that the model is not able to fit the early fluctuations in the CPUE for the winter spawning sub-fishery but it is able to achieve a reasonably good fit to the CPUE for recent years. The fit to the CPUE for the non-spawning sub-fishery is reasonably good, although the increase in the CPUE after 1998 is not as well estimated; the drop in CPUE for 2000 is not predicted by the model, which actually predicts an increase, consistent with the growth of a large cohort of grenadier spawned in 1994. Attempts to provide better fits to the non-spawning fishery cpue have not been fruitful (such as forcing fits to the cpue by lowering the cv). This issue will be explored further as a high priority. Changes to the form of the selectivity function may prove successful. The model is also not able to mimic the increase in standardized CPUE for 2005.

The estimated vulnerability of fish of a given length class to being caught (but not necessarily landed) by either sub-fishery is shown in Figure 9.8. The probability that a fish will be discarded once it has been caught is also shown. Clearly, there is very little difference between the functions estimated by the Low and High models.

The fits to the catch-at-age and the discard-at-age data for fisheries by both the Low and High model are reasonably good (Figure 9.9 to Figure 9.14). Figure 9.15 and Figure 9.16, which show the estimated annual recruitment multipliers, illustrates a long period of poor recruitment following the strong recruitments of 1994 and 1995. While an increase in recruitment is estimated by the model for years 2003 and 2004, these will not have been well estimated (as these fish have mostly not moved into the available population to any noticeable extent) and the real strength of these cohorts will need to be determined over the next few years. The pattern of recruitment multipliers seen in these figures differs somewhat from that of previous models due to the inclusion of age-reading error. Note that the High model produces a substantial recruitment in 1970 which has not been observed in previous models. However, it is clear from the confidence intervals in Figure 9.16 that the model's ability to estimate these early recruitments is poor. Generally, from years after 1977, the confidence intervals on the recruitment multipliers are relatively tight. Table 9.6 shows the results for various quantities of interest for the base case models. The quantities of interest shown are the estimated pristine female spawning biomass (B_0); the reference biomass (B_{ref}) which is the average female spawning biomass over 1979–1988; the spawning biomass in 1979 ($\tilde{B}_{79}$) and in 2005 ($\tilde{B}_{2005}$) and its size in 1986, 1993, and 2004 relative to the reference level (depletion, $\tilde{B}_y / B_{ref}$); the estimated fishing mortality rate for the spawning (F^1_{curr}) and non-spawning (F^2_{curr}) sub-fisheries for 2005 (=*curr*); the estimated recruitment residual for the strong 1994 cohort, and the 2003 cohort, and the negative log likelihood (-ln L) value from the model. Also shown are the base-case results for the previous three year's assessments. Note that the final year of biomass estimation (*curr*) is one year less than the year the assessment is produced.

The Low base-case model indicates that the reference female biomass is approximately 49,300 t and that current female spawner biomass (in the middle of 2005) is approximately 37% of the reference biomass. In contrast, the High base-case model indicates that the reference female biomass is nearly 150,000 t and that current female spawner biomass (in the middle of 2005) is approximately 42% of the reference biomass. These models illustrate that while the estimated magnitude of the biomasses differs greatly, the depletion levels do not differ by nearly as much. Figure 9.17 shows the spawning biomass trajectory for the Low and High models with the egg survey estimates (left; female spawning biomass only) and the acoustic estimates (right; total spawning biomass). Intervals on survey estimates are 2 standard deviations. Figure 9.18 shows the female spawning biomass trajectory relative to the reference biomass for each model.

The 1994 year-class is estimated to be a larger fraction of its expected value in the Low and High models, compared to past assessments and the July 2006 base-case model. This change in results is a consequence of the changes to the age-reading error matrix.

Table 9.6. Estimated values for several quantities of interest. The base case model is shown as well as sensitivity tests. Results are shown for base-case runs in the previous 3 years for comparison with the 2005 assessment. 'Curr' refers to the current or final year of the estimation. The base case (July 2006) model includes the base case estimates from the egg survey, the lower acoustic survey estimates and 2 times turnover. The High Model uses the higher acoustic survey estimates of total spawning biomass with the egg survey estimates of female spawning biomass doubled. The Low model uses the lower acoustic estimates of total spawning biomass with the base-case egg survey estimates.

Specification	B_0	B_{ref}	$\tilde{B}_{79}$	$\tilde{B}_{curr}$	$\tilde{B}_{curr} / B_{ref}$	F^1_{curr}	F^2_{curr}	R_{94}	R_{03}	-ln L
Previous assessment results										
Base-case, *curr*=2002	33026	52605	51685	31241	59.39%	0.175	0.027	6.0	-	352.42
Base-case, *curr*=2003	26877	42082	41441	18066	42.93%	0.278	0.026	6.2	-	362.06
Base-case, *curr*=2004	30241	48612	47311	21283	43.78%	0.139	0.036	6.9	0.71	396.00
2006 assessment, *curr*=2005										
Base-case (July 2006)	27557	40972	39177	15618	38.12%	0.099	0.054	7.8	1.1	418.69
Low Model	27467	49293	47396	18065	36.65%	0.085	0.067	11.4	1.7	372.67
High Model	63917	148749	155947	62203	41.82%	0.027	0.020	10.1	1.8	378.56

9.6.2 Harvest control rule application

The steps involved in computing the Recommended Biological Catch for 2007 using the Tier 1 rules are:

1. Determine the relationship between exploitation rate and spawning biomass, where the relative exploitation rates among the fleets are based on the exploitation rates estimated for 2006.
2. Find the exploitation rates so that spawning biomass is a pre-specified fraction of that in an unfished state.
3. Determine the depletion of the spawning biomass in the middle of 2007.
4. Determine the correction factor (if needed), and multiply the exploitation rates calculated at step 2 by this correction factor.
5. Multiply the numbers-at-age in the middle of 2007 by the exploitation rates calculated at step 4.

Three variants of the Tier 1 rules are applied depending on specifications for the target spawning biomass and the depletion at which the exploitation rate begins to be reduced to zero (all variants set the exploitation rate to zero if the stock is assessed to be depleted to be 20% of B_{ref}):

a) 20-48-48; a target stock size of 48% of B_{ref}, with the exploitation rate dropping off once the stock drops below the target level.
b) 20-40-48; a target stock size of 48% of B_{ref}, with the exploitation rate dropping off once the stock drops below 0.4 B_{ref}.
c) 20-40-40; a target stock size of 40% of B_{ref}, with the exploitation rate dropping off once the stock drops below the target level.

The mid-year depletion in 2007 must be calculated to apply the Tier 1 harvest control rule. The 2007 depletion for the two models is shown in Table 9.7 and is calculated by assuming a 2006 catch of 3,730 t. The ensuing landed and total Recommended Biological Catches (RBC) for 2007 are given in Table 9.7 The different scales of these RBCs reflect the large estimated differences in magnitude of the biomass of the two acoustic models.

The 2006 TAC is 3,730 t. Applying the rule that the TAC should not be increased or decreased by more than 50% of the previous year's TAC, reduces the RBCs from the 'High' model to 5,595 t (1.5 times the 2006 TAC). The RBCs under the 'Low' model are all greater than 50% of the 2006 TAC.

The time series of landed RBCs under each Tier 1 rule and each alternative model (Low and High) is given in Table 9.8 and 9.9. Note that the final depletions are not exactly 40% and 48% of B_{ref} even when the catches are those for the model concerned (i.e. RBCs determined from the Low Acoustic model projected forward when reality is assumed to be the Low Acoustic model). This occurs presumably because density-dependence in the stock recruitment model is a function of depletion relative to B_0 and

not relative to B_{ref}. As a result, the depletion in terms of B_0 is higher than in terms of B_{ref}.

From Table 9.8 and Table 9.9, the long-term RBCs under the Low model are approximately 5,300 t for a target depletion of 48% of the reference biomass and 6,000 t for 40%. For the High model, the long-term RBCs are substantially larger. For a target depletion of 48%, the RBCs are approximately 19,600 t, and for 40% the RBC is 22,150.

Table 9.7.The estimated 2007 mid-year depletion and RBCs (landed and total; tonnes) for two resource models and three Tier 1 harvest control rules with target biomass depletions of either 48% or 40%.

Model	High acoustic, double egg (High)			low acoustic, base-case egg (Low)		
Tier rule	2007 Depletion	Landed RBC	Total RBC	2007 Depletion	Landed RBC	Total RBC
20:40:40	0.41	18,231	19,492	0.36	3,350	3,560
20:48:48	0.41	11,110	11,866	0.36	1,936	2,056
20:40:48	0.41	14,097	15,062	0.36	2,636	2,801

Table 9.8. The time series of landed RBCs (referred to as Low-RBC) and corresponding depletions relative to B_{ref} for each Tier 1 rule for the Low model.

	Low acoustic model					
	Landed RBC			Depletion		
	20:40:40	20:48:48	20:40:48	20:40:40	20:48:48	20:40:48
2006	3730	3730	3730	0.36	0.36	0.36
2007	3350	1936	2636	0.36	0.36	0.36
2008	3828	2439	3165	0.37	0.39	0.38
2009	4481	3094	3852	0.38	0.41	0.40
2010	5116	3780	4263	0.39	0.44	0.41
2011	5530	4322	4522	0.40	0.45	0.43
2012	5664	4718	4706	0.41	0.47	0.44
2013	5756	5001	4845	0.41	0.48	0.46
2014	5823	5126	4954	0.42	0.48	0.47
2015	5874	5178	5039	0.42	0.49	0.47
2016	5914	5219	5108	0.42	0.49	0.48
2017	5947	5251	5164	0.42	0.50	0.49
2018	5972	5278	5209	0.43	0.50	0.49
2019	5993	5300	5245	0.43	0.50	0.50
2020	6009	5318	5274	0.43	0.51	0.50
2021	6022	5332	5297	0.43	0.51	0.50
2022	6032	5344	5316	0.43	0.51	0.51
2023	6040	5353	5331	0.43	0.51	0.51
2024	6047	5360	5342	0.43	0.51	0.51
2025	6051	5365	5351	0.43	0.51	0.51

Table 9.9. The time series of landed RBCs and corresponding depletions relative to B_{ref} for each Tier 1 rule for the High model.

High acoustic model						
	Landed RBC			Depletion		
	20:40:40	20:48:48	20:40:48	20:40:40	20:48:48	20:40:48
2006	3729	3729	3729	0.42	0.42	0.42
2007	18231	11110	14097	0.41	0.42	0.41
2008	18181	12765	14418	0.41	0.44	0.43
2009	19103	14678	15484	0.41	0.46	0.44
2010	20217	16631	16713	0.42	0.47	0.46
2011	20920	18017	17583	0.42	0.48	0.47
2012	21274	18488	18110	0.42	0.49	0.48
2013	21510	18782	18489	0.43	0.49	0.48
2014	21682	18996	18774	0.43	0.50	0.49
2015	21806	19155	18988	0.43	0.50	0.50
2016	21897	19275	19149	0.43	0.51	0.50
2017	21966	19368	19274	0.43	0.51	0.50
2018	22018	19440	19369	0.43	0.51	0.51
2019	22057	19495	19441	0.43	0.51	0.51
2020	22086	19537	19497	0.44	0.51	0.51
2021	22107	19569	19539	0.44	0.51	0.51
2022	22123	19594	19571	0.44	0.51	0.51
2023	22135	19612	19595	0.44	0.52	0.51
2024	22144	19626	19613	0.44	0.52	0.52
2025	22150	19636	19626	0.44	0.52	0.52

9.6.3 Decision analysis

The Tier 1 RBCs calculated in the previous section lead to six possible landed catch series; one for each of the three Tier 1 rules (20:40:48, 20:40:40, and 20:48:48) and for each of the alternative base-case models (Low, High). As there remains considerable uncertainty regarding the correct target strength model to apply to estimate spawning biomass from the results of the acoustic surveys, and as the choice of target strength has dramatic implications for the status of the stock, a method of looking at the consequences of each catch series was developed. The general idea of the method is to explore the impact of using each catch series on each of the two possible models of stock status. This way, the consequence of mis-matches between the resource model and the applied RBC catch series, derived from a different resource model, can be explored (e.g. applying the RBCs from the High model, to the Low stock status model).

For each catch series, including a constant catch set at the current TAC of 3,730 t, deterministic projections were conducted over a 20-year time horizon using parameter sets from either the Low or High models. The parameter sets used were (i) those corresponding to the maximum likelihood estimates and (ii) derived to account for the uncertainty in the strength of the 2003 recruitment. As there is uncertainty regarding the strength of the 2003 recruitment – the most recent improved recruitment following several years of poor recruitment – a simple exploration of the impact of the various catch series across this uncertainty was conducted. The 2000 parameter sets from the

Bayesian analysis were sorted according to the magnitude of the 2003 recruitment multiplier. Parameter sets representing low, median and high 2003 recruitments were chosen as the 12.5 percentile (250th parameter set), the 50 percentile (median; 1000th set) and the 87.5 percentile (1750th set) respectively. Figure 9.19 shows the 2003 recruitment multipliers sorted by magnitude for the Low and High models.

The additional rule for setting the TAC selected by SlopeRAG requires that the TAC not increase or decrease by more than 50% of the current year's TAC. All of the RBCs from the Low model show changes within this bound (Table 9.8). However the High model RBCs increase immediately to well above 50% of the 2006 TAC (Table 9.9). To account for this, the annual landed RBCs for the High Model were multiplied by 1.5 each year until the adjusted RBC was greater than the estimated RBC. Table 9.10 provides the time-series of adjusted landed RBCs for the High model used in the projections.

The results, using the depletion relative to B_{ref} as the performance measure, are illustrated in Table 9.11 (for all Tier 1 rules, and for years 2007 and 2012) and Figure 9.20 (for the 20:40:48 Tier 1 rule only). Table 9.11 and Figure 9.20 show that applying the RBCs derived from the High model when the Low model is the actual biological model will very quickly collapse the spawning stock. Not surprisingly, if the lower catch series is applied to a stock that is much larger in magnitude (the High models), then the depletion levels reduce markedly. The trajectories of spawning biomass depletion remain fairly stable, at or about the target level (except for the lower recruitment parameter set, for which depletion in 2012 is below the target level) if the catch series and state of nature match (i.e. Low-RBC with Low model, High-RBC with High model). In general, and as expected, the depletion levels are higher for the parameter sets that use the higher recruitment values for 2003. If the annual catch is fixed at the current TAC of 3,730 t (Figure 9.21) then, under the Low resource model, the depletion gradually rises to about 60% of the reference biomass in 10 years. For the High model, by 2016 the depletion is at or above 70% of the reference biomass.

Table 9.11 illustrates that the impact of each of the 2007 RBCs is not great. However, over a fairly short period of time (5 years), the consequences of the RBCs on the stock can be substantial.

Table 9.10. The time-series of landed RBCs for the High model (referred to as High-RBC) adjusted so that the change in the TAC from one year to the next is not greater than 50% of the current TAC. The shaded cells have been adjusted to some extent.

High acoustic model			
	Adjusted Landed RBC		
	20:40:40	20:48:48	20:40:48
2006	3730	3730	3730
2007	5595	5595	5595
2008	8393	8393	8393
2009	12589	12589	12589
2010	18883	16631	16713
2011	20920	18017	17583
2012	21274	18488	18110
2013	21510	18782	18489
2014	21682	18996	18774
2015	21806	19155	18988
2016	21897	19275	19149
2017	21966	19368	19274
2018	22018	19440	19369
2019	22057	19495	19441
2020	22086	19537	19497
2021	22107	19569	19539
2022	22123	19594	19571
2023	22135	19612	19595
2024	22144	19626	19613
2025	22150	19636	19626

Table 9.11. The 2007 and 2012 depletion relative to the reference biomass for the two acoustic models (Low, High), four parameters sets (MLE, R125, R500, R875) for an application of a catch time series relating to the three Tier 1 rules under either the Low or High (Low-RBC, High-RBC) models or the current TAC.

2007 Depletion		Low acoustic model				High acoustic model			
Rule	Catch	MLE	R125	R500	R875	MLE	R125	R500	R875
	Ccurr	0.35	0.23	0.40	0.49	0.43	0.37	0.42	0.56
20:40:48	High-RBC	0.34	0.22	0.39	0.48	0.43	0.36	0.42	0.55
20:40:48	Low-RBC	0.36	0.23	0.41	0.49	0.43	0.37	0.42	0.56
20:40:40	High-RBC	0.34	0.22	0.39	0.48	0.43	0.36	0.42	0.55
20:40:40	Low-RBC	0.36	0.23	0.41	0.49	0.43	0.37	0.42	0.56
20:48:48	High-RBC	0.34	0.22	0.39	0.48	0.43	0.36	0.42	0.55
20:48:48	Low-RBC	0.36	0.23	0.41	0.50	0.43	0.37	0.42	0.56

2012 Depletion		Low acoustic model				High acoustic model			
Rule	Catch	MLE	R125	R500	R875	MLE	R125	R500	R875
	Ccurr	0.45	0.27	0.53	0.60	0.66	0.52	0.62	0.75
20:40:48	High-RBC	0.01	0	0.03	0.07	0.52	0.38	0.51	0.63
20:40:48	Low-RBC	0.44	0.26	0.52	0.60	0.65	0.52	0.61	0.74
20:40:40	High-RBC	0	0	0	0	0.50	0.35	0.49	0.61
20:40:40	Low-RBC	0.41	0.24	0.48	0.55	0.64	0.50	0.61	0.73
20:48:48	High-RBC	0.01	0	0.02	0.06	0.52	0.37	0.51	0.62
20:48:48	Low-RBC	0.47	0.28	0.54	0.62	0.66	0.52	0.62	0.75

9.7 Acknowledgements

Many thanks are due to Tony Smith, Gavin Fay, Rick Methot and all of the SS2-WG for their assistance with the SS2 model development (even if we did not use it for BG… next year). Malcolm Haddon is thanked for providing catch rate indices, and Matt Koopman, Mike Fuller and Neil Klaer for their advice on data matters. The Central Aging Facility and the AFMA observer section are thanked for providing the aging data and spawning length frequency data respectively.

9.8 References

Bulman, C. M., Koslow, J. A., and Haskard, K. A. 1999. Estimation of the spawning stock biomass of blue grenadier (*Macruronus novaezelandiae*) off western Tasmania based upon the annual egg production method. Marine and Freshwater Research. 50:197-207.

Francis, R.I.C.C. 1992. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplosethus atlanticus*) on the Chatham Rise, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences 49: 922-930.

Gelman, A., Carlin, J.B., Stern, H.S., and Rubin, D.B. 1995. Bayesian Data Analysis. Chapman and Hall, London.

Hastings, W.K. 1970. Monte Carlo sampling methods using Markov chains and their applications. Biometrika 57: 97–109.

Livingston, M.E., Vignaux, M. and Schofield, K.A. 1997. Estimating the annual proportion of non-spawning adults in New Zealand hoki, *Macruronus novaezelandiae.* Fishery Bulletin (US) 95:99-113.

McAllister, M.K., Pikitch, E.K., Punt, A.E., and Hilborn, R. 1994. A Bayesian approach to stock assessment and harvest decisions using catch-age data and the sampling/importance resampling algorithm. Canadian Journal of Fisheries and Aquatic Sciences 51: 2673-2687.

Punt, A.E., Smith, D.C., Thomson, R.B., Haddon, M., He. X and Lyle, J.M. 2001. Stock assessment of the blue grenadier *Macruronus novaezelandiae* resource off south eastern Australia. Marine and Freshwater Resources. 52:701-717.

Haddon, M. 2006. Standardized Commercial Catch-Effort data for selected Shelf and Slope Assessment Group Species for 1986 - 2005. Prepared for the Slope Resource Assessment Group. July 24-25, 2006.

Tuck, G.N. 2006. Updated stock assessment for blue grenadier in the Southern and Eastern Scalefish and Shark Fishery: July 2006. Report to the Slope Resource Assessment Group. 24-25 July 2006.

Tuck, G.N., Koopman, M. 2005. Updated stock assessment for blue grenadier in the South East Fishery, August 2005. Report to the Slope Resource Assessment Group. 25-26 August 2005.

9.9 Figures

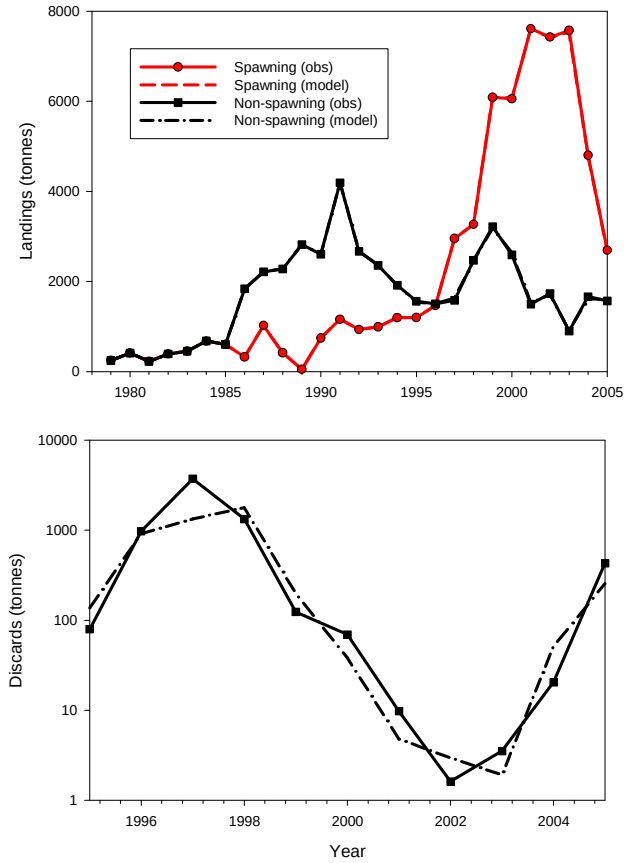


Figure 9.5. Top plot: Annual estimated landings of blue grenadier (obs; scaled to account for headed and gutted fish and to SEF2) and estimated by the Low base case model (model). Bottom plot: Discards estimated from the ISMP (solid line) and Low model estimated values (dashed line). The spawning and non-spawning sub-fisheries are shown.

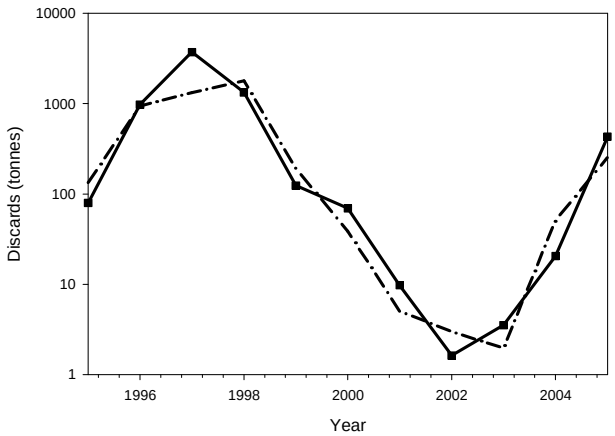


Figure 9.6. Discards estimated from the ISMP (solid line) and High model estimated values (dashed line).

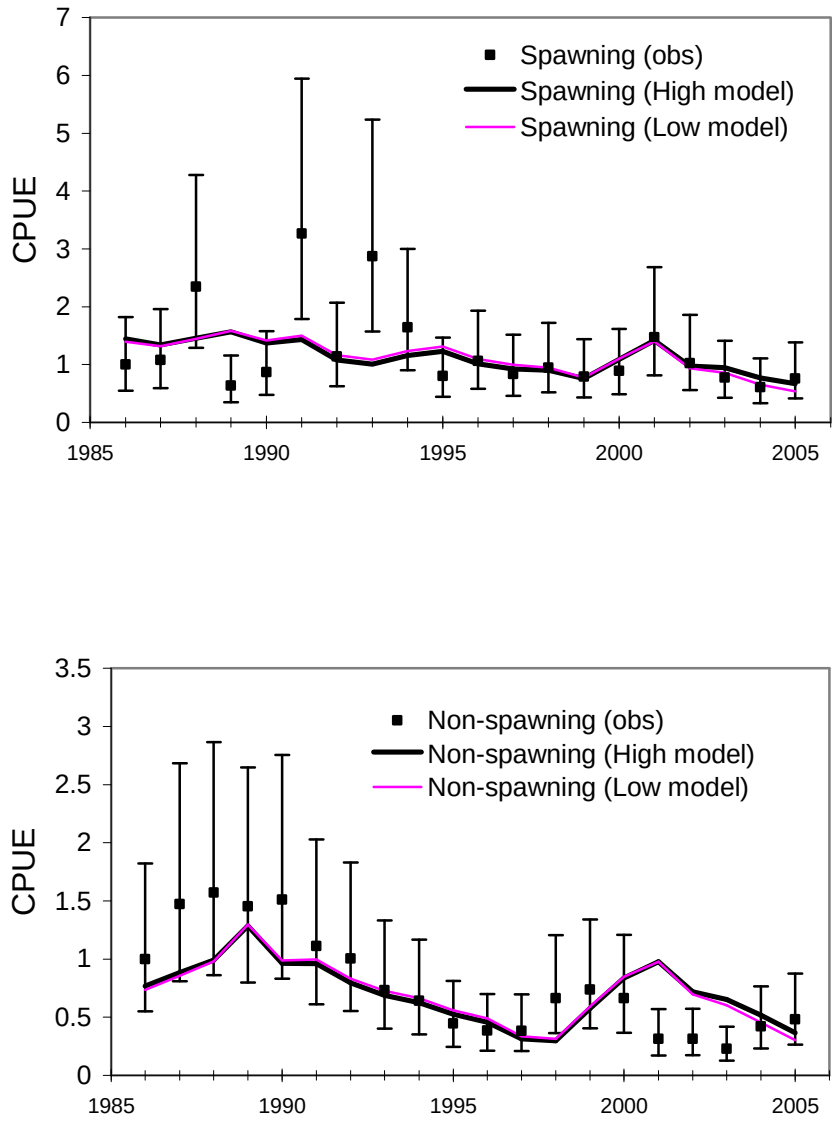


Figure 9.7. Catch-per-unit-effort (CPUE) calculated using a GLM to standardise CPUE from log-books (obs) and the High and Low model estimated CPUE for the spawning fishery (top) and the non-spawning fishery (bottom).

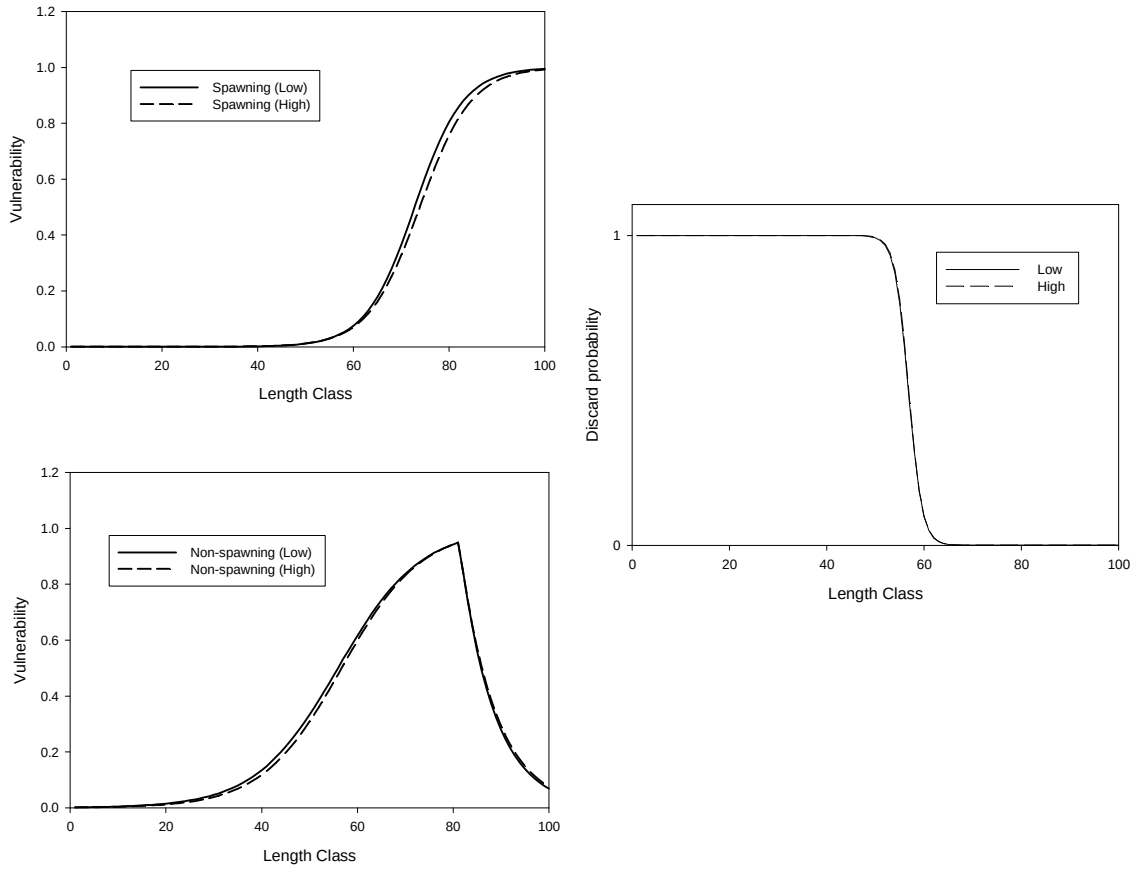


Figure 9.8. Vulnerability of blue grenadier to being caught (but not necessarily landed) by the two sub-fisheries (left) and the probability of being discarded if caught (right) as a function of length class for the Low and High models.

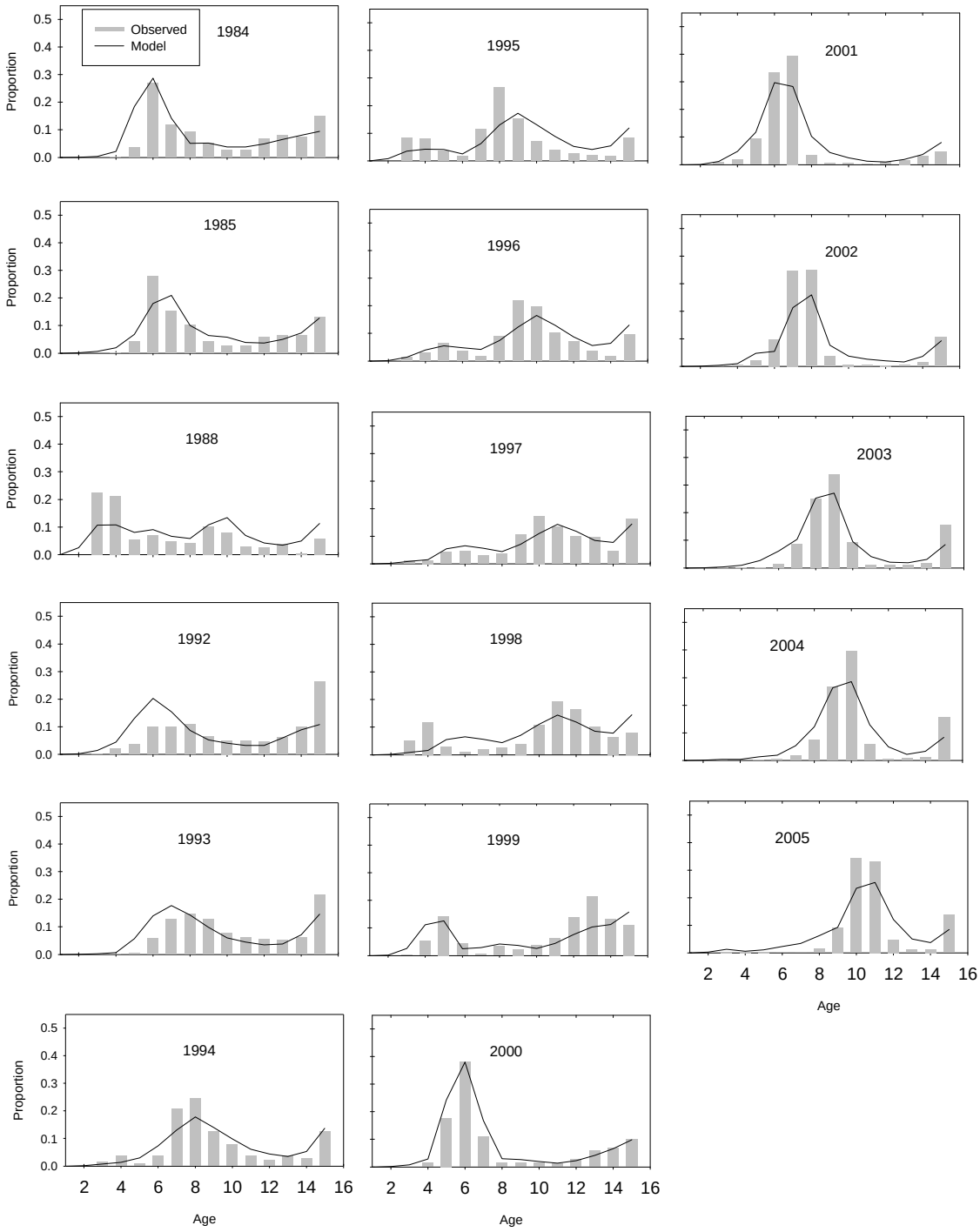


Figure 9.9. Observed (bars) and model estimated (lines) proportion caught at age for the spawning sub-fishery and Low model.

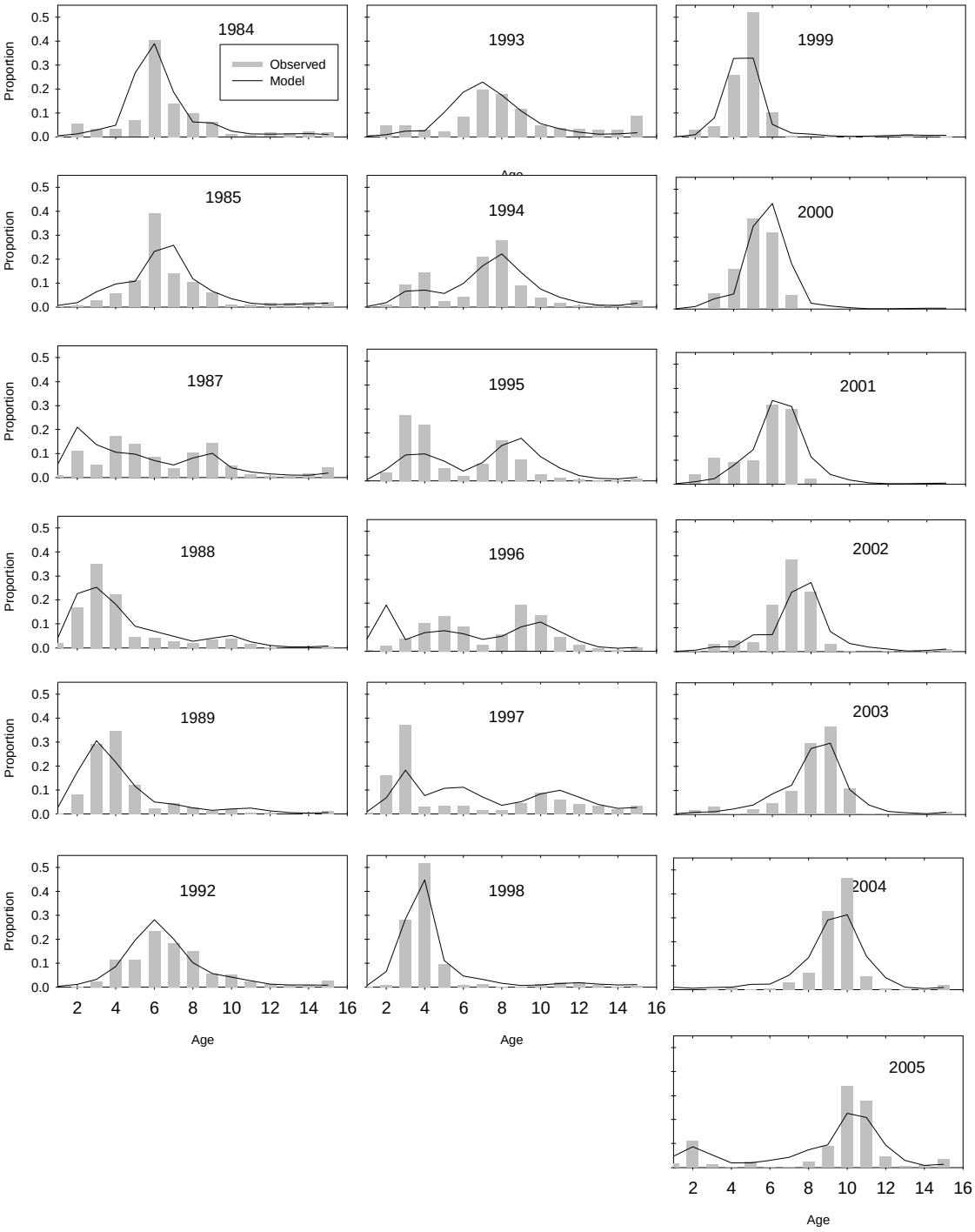


Figure 9.10. Observed (bars) and model estimated (lines) proportion caught at age for the non-spawning sub-fishery and Low model.

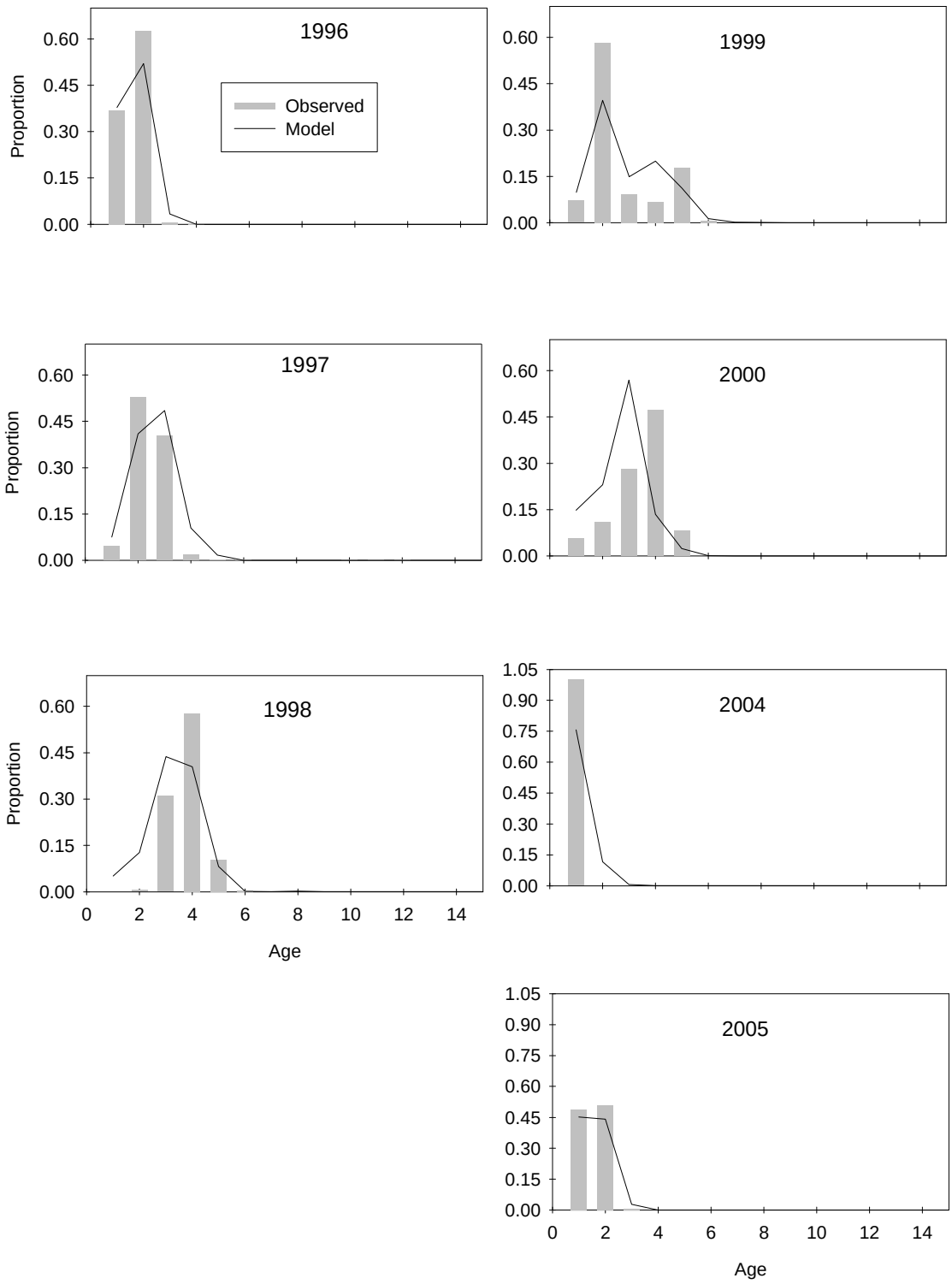


Figure 9.11. Observed (bars) and model estimated (lines) proportion discarded-at-age for the non-spawning sub-fishery and Low model.

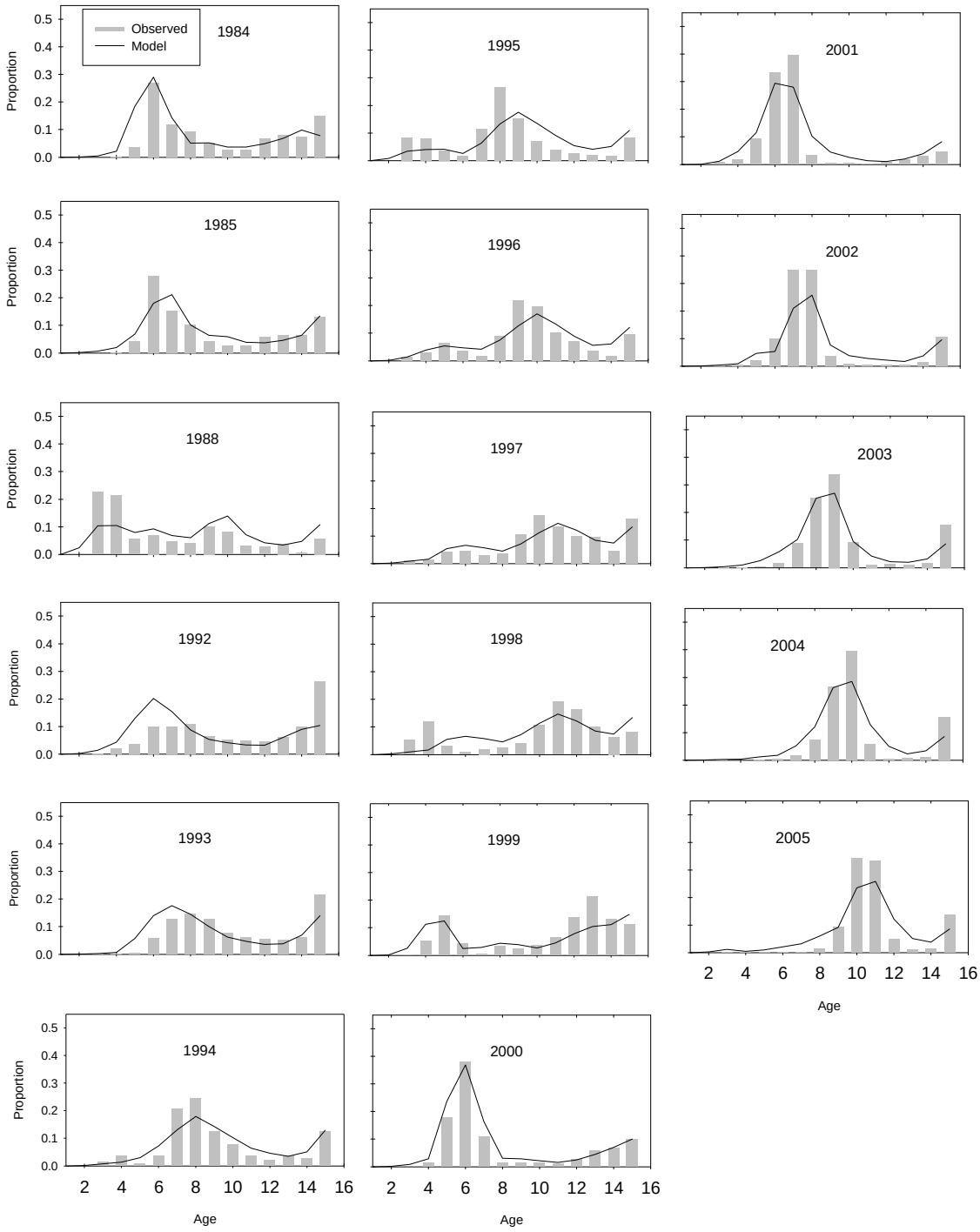


Figure 9.12. Observed (bars) and model estimated (lines) proportion caught at age for the spawning sub-fishery and High model.

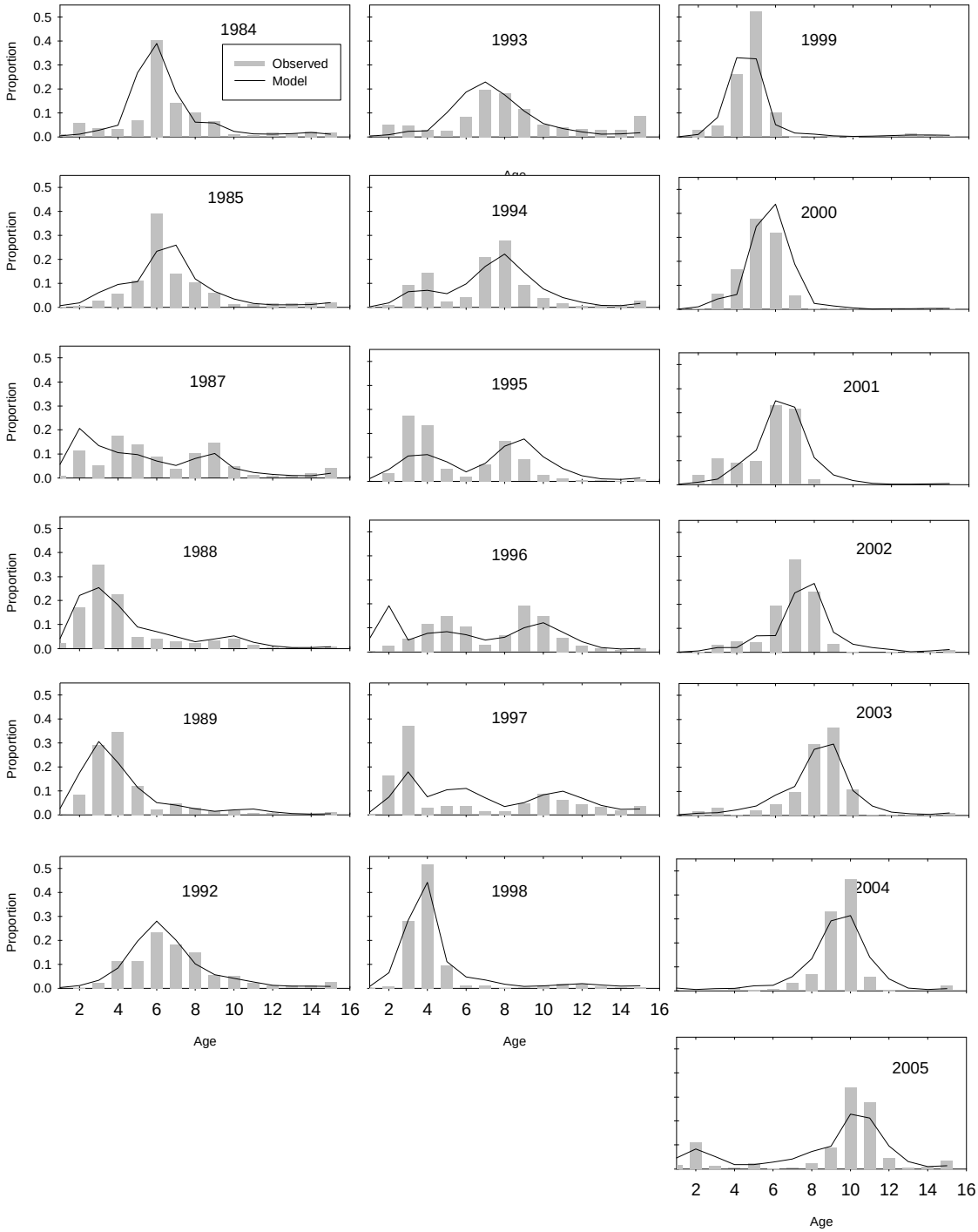


Figure 9.13. Observed (bars) and model estimated (lines) proportion caught at age for the non-spawning sub-fishery and High model.

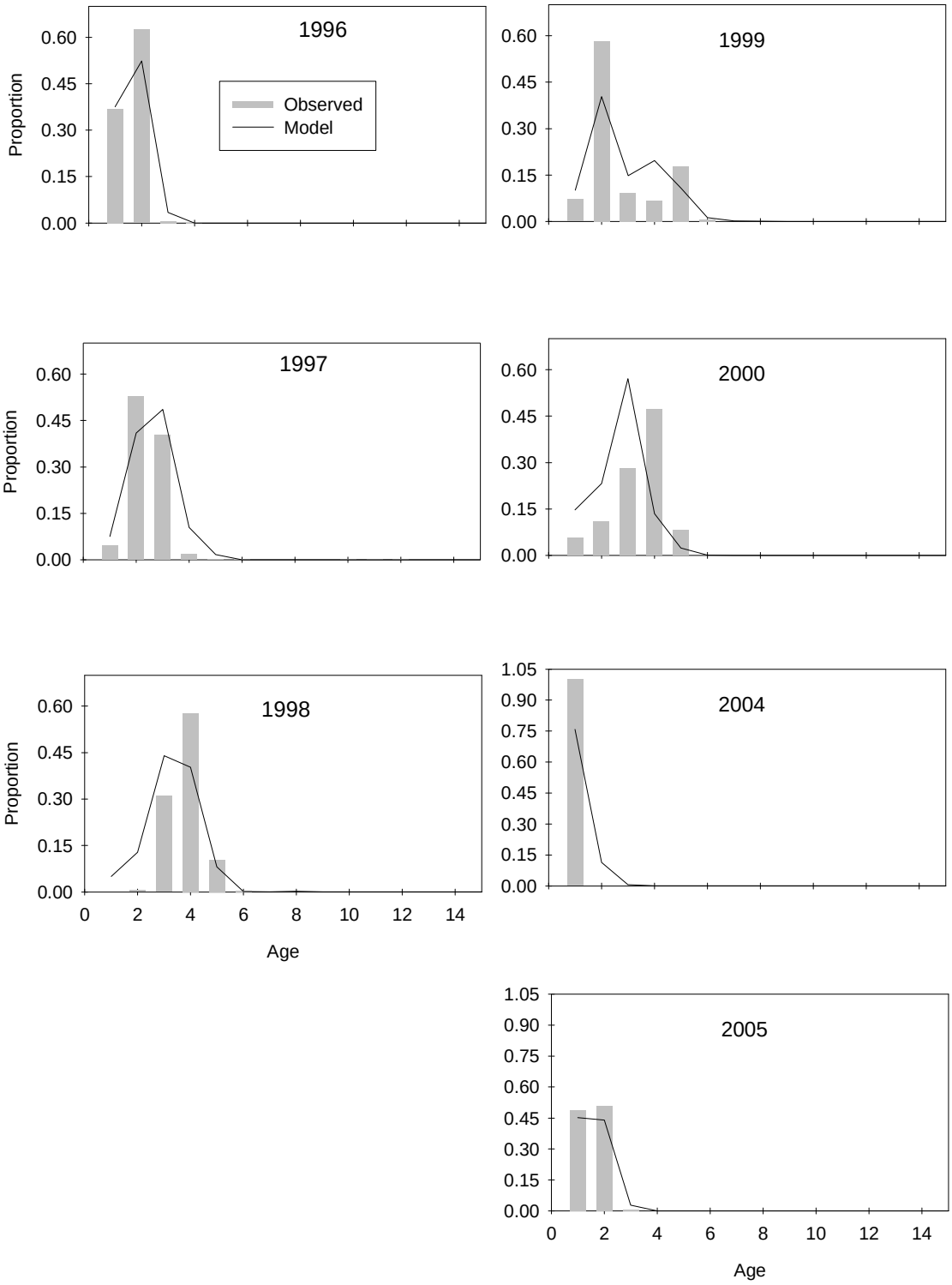


Figure 9.14. Observed (bars) and model estimated (lines) proportion discarded-at-age for the non-spawning sub-fishery and High model.

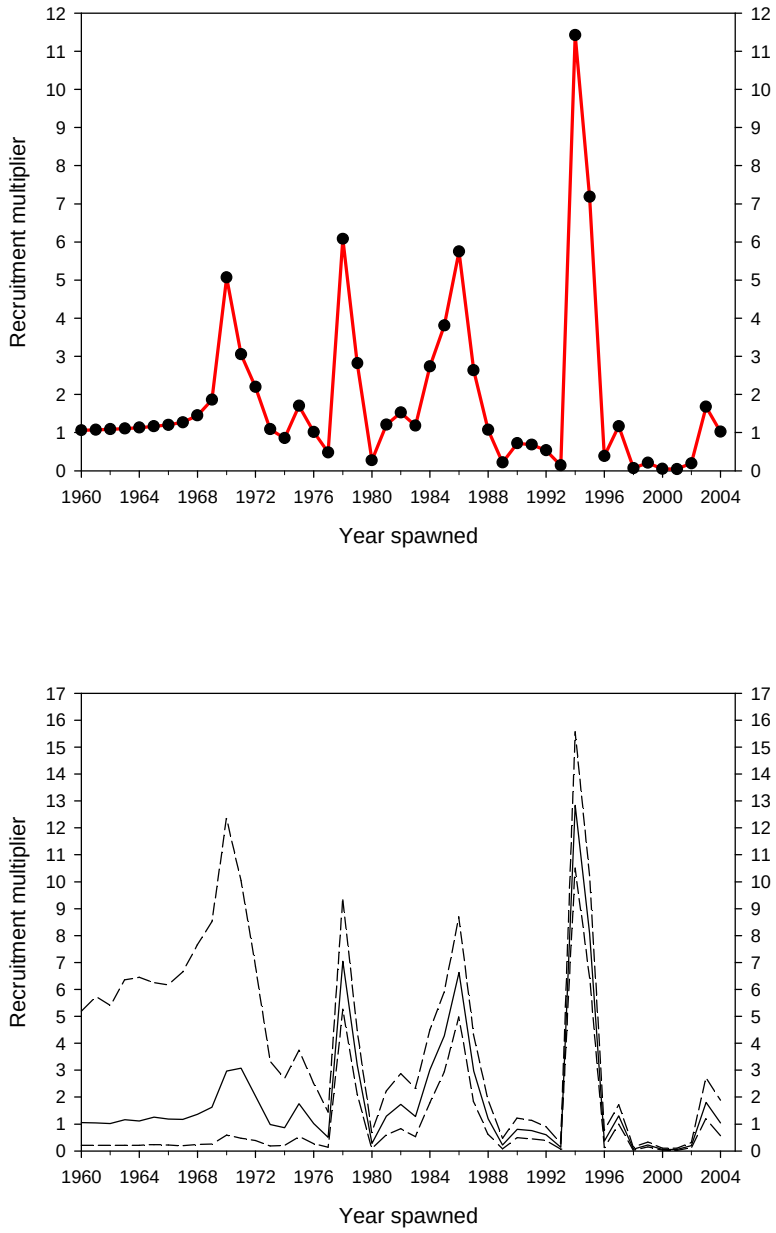


Figure 9.15. Top: Estimated recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning from Low model. Bottom: The median (solid line), upper and lower 95% bounds (dashed lines) on the recruitment multipliers for the Low model.

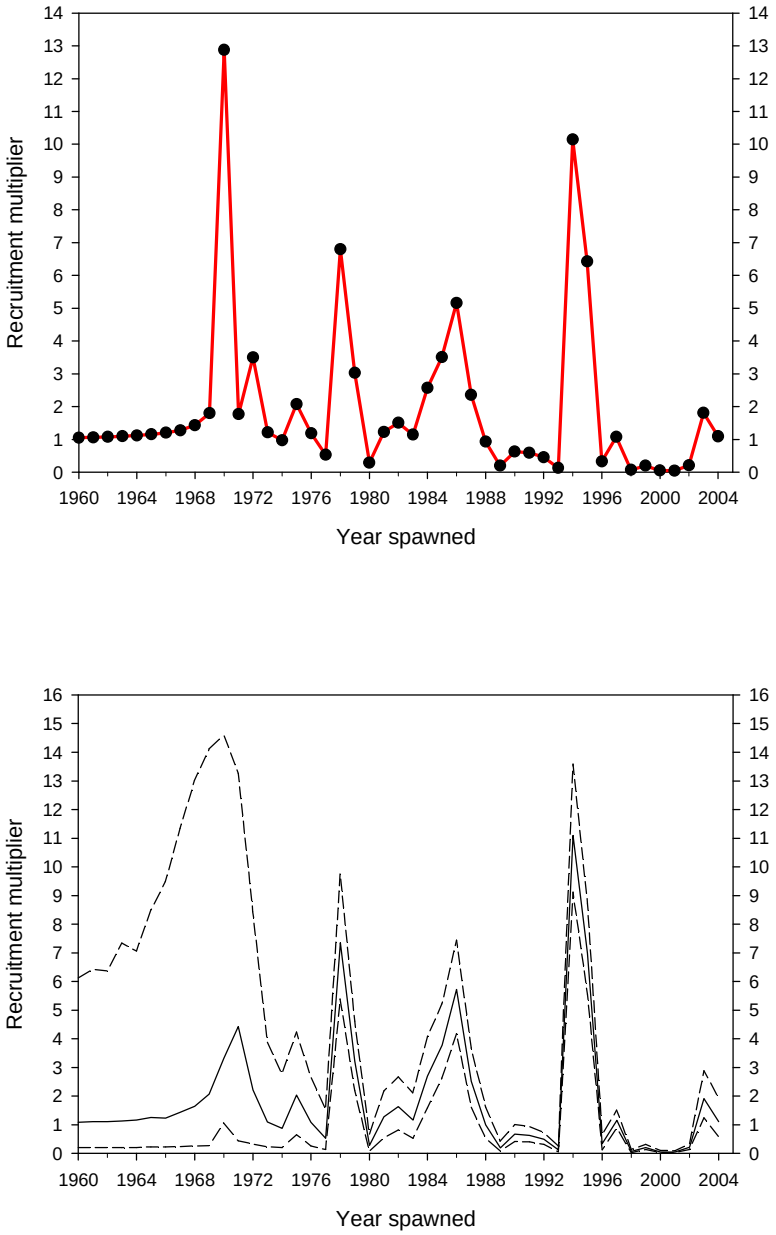


Figure 9.16. Top: Estimated recruitment multipliers (the amount by which the recruitment deviated from that predicted by the stock-recruit relationship) versus year of spawning from High model. Bottom: The median (solid line), upper and lower 95% bounds (dashed lines) on the recruitment multipliers for the High model.

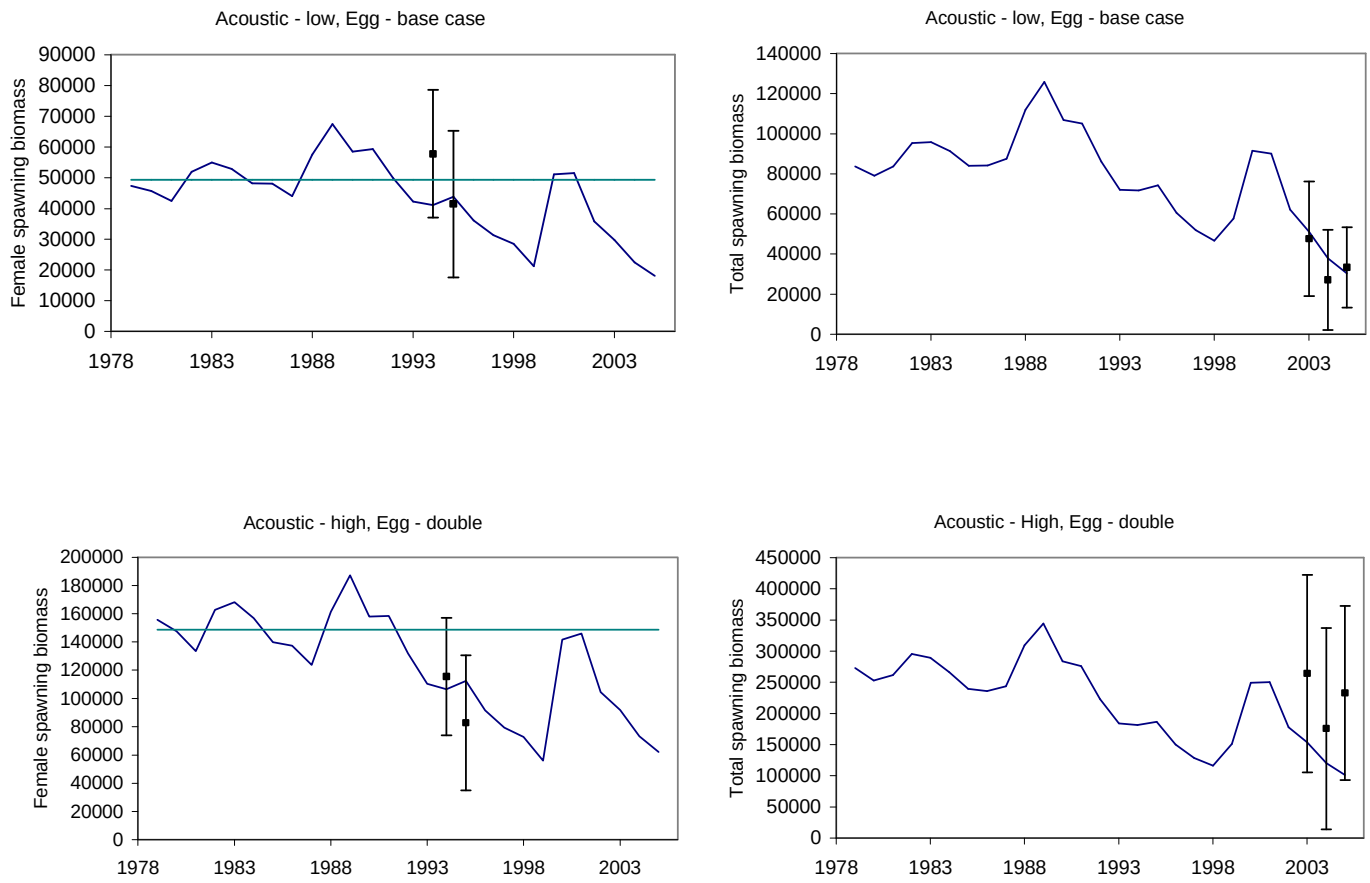


Figure 9.17. The time-trajectory of female spawning biomass (left) and total spawning biomass (right) for the Low model (top) and High model (bottom). The vertical lines show the estimates of spawning biomass derived from surveys of egg abundance in 1994 and 1995 and acoustic surveys from 2003 to 2005. The horizontal line shows B_{ref}, which is defined as the average female spawning biomass over 1979–1988.

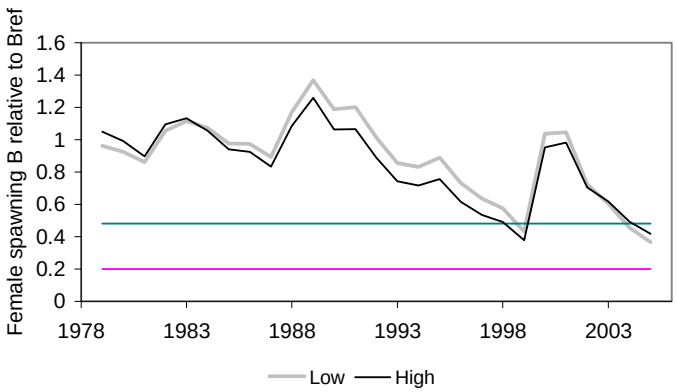


Figure 9.18. The trajectory of female spawning biomass relative to the reference biomass, B_{ref} for the Low and High models. The horizontal lines show the 0.48 and 0.20 levels.

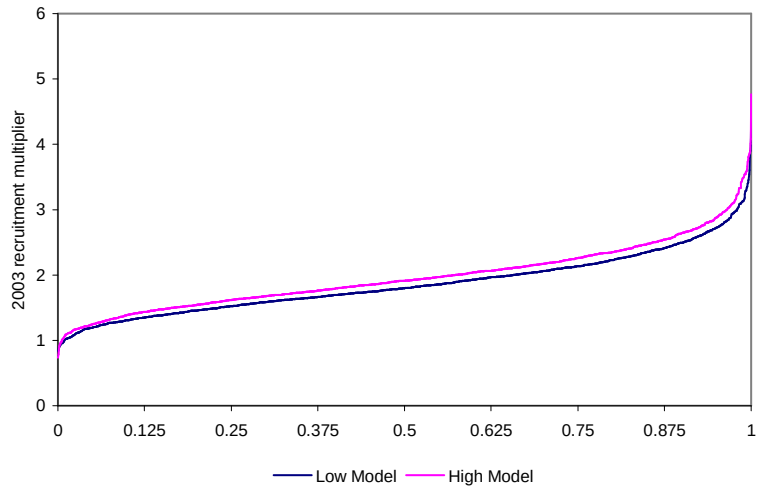


Figure 9.19. The 2003 recruitment multipliers from a Bayesian analysis sorted by increasing magnitude for the Low and High models. The parameter sets chosen for the decision analysis correspond to 0.125 (referred to as R125), 0.5 (R500) and 0.875 (R875).

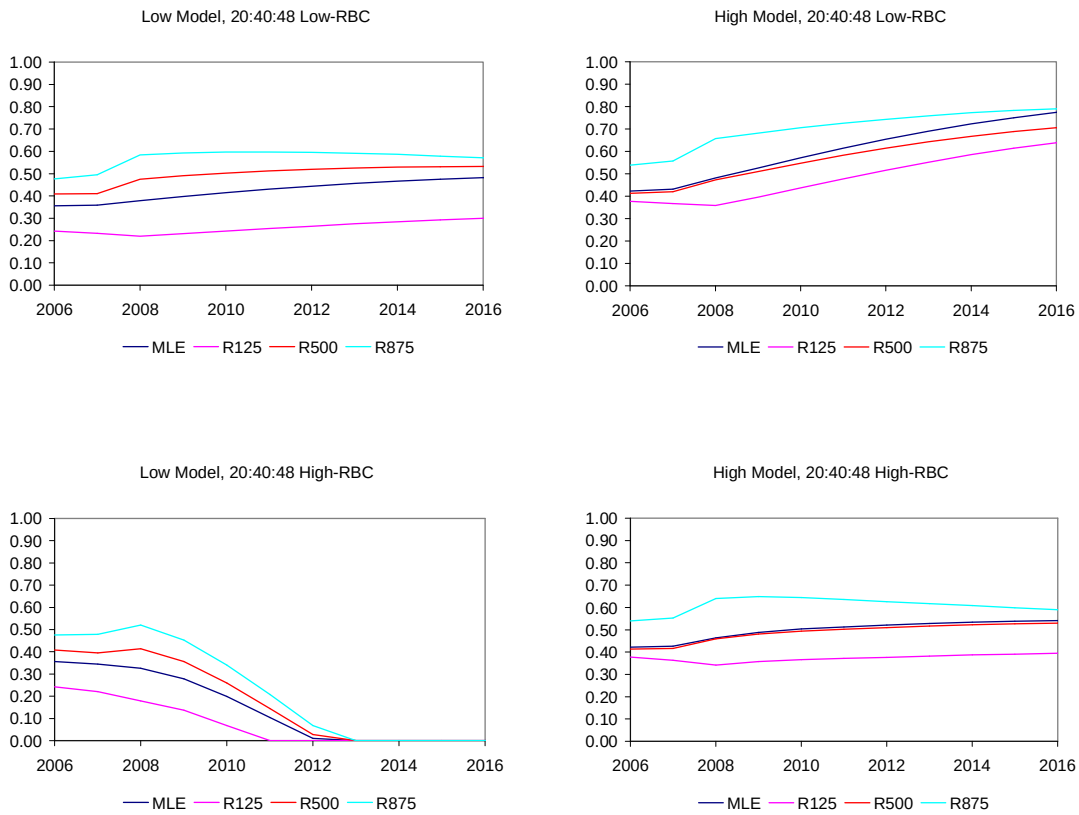


Figure 9.20. Projections over a 10-year period for the two catch series based on the 20:40:48 Tier 1 rule (Low-RBC, High-RBC) when the true state of nature is either of the two alternative models (High, Low Model), i.e. leading to four possible crosses of model and catch series. Results are shown for four different parameters sets (MLE, R125, R500, and R875) for each model.

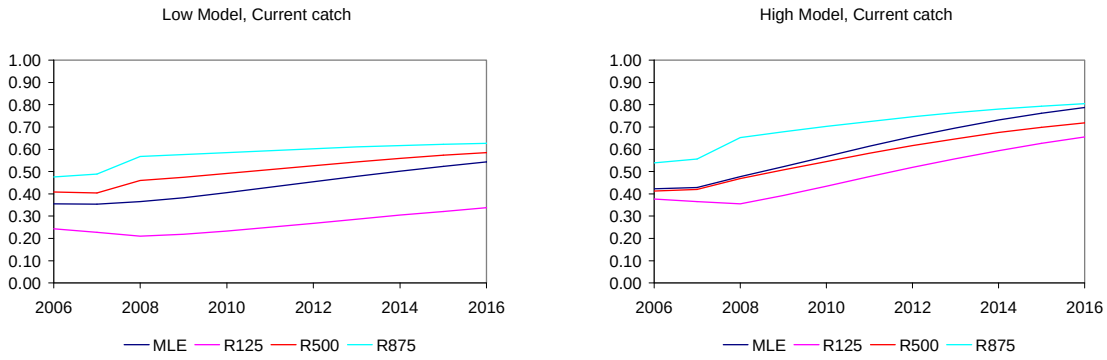


Figure 9.21. Projections over a 10-year period for fixed annual catch equal to the current TAC (3,730 t) when the true state of nature is either of the two alternative models (High, Low Model). Results are shown for four different parameters sets (MLE, R125, R500, and R875) for each model.

9.10 Appendix: The population dynamics model and likelihood model

The equations presented in this appendix have been adapted from those in Punt *et al.* (2001).

9.10.1 Basic dynamics

The dynamics of animals of sex *s* aged 1 and above are governed by the equation:

$$N^s_{y+1,a} = \begin{cases} N^s_{y+1,1} & \text{if } a = 1 \\ N^s_{y,a-1} e^{-Z^s_{y,a-1}} & \text{if } 1 < a < x \\ N^s_{y,x}\, e^{-Z^s_{y,x}} + N^s_{y,x-1}\, e^{-Z^s_{y,x-1}} & \text{if } a = x \end{cases} \qquad \text{(A.1)}$$

where $N^s_{y,a}$ is the number of fish of sex *s* and age *a* at the start of year *y* (where *y* runs from 1 to *t*),

$Z^s_{y,a}$ is the total mortality on fish of sex *s* and age *a* during year *y*:

$$Z^s_{y,a} = M^s + S^1_a F^1_y + S^2_a F^2_y \qquad \text{(A.2)}$$

M^s is the (age-independent) rate of natural mortality for animals of sex *s*,

$S^f_{y,a}$ is the vulnerability by sub-fishery *f* (*f*=1 for the 'spawning' sub-fishery, and *f*=2 for the 'non-spawning' sub-fishery) on fish of age *a* during year *y*,

F^f_y is the fully-selected fishing mortality by sub-fishery *f* during year *y*, and

x is the maximum age-class (taken to be a plus-group).

The number of 1-year-olds of sex *s* at the start of year *y*+1 is related to the spawner biomass of females in the middle of the preceding year according to the equation:

$$N^s_{y+1,1} = \left[0.5\,\tilde{B}_y / (\alpha + \beta \tilde{B}_y)\right] e^{\varepsilon_y} \qquad \text{(A.3)}$$

where $\tilde{B}_y$ is the spawner biomass of females in the middle of year *y*:

$$\tilde{B}_y = \mu \sum_{a=1}^{x} f_{y,a}\, w_{y,a}\, N^{\mathrm{f}}_{y,a}\, e^{-Z^{\mathrm{f}}_{y,a}/2} \qquad \text{(A.4)}$$

is the proportion of mature females that spawn each year,

$f_{y,a}$ is the proportion of females of age *a* that are mature during year *y*:

$$f_{y,a} = \begin{cases} 1 & \text{if } L_{y,a} \geq 70\,\text{cm} \\ 0 & \text{otherwise} \end{cases}$$

$w_{y,a}$ is the mass of a fish of age *a* in the middle of the year *y*,

$L_{y,a}$ is the mean length of a fish of age *a* during year *y* (given either by the empirical mean length-at-age each year, or from the fit of a von Bertalanffy growth curve),

α, β are the parameters of the stock-recruitment relationship, and

ε_y is the recruitment residual for year *y* (for ease of presentation, $\exp(\varepsilon_y)$ will be referred to as the recruitment anomaly for year *y*).

The values for α and β are determined from the steepness of the stock-recruitment relationship (*h*) and the virgin biomass (B_0) using the equations of Francis (1992). The assumption that maturity is knife-edged at 70 cm is very crude and a research project has been proposed to provide a more realistic picture of maturity as a function of length. In principle, the probability of being mature-at-length could have been assumed to be the same as vulnerability to the 'spawning' sub-fishery. This assumption has been made for assessments of blue grenadier in New Zealand (e.g. McAllister *et al*., 1994). However, it may be substantially in error for blue grenadier in Australia because it is known that fish of different sizes arrive on the spawning grounds at different times, and that some immature fish are caught during the 'spawning' sub-fishery.

The specifications for the numbers-at-age at the start of 1979 are based on the assumption that the stock would have been close to its unexploited equilibrium size at that time:

$$N^s_{1979,a} = 0.5 \begin{cases} R_0\, e^{-(a-1)M^s}\, e^{\varepsilon_a} & \text{if } a < x \\ R_0\, e^{-(x-1)M^s} / (1 - e^{-M^s}) & \text{if } a = x \end{cases} \qquad \text{(A.5)}$$

where R_0 is the expected number of 1-year-olds at unexploited equilibrium (the sex ratio at age 1 is taken to be 1:1), and

ε_a is the recruitment residual for age a.

The equation for the plus-group does not include a contribution by a recruitment residual because this group comprises several age-classes, which will largely damp out the impact of inter-annual variation in year-class strength.

9.10.2 Vulnerability

The vulnerability of the gear is governed by a logistic curve that permits the probability of capture to drop off with length:

$$S_{y,a}^{f} = \begin{cases} (1+e^{-\ell n19(L_{y,a}-L_{50}^{f})/(L_{95}^{f}-L_{50}^{f})})^{-1} & \text{if } L_{y,a} \le L_{95}^{f} \\ (1+e^{-\ell n19(L_{y,a}-L_{50}^{f})/(L_{95}^{f}-L_{50}^{f})})^{-1} e^{-\lambda^{f}(L_{y,a}-L_{95}^{f})} & \text{otherwise} \end{cases} \qquad \text{(A.6)}$$

where L_{50}^{f} is the length-at-50%-vulnerability for sub-fishery *f*,

L_{95}^{f} is the length-at-95%-vulnerability for sub-fishery *f*, and

λ^{f} is the "vulnerability slope" for sub-fishery *f*.

The vulnerability pattern for the 'spawning' sub-fishery is assumed to be asymptotic (i.e. $\lambda = 0$ for the 'spawning' sub-fishery).

9.10.3 Catches

The catch (in number) of fish of age *a* by sub-fishery *f* during year *y*, $\hat{C}_{y,a}^{f}$, and the number of fish of age *a* discarded by sub-fishery *f*, during year *y*, $\hat{D}_{y,a}^{f}$, are given by the equations:

$$\hat{C}_{y,a}^{f} = \sum_{s} \frac{(1-P_{y,a})\, S_{y,a}^{f}\, F_{y}^{f}}{Z_{y,a}^{s}} N_{y,a}^{s} (1-e^{-Z_{y,a}^{s}}) \qquad \text{(A.7a)}$$

$$\tilde{D}_{y,a}^{f} = \sum_{s} \frac{P_{y,a}\, S_{y,a}^{f}\, F_{y}^{f}}{Z_{y,a}^{s}} N_{y,a}^{s} (1-e^{-Z_{y,a}^{s}}) \qquad \text{(A.7b)}$$

where $P_{y,a}$ is the probability of discarding a fish of age *a* during year *y*:

$$P_{y,a} = \frac{\gamma(\sum_{s} N_{y,1}^{s})^{\phi} / \max_{y'}(\sum_{s'} N_{y',1}^{s'})^{\phi}}{1+e^{-(L_{a}-L_{50}^{D})/\delta}} \qquad \text{(A.8)}$$

γ is the maximum possible discard rate for the largest year-class,

L_{50}^{D} is the length at which discarding is half the maximum possible rate,

δ is the parameter that determines the width of the relationship between length and the discard probability, and

ϕ is the parameter that controls the extent of density-dependent discarding.

The rate of discarding is therefore assumed to be related only to the size of the year-class at birth; the impact of density-dependence on the rate of discarding is assumed to be constant during the whole of an animal's life. The first assumption will be violated to some extent because *inter alia* the rate of discarding will depend on the abundance of other year-classes in the population (through high-grading). Violation of the second

assumption is probably inconsequential because for older ages the form of the denominator of Equation (A.8) will mean that $P_{y,a} \approx 0$.

The model estimates of the catch (in mass) by sub-fishery *f* during year *y*, $\hat{C}_y^f$, and of the mass of fish discarded by sub-fishery *f* during year *y*, $\hat{D}_y^f$, are given by the equations:

$$\hat{C}_y^f = \sum_{a=1}^{x} w_{y,a} \hat{C}_{y,a}^f \tag{A.9a}$$

$$\hat{D}_y^f = \sum_{a=1}^{x} w_{y,a} \hat{D}_{y,a}^f \tag{A.9b}$$

Equations (A.9a) and (A.9b) imply that the (expected) mass of a fish of age *a* that is discarded is the same as the (expected) mass of a fish of age *a* that is retained.

9.10.4 The likelihood function

The negative of the logarithm of the likelihood function includes five contributions. These relate to minimising the sizes of recruitment residuals, fitting the observed catches / discards by fleet, fitting the observed catch / discard age-compositions, fitting the catch rate information, and fitting the estimates of spawner biomass from the egg-production method.

$$L = \sum_{i=1}^{5} L_i \tag{A.10}$$

The contribution of the recruitment residuals to the negative of the logarithm of the likelihood function is based on the assumption that the inter-annual fluctuations in year-class strength are independent and log-normally distributed with a CV of σ_r [4]:

$$L_1 = \tfrac{1}{2\sigma_r^2}\left(\sum_{a=1}^{x-1} \varepsilon_a^2 + \sum_{y=1}^{t-1} \varepsilon_y^2\right) \tag{A.11}$$

The contribution of the observed catch (in mass) information to the negative of the logarithm of the likelihood function is based on the assumption that the errors in measuring the catch in mass are log-normally distributed with a CV of σ_c:

$$L_2 = \tfrac{1}{2\sigma_c^2} \sum_f \sum_{y=1}^{t} (\ell\mathrm{n} C_y^{f,\mathrm{obs}} - \ell\mathrm{n} \hat{C}_y^f)^2 \tag{A.12}$$

where $C_y^{f,\mathrm{obs}}$ is the observed catch (in mass) by sub-fishery *f* during year *y*.

[4] The summation in Equation (A.11) runs to *x*-1 and *t*-1 because the plus-group (age *x*) is not impacted by variability in year-class strength, and because the model is not used to predict the number of 1-year-olds for year *t*+1.

The contribution of the observed mass of discards to the negative of the logarithm of the likelihood function follows Equation (A.12) except that $\hat{C}_y^f$ is replaced by $\hat{D}_y^f$, $C_y^{f,obs}$ is replaced by the observed mass of discards by sub-fishery *f* during year *y*, and the summations over year are restricted to those years for which estimates of discards are available.

The contribution of the age composition information to the negative of the logarithm of the likelihood function is based on the assumption that the age-structure information is determined from a random sample of *N* animals from the catch:

$$L_3 = -\sum_f \sum_y \sum_{a=1}^{15+} N\, \rho_{y,a}^{f,\text{obs}}\, \ell n(\hat{\rho}_{y,a}^f) \qquad \text{(A.13)}$$

where $\rho_{y,a}^{f,\text{obs}}$ is the observed proportion which fish of age *a* made up of the catch during year *y* by sub-fishery *f*,

$\hat{\rho}_{y,a}^f$ is the model-estimate of the proportion which fish of age *a* made up of the catch during year *y* by sub-fishery *f*:

$$\hat{\rho}_{y,a}^f = \sum_{a''} \chi_{a,a''}\, \hat{C}_{y,a''}^f \Big/ \sum_{a'=1}^{x} \hat{C}_{y,a'}^f \qquad \text{(A.14)}$$

$\chi_{a,a'}$ is the probability that an animal of age *a*' will be found to be age *a* (the age-reading error matrix).

Note that all animals aged 15 and older are treated as a single "age-class" when fitting to the catch proportion-at-age information. This prevents data for older fish (for which there is relatively little data) having a disproportionate influence on the results. The summations over year include only those years for which age-composition data are available. The contribution of the age-composition of the discards follows Equations (A.13) and (A.14), except that $\hat{\rho}_{y,a}^f$ is replaced by the model-estimate of the proportion which fish of age *a* made up of the discards during year *y* by sub-fishery *f*, and $\rho_{y,a}^{f,obs}$ is replaced by the observed proportion which fish of age a made up of the discards during year *y* by sub-fishery *f*.

The contribution of the catch rate data to the negative of the logarithm of the likelihood function is based on the assumption that fluctuations in catchability are log-normally distributed with a CV of σ_q:

$$L_4 = \tfrac{1}{2\sigma_q^2} \sum_f \sum_y (\ell \mathrm{n} I_y^f - \ell \mathrm{n}(q^f \, B_y^f))^2 \qquad \text{(A.15)}$$

where q^f is the catchability coefficient for sub-fishery *f*,

I_y^f is the catch-rate index for sub-fishery *f* and year *y*, and

B_y^f is the mid-season (available) biomass for sub-fishery *f* and year *y*:

$$B_y^f = \sum_s \sum_a w_{y,a} \, (1 - P_{y,a}) \, S_a^f \, N_{y,a}^s \, e^{-Z_{y,a}^s / 2} \qquad \text{(A.16)}$$

The summation over year includes only those years for which catch rate data are available.

The contribution of the egg-production or acoustic estimates to the negative of the logarithm of the likelihood function is given by:

$$L_5 = \sum_{y=1994/5} (\tilde{B}_y - B_y^{obs})^2 / (2\sigma_y^2) \qquad \text{(A.17)}$$

where B_y^{obs} is the estimate of female spawner biomass for year *y* based on egg-production or acoustic methods, and

σ_y is the standard error of B_y^{obs}.

10. Blue Warehou Catches Within the Industry Survey Strata

Malcolm Haddon[1]

[1]Marine Research Laboratory, Tasmanian Aquaculture and Fisheries Institute,
University of Tasmania, Private Bag 49, Hobart TAS 7001

10.1 Introduction

Blue Warehou is now considered to constitute two stocks, one in the East and the other in the West (divided by Bass Strait).

With the TAC now being at a low level and most of the catch being taken only in the western area, many fishers are reporting that they are having to avoid blue warehou. The stock assessment is especially sensitive to the standardized catch rates but if fishers are avoiding blue warehou then catch rates are less likely to be representative of the status of the stocks.

In response to this state of affairs Industry members have designed and organized a research trawl survey operating in five separate strata (three in the west and two in the east). The objective is to obtain an index of relative abundance that would provide insight into the present status of the blue warehou resource independently of the commercial catch and effort reporting. The first survey was conducted in 2005 and reported in Hudson and Knuckey (2006).

To use the data deriving from these Industry surveys it will be necessary to compare the catches and catch rates from the known survey strata with those exhibited by the commercial fishery during earlier years. That is the aim of this brief report. Ideally if any previous ISMP data has been collected from within these strata in the same periods as the surveys are run this too may be worth considering.

10.2 Methods

All data relating to Blue Warehou catches (by trawl) were extracted from the AFMA commercial catch and effort database (SEF1 data). The survey in the west has been designed to operate in August and September each year (a period when peak catch rates are expected) and in the east will operate in September and October. Therefore the SEF1 data were restricted to only those months.

The strata definitions used to identify previous catches were provided by Russell Hudson and input into ArcView along with all the Blue Warehou data. In this way it was possible to select only those records which were reported to have occurred (at least started) within the survey strata.

The survey strata definitions (Table 10.1; in decimal degrees) identified five areas that traditionally receive a significant amount of fishing effort aimed at blue warehou and constitute important areas for blue warehou catches (Figure 10.1).

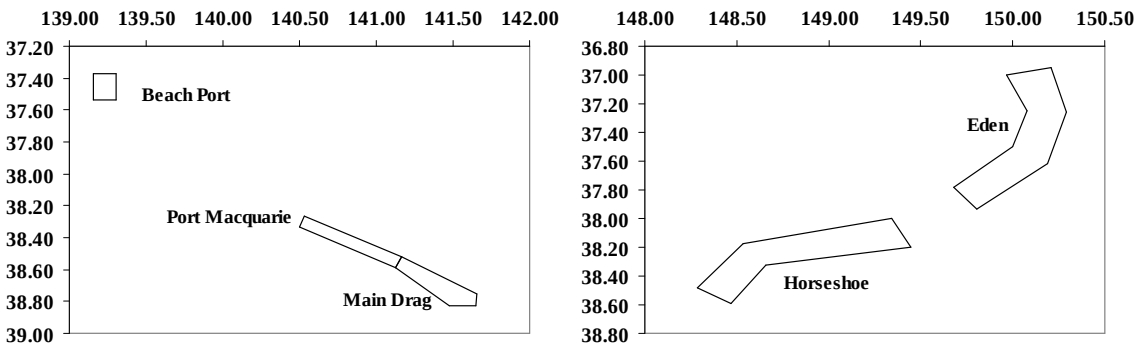


Figure 10.1. Schematic map of the strata used in the Industry Surveys for Blue Warehou (Table 10.1).

Table 10.1. Stratum definitions used in the Industry surveys.

Stratum	Longitude	Latitude
Beachport	139.15517	37.37467
Beachport	139.30383	37.37467
Beachport	139.30383	37.54050
Beachport	139.15517	37.54050
Beachport	139.15517	37.37467
Main Drag	141.16200	38.51900
Main Drag	141.65817	38.75317
Main Drag	141.65183	38.82417
Main Drag	141.47467	38.82417
Main Drag	141.12650	38.58967
Main Drag	141.16200	38.51900
Port Macquarie	140.53167	38.26583
Port Macquarie	141.16200	38.51900
Port Macquarie	141.12650	38.58967
Port Macquarie	140.50000	38.33333
Port Macquarie	140.53167	38.26583
Horse Shoe	148.28817	38.48133
Horse Shoe	148.53167	38.17233
Horse Shoe	149.33817	38.00000
Horse Shoe	149.44250	38.20050
Horse Shoe	148.65517	38.32183
Horse Shoe	148.46983	38.59050
Horse Shoe	148.28817	38.48133
Eden	149.96500	37.00000
Eden	150.20683	36.94967
Eden	150.29167	37.26000
Eden	150.18700	37.61350
Eden	149.80017	37.93683
Eden	149.68100	37.78300
Eden	150.00000	37.50150
Eden	150.07467	37.24717
Eden	149.96500	37.00000

The simple geometric mean catch rates by year were estimated using the catch and effort data found inside these strata.

10.3 Results

10.3.1 Western Area

The strata were labelled Beachport, Main Drag, and Port Macquarie (Figure 10.1). Commercial catch and effort data were available from 1986 to 2005. Most records in the west occurred in the Main Drag stratum, while records were relatively sparse in the stratum off Beachport. Those values that were the results of less than 5 records were ignored in the plot and omitted from the table (Table 10.2) of catch rates (Figure 10.2).

Except in the latest years only the Main Drag exhibited high catch rates in the past during August and September. Port Macquarie exhibited elevated catch rates in 1987 and 1994, but has not performed like that since. Beachport has only exhibited high catch rates in the last two years.

Catch rates are naturally variable between years. In the Main Drag there were some exceptionally high catch rates (in 1991 and 1997) and some significant lows (in 1996 and 2000). In the latest year, 2005 catch rates were almost as high as in 1997 for both the Main Drag and Beachport. However, Port Macquarie remained relatively low, as it has been since 1995.

Table 10.2.The geometric mean catch rate (kgs/hr) for each year in each of the three western strata plus the number of observations (#Obs) in each case. Beach is Beachport, Main is the Main Drag, and Port is Port Macquarie (Figure 10.1).

Year	Beach	#Obs	Main	#Obs	Port	#Obs	Total
1986				2	94.302	8	141.427
1987			132.185	22	184.480	14	150.481
1988			156.373	57	47.732	36	98.780
1990			294.695	111	29.596	6	261.930
1991			407.657	204		1	403.890
1992			187.122	130	29.542	7	169.921
1993			131.331	90	75.731	16	120.763
1994		2	84.463	103	109.405	9	84.266
1995		2	122.423	126	43.688	30	101.371
1996		2	25.462	87	7.653	29	18.543
1997	34.044	12	231.156	42	6.945	18	68.769
1998	36.169	6	80.334	92	14.139	11	64.387
1999	12.153	14	60.140	170	11.068	10	49.108
2000		1	28.668	36	11.510	35	17.832
2001	27.268	19	45.996	87	39.534	33	41.311
2002		4	116.871	123	17.050	15	89.600
2003	69.869	6	118.772	55	45.544	20	89.818
2004	141.644	6	94.636	33	46.045	15	81.664
2005	214.739	22	205.592	55	46.387	19	154.654
Total		96		1625		332	

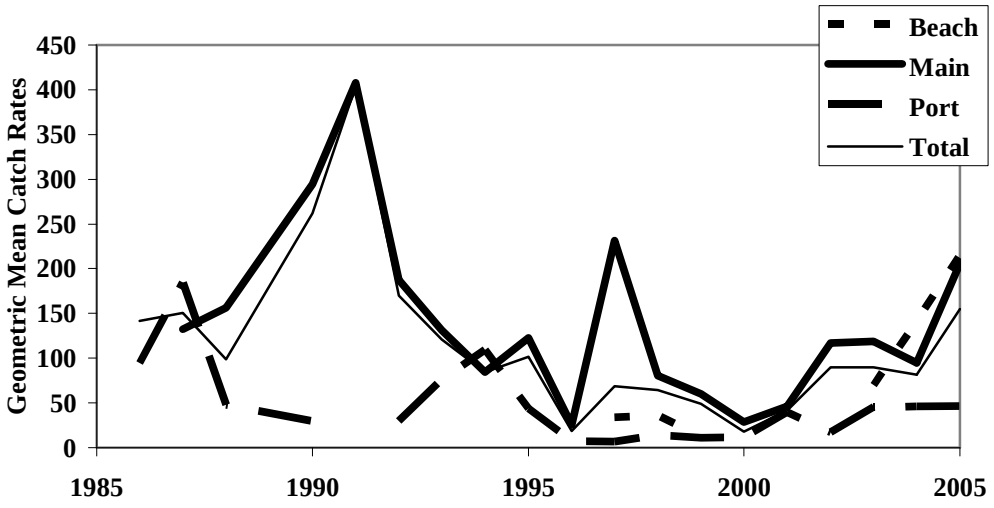


Figure 10.2. Plot of the geometric mean catch rate for blue warehou in each of the three western strata. Beachport data only begin in 1997.

10.3.2 Eastern Area

The two strata were labelled Eden and Horse Shoe (Figure 10.1). The eastern strata both received many more shots than records for most western strata, with Eden receiving three times as many as the Horse Shoe (Table 10.3).

Catch rates of blue warehou in September and October in the Horse Shoe stratum were highest before 1990 but since then have always been relatively low (Table 10.3; Figure 10.3). In the Eden stratum, however, catch rates were relatively high until 1990 when then dropped to approximately 30 kg/hr with a further minor peak in 1998 (Table 10.3; Figure 10.3).

Since 2001 even the Eden stratum has only exhibited very low commercial catch rates.

Table 10.3. The geometric mean catch rate (kgs/hr) for each year in each of the two eastern strata plus the number of observations (#Obs) in each case.

Year	Eden	#Obs	Horse	#Obs	Total
1986	40.971	232	12.906	7	39.608
1987	91.266	82	28.903	33	66.090
1988	59.960	164	22.491	62	45.763
1989	82.419	195	20.545	18	73.249
1990	59.881	164	38.330	40	54.770
1991	27.873	217	9.456	29	24.450
1992	34.477	365	13.610	18	32.984
1993	24.988	343	6.231	9	24.586
1994	22.902	332	9.583	63	19.909
1995	18.925	230	3.612	90	11.967
1996	29.483	543	5.779	114	22.164
1997	33.967	194	3.450	127	13.743
1998	42.737	448	6.072	147	26.520
1999	20.047	175	3.718	138	9.599
2000	11.388	393	2.031	150	7.100
2001	4.531	110	1.783	71	3.194
2002	7.138	222	1.366	112	4.148
2003	6.762	99	1.840	124	3.332
2004	4.359	71	1.740	29	3.331
2005	9.800	78	1.264	38	5.197
Total		4657		1419	

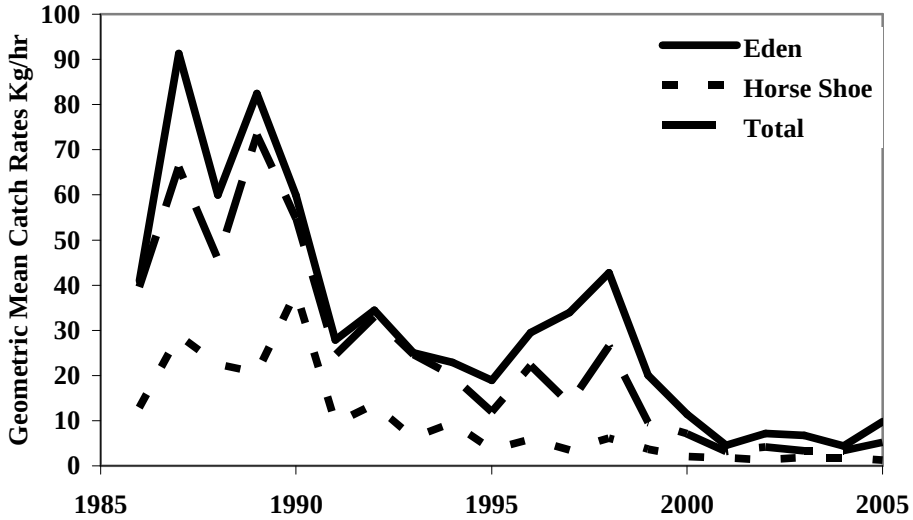


Figure 10.3. Plot of the geometric mean catch rate for blue warehou in each of the two eastern strata.

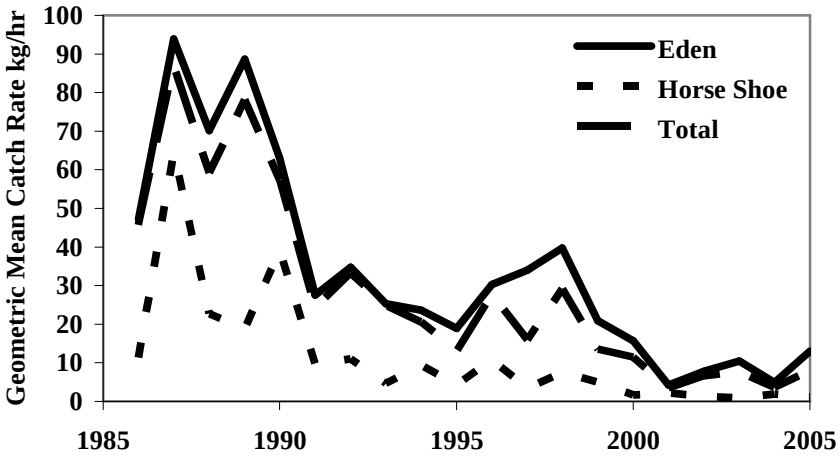


Figure 10.4. Plot of the geometric mean catch rate for blue warehou in each of the two eastern strata with the data restricted to those vessels that fished in the respective strata more than two years and had medina annual catches greater than 300 kg. This has only minor effects upon the trends exhibitedthrough time.

10.4 Discussion

The objectives of the surveys are to detect changes in the blue warehou stocks I the eastern and western areas. In the eastern area a comparison was made between the trends exhibited by using all available data and the trends generated after those vessels that had fished in the strata for two or fewer years were omitted along with those vessels that had a medina annual catch of less than 300kg. While there were differences they were minor. Using the simple geometric mean catch rate is possibly too simplistic an approach but debate should precede any attempt to standardize the available data.

A further issue is whether all selected strata are equally useful for achieving the objectives. The Horse shoe in the east, for example, exhibits far lower catch rates than

the Eden Strata. It would seem more likely that if changes occur they will be more easily detected in the Eden stratum rather than the Horse Shoe stratum. Similarly, in the west, while the catch rates there are generally much higher, it would appear that if any changes were to occur they would be more easily detected in the Main Drag and of Beachport rather than in the Port Macquarie stratum. There should be debate over whether all current strata should continue to be used.

Time series of catch rates within the strata can be generated and these provide an indication of the natural variation (under fishing pressure) that can occur in the blue warehou fishery from year to year. Only with a time series of survey indices can the survey information be compared in any way to the past commercial fishery trends.

10.5 Reference

Hudson, R. and I. Knuckey (2006) Fishery Independent Survey for Blue Warehou in the South East Fishery. A Fishwell Consulting Report. 24p.

11. Further Analysis of the Blue Warehou Industry Survey

Malcolm Haddon[1]

[1]Marine Research Laboratory, Tasmanian Aquaculture and Fisheries Institute,
University of Tasmania, Private Bag 49, Hobart TAS 7001

11.1 Introduction

Recent management of blue warehou (*Seriolella brama*) stocks has led to a reduction in the commercial TAC. This is reported to be constraining catches so seriously that monitoring any stock recovery is also being prevented, with Industry members reporting they now have to avoid large amounts of fish.

To avoid being reliant on data coming from the curtailed fishery it was decided to conduct a fishery independent survey in a number of separate strata both in the east and western regions of the fishery. Both regions were required because of the inferred stock structure of blue warehou, which currently suggests the eastern and western sides of Bass Strait form different stocks.

Methods were agreed and survey trips were made by specific vessels during the full moon periods of August, September, and October 2005.

This report aims to combine the fishery independent data obtained in the survey with available commercial catch and effort data to provide a time-series of data for inclusion in the formal stock assessment modelling. The outputs are therefore restricted to generating tables of these indices without the provision of discussion.

Nevertheless, because of the lack of prior data from the Beachport stratum as currently defined, future surveys may be more effective by using the effort directed there to the other strata in the west.

11.2 Methods

The survey stratum definitions (Section 11.7, Appendix 1) and raw shot by shot data (Section 11.8, Appendix 2) were provided by Russell Hudson, whose assistance with this is gratefully appreciated and acknowledged.

Five strata were surveyed in total, three in the western stock area and two in the eastern stock area (Table A1, Appendix 1, Section 11.7).

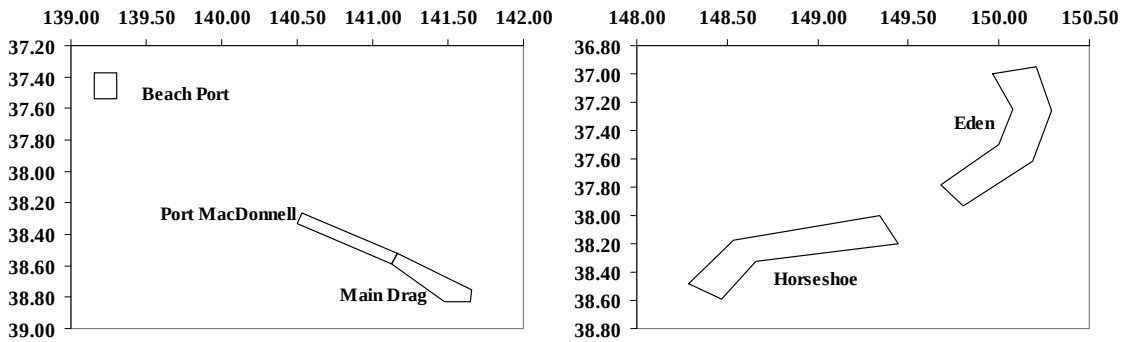


Figure 11.1. Schematic map of the strata used in the 2005 fishery independent survey for blue warehou, with the western strata in the left-hand panel and the eastern strata in the right-hand panel. Strata definitions are provided in Appendix 1, Section 11.7.

The strata definitions and AFMAs commercial catch and effort database on blue warehou were imported into the GIS software ArcView to identify those historical shots that occurred inside the defined strata. The associated data were extracted and subsequent analyses based upon those records. Obviously, any records with inexact or incorrect coordinates would not be included. Only those records taken by trawler were included.

The strategy for including the fishery independent survey results into a time series usable in the formal stock assessment was to consider the survey as an independent estimate of the final year's stock status. Three options were considered:

1) Geometric mean catch rates were estimated for each year from 1986 to 2005 including the survey as an extra year, 2006 (assuming there were at least five records in each year, which was not always the case in all western strata).
2) The catch rates from the earliest available year to 2005 were standardized including the survey results as an extra final year.
3) The catch rates from the earliest available year to 1997 were standardized including the survey results as an extra final year.

There was no point in constructing an abbreviated time series of geometric means as these would not vary between analyses. The labelling of the survey data as an extra year was simply for convenience.

In all cases the optimum statistical model in the standardizations was LnCE = Year + Vessel + Month. Unfortunately, there were too few records in the survey to represent the depth categories well enough to be included in the analysis. Standardization were only conducted using data from vessels that had fished in the strata areas for at least 3 years and had taken a median annual catch of blue warehou from the areas of more than 500 kgs in the west or more than 300 kg in the east.

For each stratum separately, three sets of values are provided the geometric mans across all available years where there are more than 5 observations. Then the standardized catch rates across all available years (with the survey labelled 2006). Finally, the standardized catch rates for the early time series restricted to available years up to and including 1997 (with the survey labelled 1998). There were so few records from the

commercial catch and effort database that were reported inside the Beachport stratum that this could not be included in the analyses (Section 11.8, Appendix 2 – Table A3).

With the Survey data, where catch rates were zero then the Log of catch rate was recorded as "NA", which enabled such records to be easily omitted from the analyses. Results were plotted for ease of initial comparison, along with diagnostic plots concerning the statistical models used. In the plots of the parameters two times the standard error was added and subtracted from the parameters before transformation out of log space to provide a visual estimate of the precision of the estimates.

All analyses were conducted using the statistical software R 2.3.1. The code used is presented in Section 11.9, Appendix 3.

11.3 Eden

11.3.1 Geometric Mean Eden

Table 11.1. The geometric mean catch rates in the Eden stratum (LnCE = Year). The parameters are under Coeff, C_USE and C_LSE are the coefficient ± 2 × Standard Error. Nobs is the number of observations in each case. The adjusted R2 = 0.14914.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	124
1987	0.683462	0.218104	1.980723	3.063845	1.280503	74
1988	0.392597	0.186377	1.480821	2.149749	1.020041	130
1989	0.634901	0.173477	1.886834	2.669403	1.333685	179
1990	0.308035	0.183721	1.360748	1.96497	0.942323	138
1991	-0.54247	0.174081	0.581308	0.823401	0.410394	176
1992	-0.30406	0.15511	0.737818	1.006181	0.541031	351
1993	-0.62412	0.156722	0.53573	0.732948	0.391579	325
1994	-0.69698	0.157197	0.498087	0.682096	0.363719	318
1995	-0.91163	0.165801	0.40187	0.559885	0.288451	227
1996	-0.45243	0.148837	0.636083	0.856628	0.472319	504
1997	-0.37824	0.176009	0.685063	0.974115	0.481782	167
1998	-0.17119	0.156394	0.84266	1.15211	0.616326	330
1999	-0.84422	0.182492	0.429895	0.61926	0.298436	142
2000	-1.12307	0.161743	0.32528	0.449516	0.23538	263
2001	-2.44041	0.214574	0.087125	0.133819	0.056724	78
2002	-1.76286	0.18161	0.171553	0.246685	0.119304	145
2003	-1.43691	0.227364	0.23766	0.374492	0.150824	65
2004	-2.20403	0.25433	0.110357	0.18353	0.066358	47
2005	-1.13639	0.236194	0.320975	0.514786	0.200131	58
2006	0.27867	0.432849	1.321372	3.140456	0.555978	13

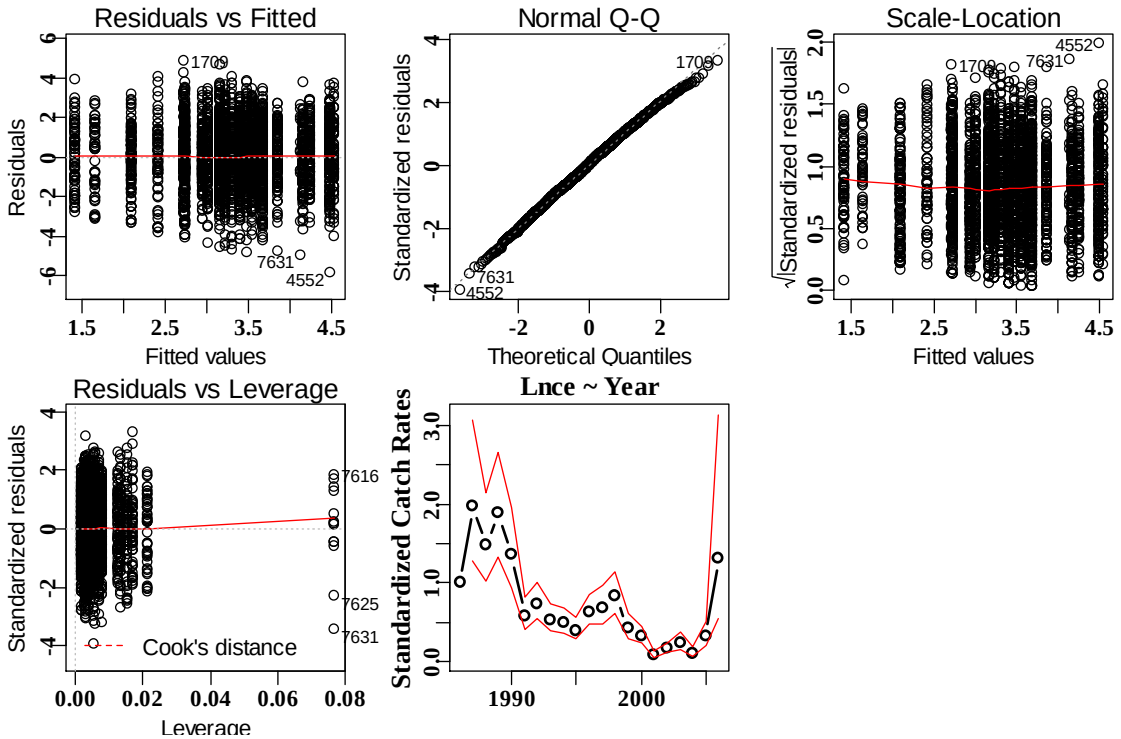


Figure 11.2. Diagnostic plots and depiction of the trend in geometric mean catch rates (relative to 1986) for the Eden stratum.

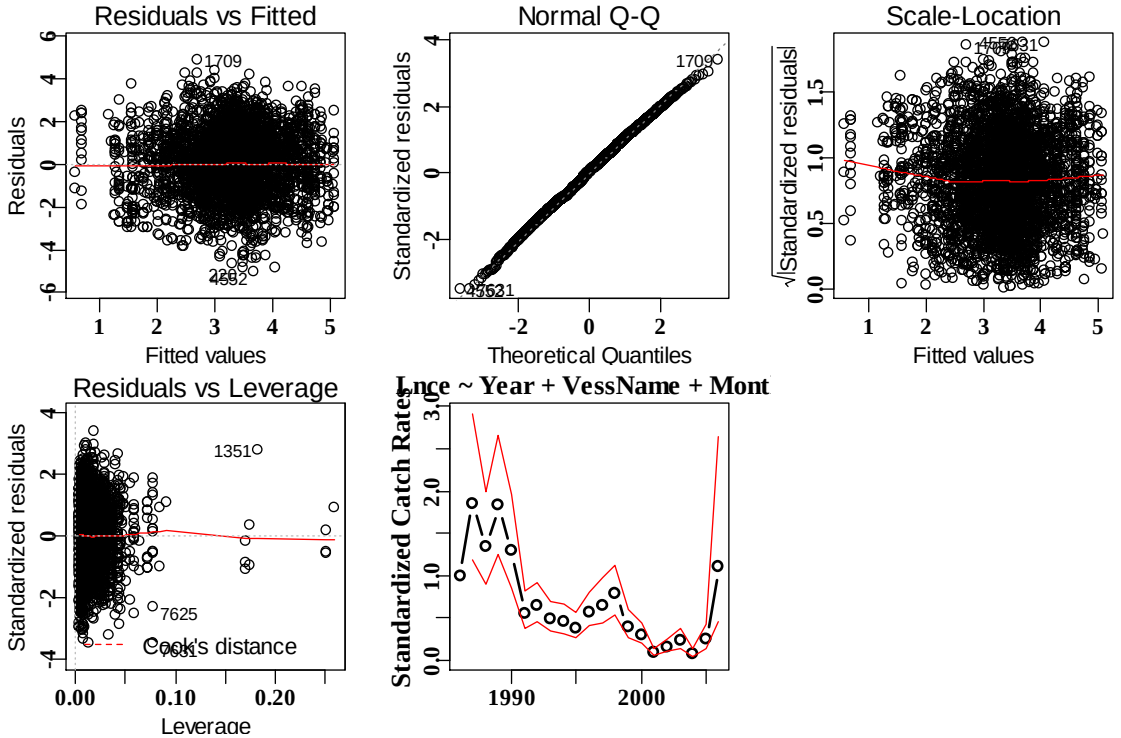


Figure 11.3. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1986) for the Eden stratum. The optimal model was LnCE = Year + Vessel + Month.

11.3.2 Standardized LnCE = Year + Vessel + Month Eden.

Table 11.2. The standardized mean catch rates and standard errors for the eastern stratum at Eden. Optimum model was LnCE = Year + Vessel + Month. 55 parameters with an R2 = 0.1879.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	124
1987	0.616856	0.225781	1.853092	2.910769	1.17974	74
1988	0.291701	0.197708	1.338702	1.987974	0.901483	130
1989	0.603156	0.188011	1.827878	2.662267	1.254997	179
1990	0.25459	0.209258	1.289932	1.960315	0.848805	138
1991	-0.58596	0.195607	0.556574	0.823047	0.376375	176
1992	-0.4348	0.176951	0.647392	0.922285	0.454433	351
1993	-0.71861	0.177267	0.487431	0.694841	0.341933	325
1994	-0.76935	0.179021	0.463314	0.662782	0.323877	318
1995	-0.95075	0.188298	0.386453	0.563184	0.265181	227
1996	-0.55599	0.173535	0.573507	0.811463	0.40533	504
1997	-0.4214	0.198929	0.656128	0.976735	0.440759	167
1998	-0.24131	0.180972	0.785596	1.12821	0.547027	330
1999	-0.91638	0.203766	0.399964	0.601187	0.266092	142
2000	-1.18145	0.187512	0.306834	0.446452	0.210879	263
2001	-2.37527	0.237475	0.092989	0.14952	0.057832	78
2002	-1.7961	0.203954	0.165945	0.249526	0.11036	145
2003	-1.45429	0.248281	0.233566	0.383764	0.142153	65
2004	-2.45179	0.269635	0.086139	0.147707	0.050234	47
2005	-1.37822	0.256177	0.252026	0.420686	0.150985	58
2006	0.096995	0.437963	1.101855	2.645663	0.458896	13

11.3.3 East Eden Restricted years 1986-1997 Standardized CE Series

Table 11.3. Standardized mean catch rate series for the Eden stratum over restricted years. R2 = 0.1114

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	124
1987	0.590281	0.220595	1.804495	2.805186	1.16078	74
1988	0.255507	0.193587	1.291116	1.901572	0.876633	130
1989	0.53345	0.185631	1.704803	2.471221	1.17608	179
1990	0.256356	0.205786	1.292213	1.950193	0.85623	138
1991	-0.57925	0.19278	0.560317	0.823912	0.381055	176
1992	-0.39549	0.174085	0.673351	0.953782	0.475372	351
1993	-0.67633	0.174223	0.508478	0.720445	0.358876	325
1994	-0.71873	0.175881	0.48737	0.692831	0.34284	318
1995	-0.92842	0.185554	0.395178	0.572748	0.272661	227
1996	-0.52298	0.171268	0.592754	0.834903	0.420836	504
1997	-0.42922	0.196835	0.651015	0.965072	0.439159	167
1998	0.172713	0.430455	1.188525	2.811232	0.502481	13

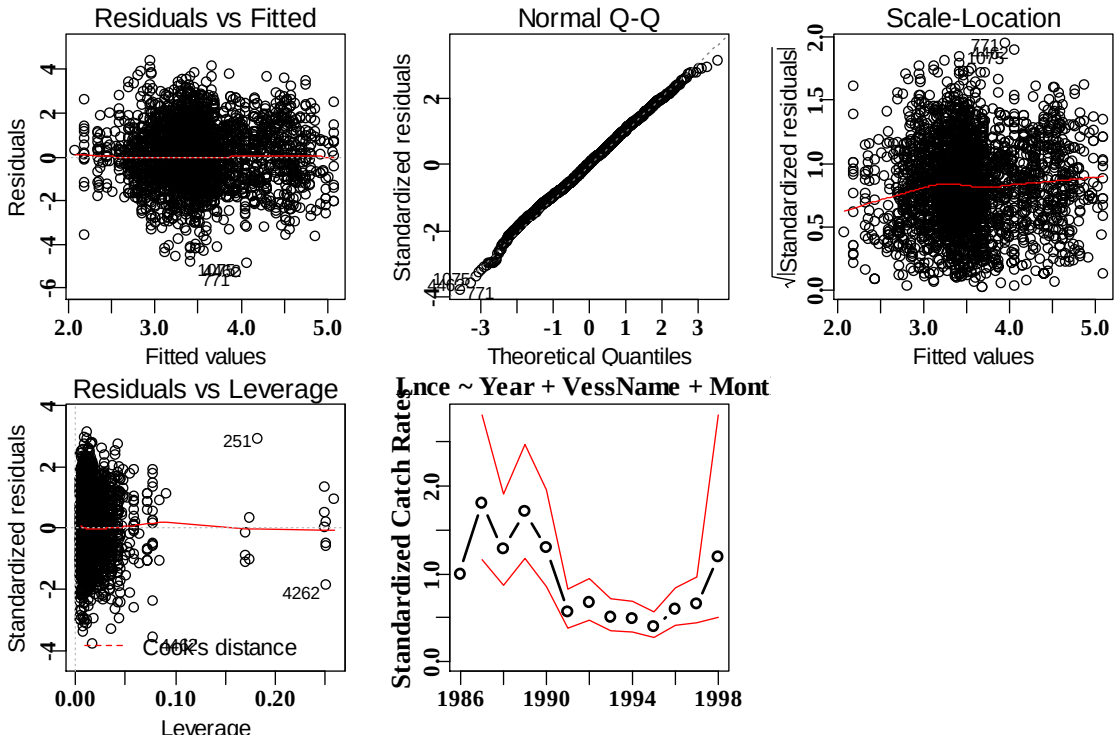


Figure 11.4. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1986) for the Eden stratum over the restricted time series 1986 – 1997 (survey depicted as 1998). The optimal model was LnCE = Year + Vessel + Month.

11.4 Horse Shoe Stratum

11.4.1 Geometric Mean Horse Shoe

Table 11.4. The geometric mean catch rates in the Horse Shoe stratum (LnCE = Year). The parameters are under Coeff, C_USE and C_LSE are the coefficient ± 2 × St Error. Nobs is the number of observations in each case. The adjusted R2 = 0.2737.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	3
1987	1.735916	0.91072	5.674126	35.07039	0.918031	19
1988	0.696284	0.899857	2.006283	12.13382	0.331732	23
1989	0.507116	0.92229	1.660495	10.50336	0.262511	16
1990	1.181621	0.885135	3.259655	19.14213	0.555077	32
1991	-0.273201	0.904787	0.76094	4.647705	0.124584	21
1992	0.076136	0.954813	1.079109	7.284593	0.159855	11
1993	-1.132767	1.338199	0.322141	4.681555	0.022167	2
1994	-0.43518	0.874728	0.647148	3.722057	0.112519	44
1995	-1.125687	0.867964	0.324429	1.840873	0.057176	58
1996	-0.775647	0.889051	0.460406	2.724962	0.07779	29
1997	-1.292489	0.864554	0.274587	1.547467	0.048723	69
1998	-0.692992	0.867602	0.500078	2.835481	0.088196	59
1999	-1.077204	0.869975	0.340546	1.940112	0.059776	53
2000	-2.254786	0.954813	0.104896	0.708107	0.015539	11
2001	-0.566171	0.938942	0.567695	3.712531	0.086808	13
2002	-2.206874	0.992435	0.110044	0.800911	0.01512	8
2003	-2.721792	1.338199	0.065757	0.95562	0.004525	2
2004	0.908515	1.070559	2.480637	21.10759	0.291533	5
2005	-1.43707	1.036564	0.237623	1.88902	0.029891	6
2006	-2.509823	0.992435	0.081283	0.591583	0.011168	8

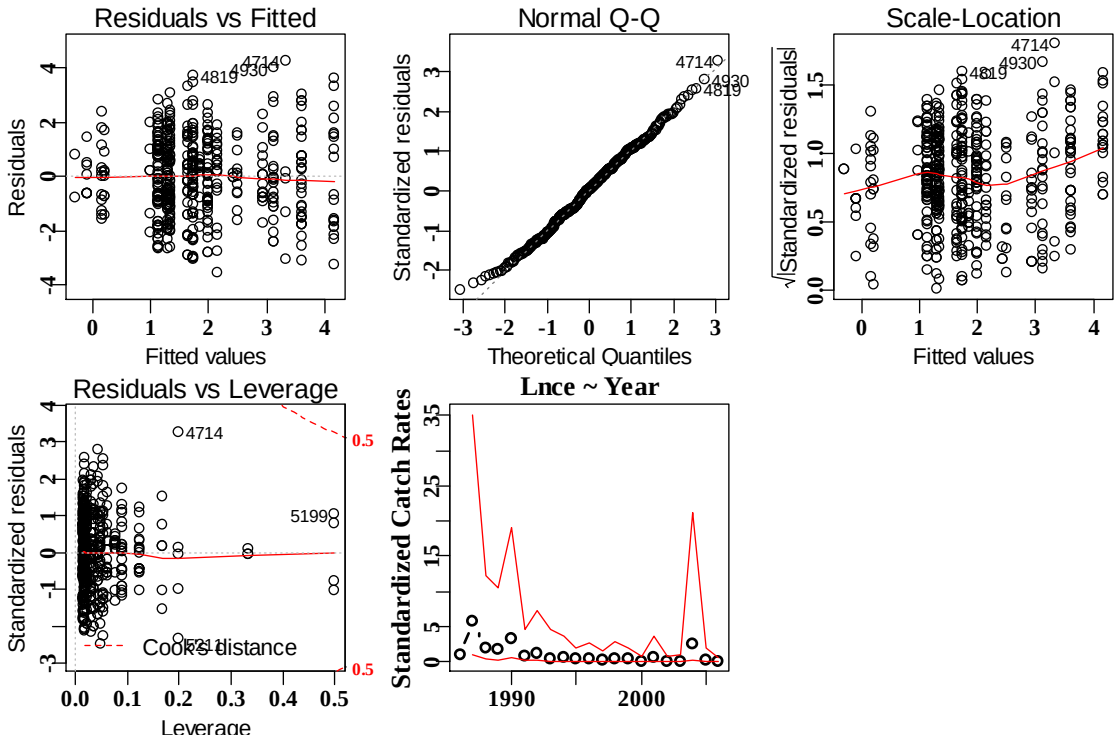


Figure 11.5. Diagnostic plots and depiction of the trend in geometric mean catch rates (relative to 1986) for the Horse Shoe stratum.

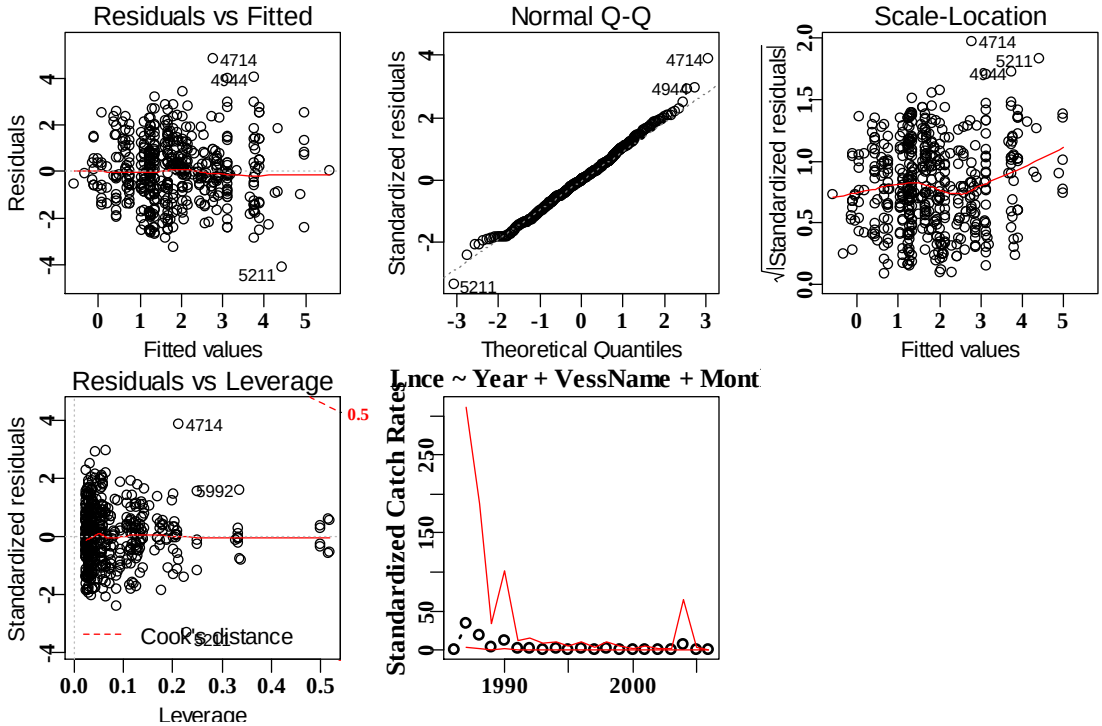


Figure 11.6. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1986) for the Horse Shoe stratum. The optimal model was LnCE = Year + Vessel + Month.

11.4.2 Standardized CE LnCE = Year + Vessel + Month Horse Shoe

Table 11.5. The standardized mean catch rates and standard errors for the eastern stratum at the Horse Shoe. Optimum model was LnCE = Year + Vessel + Month. 43 parameters with an R2 = 0.3339.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	3
1987	3.528779	1.106673	34.08232	311.7257	3.726367	19
1988	2.97495	1.129695	19.58864	187.605	2.045333	23
1989	1.366192	1.089754	3.920394	34.66392	0.443386	16
1990	2.529391	1.048688	12.54586	102.183	1.540359	32
1991	0.450098	1.027872	1.568467	12.25389	0.20076	21
1992	0.646077	1.046828	1.90804	15.48283	0.235139	11
1993	-0.686895	1.382586	0.503136	7.990686	0.03168	2
1994	0.310015	0.989897	1.363445	9.873048	0.188289	44
1995	-0.227904	0.977112	0.7962	5.619935	0.112801	58
1996	0.337296	0.980206	1.401154	9.951354	0.197283	29
1997	-0.522137	0.948559	0.593251	3.955003	0.088988	69
1998	0.377315	0.955333	1.458364	9.855016	0.215812	59
1999	-0.212012	0.969714	0.808955	5.626095	0.116316	53
2000	-1.738825	1.049345	0.175727	1.433134	0.021547	11
2001	-0.384582	1.055567	0.680735	5.621235	0.082438	13
2002	-1.950037	1.105526	0.142269	1.298248	0.015591	8
2003	-2.47659	1.383131	0.084029	1.335988	0.005285	2
2004	1.877563	1.143224	6.537553	64.32898	0.664391	5
2005	-1.225106	1.122478	0.293727	2.772782	0.031115	6
2006	-2.565736	1.095457	0.076863	0.687411	0.008594	8

11.4.3 East Horse Shoe Restricted years 1986 – 1997

Table 11.6. Standardized mean catch rate series for the Horse Shoe stratum over restricted years. R2 = 0.3561. Lnce ~ Year + VessName + Month

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1986	0	NA	1	NA	NA	3
1987	3.987213	1.184533	53.90444	576.0992	5.04373	19
1988	3.364104	1.210472	28.90757	325.3978	2.568081	23
1989	1.736587	1.169436	5.677934	58.87758	0.547559	16
1990	2.931516	1.132442	18.75605	180.6209	1.947668	32
1991	0.856642	1.115939	2.355238	21.94458	0.25278	21
1992	0.879871	1.139557	2.410589	23.54668	0.246784	11
1993	-0.400075	1.454821	0.67027	12.2996	0.036527	2
1994	0.729346	1.077793	2.073724	17.90236	0.24021	44
1995	0.118973	1.06679	1.126339	9.511992	0.133373	58
1996	0.558128	1.079217	1.747399	15.12823	0.201835	29
1997	-0.163012	1.030953	0.849581	6.678503	0.108076	69
1998	-2.307234	1.19952	0.099536	1.096152	0.009038	8

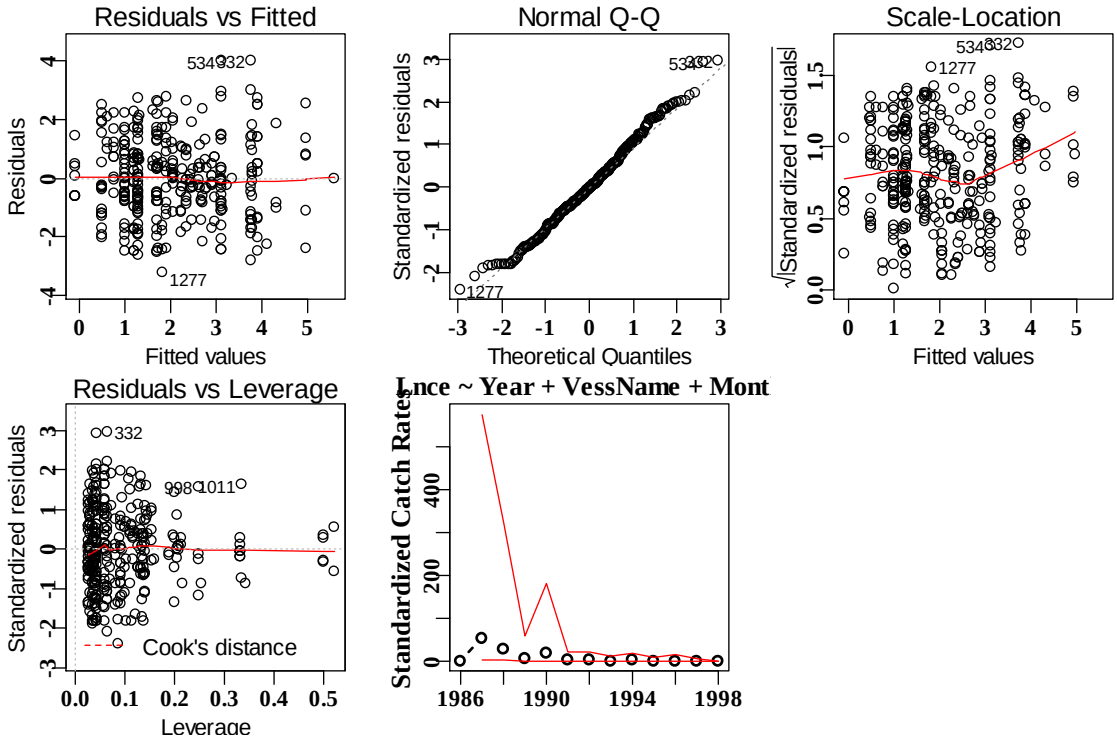


Figure 11.7. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1986) for the Horse Shoe stratum over the restricted time series 1986 – 1997 (survey depicted as 1998). The optimal model was LnCE = Year + Vessel + Month

11.5 Main Drag

11.5.1 Geometric Mean Main Drag

Table 11.7. The geometric mean catch rates in the western Main Drag stratum (LnCE = Year). The parameters are under Coeff, C_USE and C_LSE are the coefficient ± 2 × St Error. Nobs is the number of observations in each case. The adjusted R2 = 0.2216. 2006 = survey, years before 1990 had too few observations for inclusion. Note large CVS in survey.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1990	0	NA	1	NA	NA	31
1991	-0.48898	0.307176	0.61325	1.133567	0.331763	131
1992	-1.37693	0.312122	0.252353	0.471102	0.135177	112
1993	-1.79993	0.323203	0.165311	0.315523	0.086611	84
1994	-2.23868	0.318535	0.106599	0.201571	0.056374	94
1995	-1.78153	0.317311	0.16838	0.317616	0.089264	97
1996	-3.45975	0.323203	0.031438	0.060004	0.016471	84
1997	-1.24368	0.379318	0.28832	0.615667	0.135022	35
1998	-2.22675	0.325948	0.107879	0.207038	0.056211	79
1999	-2.61812	0.300358	0.07294	0.133	0.040001	170
2000	-3.26938	0.393885	0.03803	0.083609	0.017298	30
2001	-2.83469	0.324263	0.058737	0.112347	0.030709	82
2002	-1.94023	0.309337	0.143672	0.266721	0.07739	122
2003	-1.99357	0.34775	0.136208	0.273057	0.067944	53
2004	-2.18189	0.408993	0.112828	0.255662	0.049793	26
2005	-1.26079	0.358977	0.283429	0.581095	0.138242	45
2006	-0.48737	0.508183	0.614237	1.69722	0.222297	13

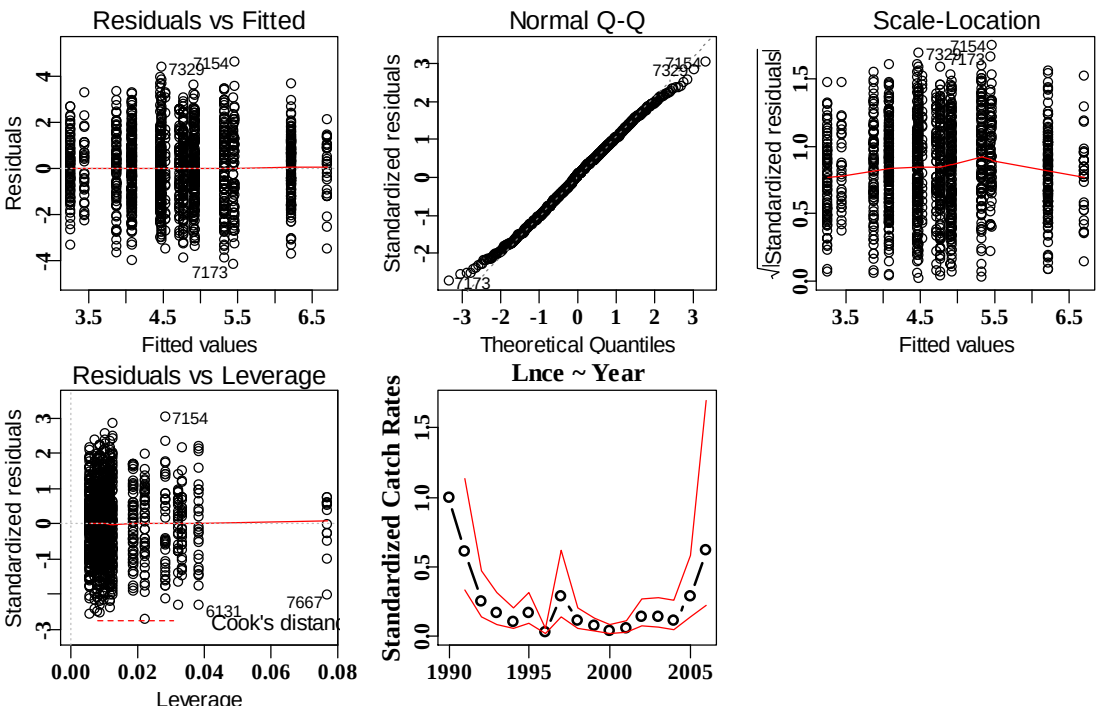


Figure 11.8. Diagnostic plots and depiction of the trend in geometric mean catch rates (relative to 1990) for the Main Drag stratum.

11.5.2 Main Drag Standardized LnCE = Year + Vessel + Month

Table 11.8. The standardized mean catch rates and standard errors for the western stratum at the Main Drag. Optimum model was LnCE = Year + Vessel + Month. 29 parameters with an R2 = 0.2589. 2006 = survey year, yeas before 1990 had too few observations for inclusion.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1990	0	NA	1	NA	NA	31
1991	-0.42442	0.322175	0.654148	1.245987	0.34343	131
1992	-1.36637	0.321406	0.255031	0.485024	0.134098	112
1993	-1.81292	0.341674	0.163176	0.32317	0.082392	84
1994	-2.10029	0.333877	0.122421	0.238703	0.062785	94
1995	-1.54513	0.327039	0.213285	0.410226	0.110891	97
1996	-3.14226	0.336773	0.043185	0.084694	0.02202	84
1997	-1.08463	0.387346	0.338028	0.733495	0.155779	35
1998	-2.12278	0.332583	0.119698	0.232791	0.061547	79
1999	-2.3538	0.312751	0.095008	0.177587	0.050828	170
2000	-3.25738	0.405188	0.038489	0.086553	0.017116	30
2001	-2.58548	0.331672	0.07536	0.146294	0.03882	82
2002	-1.72948	0.319876	0.177376	0.336307	0.093552	122
2003	-1.77488	0.362731	0.169504	0.350142	0.082057	53
2004	-2.09478	0.411525	0.123097	0.280346	0.054051	26
2005	-1.04051	0.373691	0.353276	0.745929	0.167313	45
2006	-0.31866	0.521567	0.727126	2.063652	0.256202	13

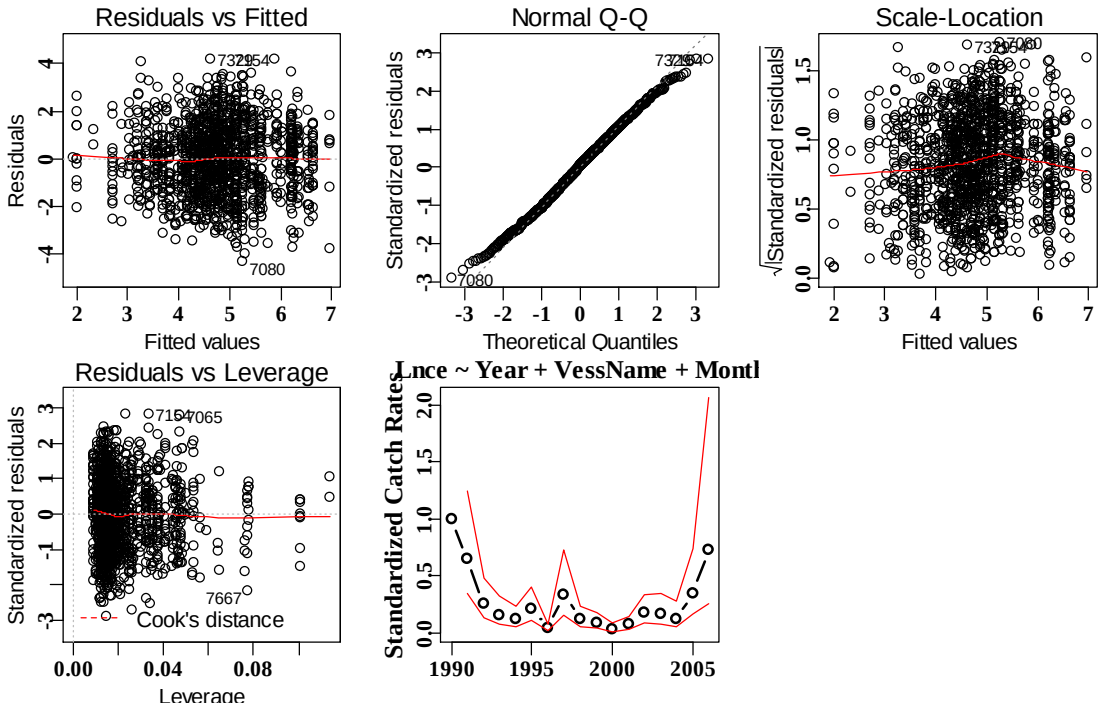


Figure 11.9. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1990) for the Main Drag stratum. The optimal model was LnCE = Year + Vessel + Month.

11.5.3 Main Drag – restricted years 1990 – 1997

Table 11.9. Standardized mean catch rate series for the Main Drag stratum over restricted years. R2 = 0.3023. Lnce ~ Year + VessName + Month

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1990	0	NA	1	NA	NA	31
1991	-0.41804	0.326399	0.658334	1.2646	0.34272	131
1992	-1.39868	0.327735	0.246923	0.475585	0.128202	112
1993	-1.8191	0.354891	0.162171	0.329783	0.079748	84
1994	-2.16135	0.349773	0.11517	0.231818	0.057218	94
1995	-1.62035	0.337012	0.197829	0.388163	0.100824	97
1996	-3.30864	0.35489	0.036566	0.074358	0.017981	84
1997	-1.12618	0.417502	0.32427	0.747386	0.140692	35
Survey	-0.55305	0.543042	0.575194	1.704098	0.194148	13

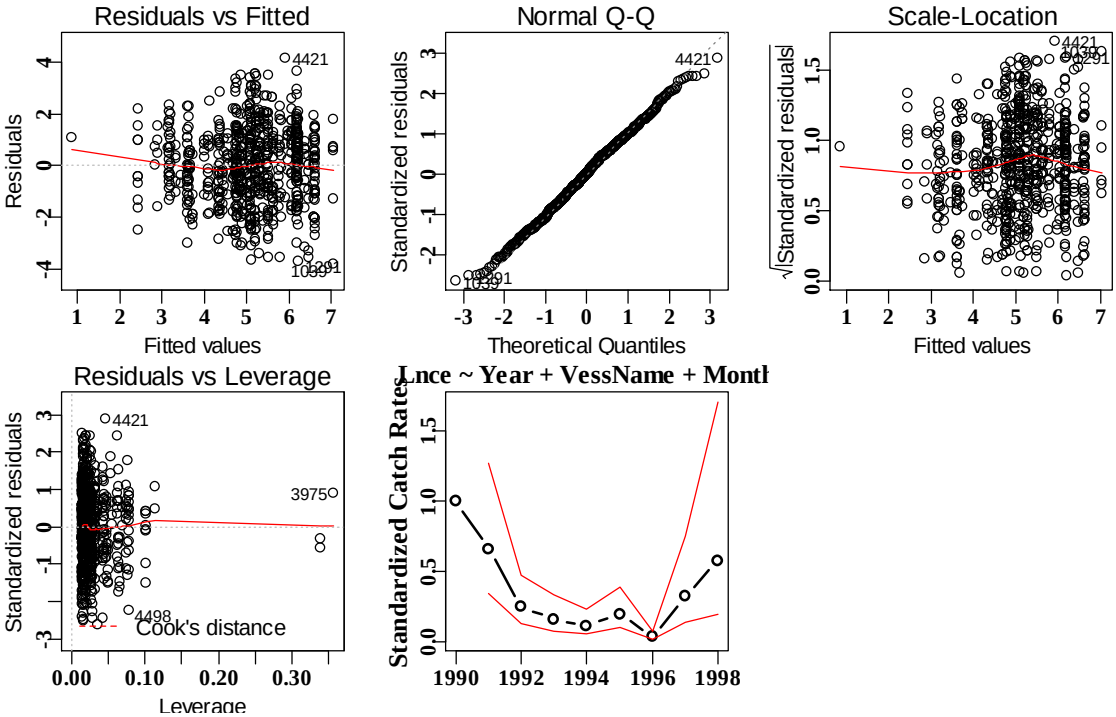


Figure 11.10. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1990) for the Main Drag stratum over the restricted time series 1990 – 1997 (survey depicted as 1998). The optimal model was LnCE = Year + Vessel + Month.

11.6 Port MacDonnell

11.6.1 Geometric Mean Port MacDonnell

Table 11.10. The geometric mean catch rates in the western Main Drag stratum (LnCE = Year). The parameters are under Coeff, C_USE and C_LSE are the coefficient ± 2 × St Error. Nobs is the number of observations in each case. The adjusted R2 = 0.2684. 2006 = survey, years before 1992 had too few observations for inclusion.

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1992	0	NA	1	NA	NA	7
1993	0.941384	0.601877	2.563527	8.543214	0.769227	16
1994	1.512966	0.738924	4.540179	19.90188	1.035743	6
1995	0.757401	0.591613	2.132727	6.963111	0.653232	18
1996	-1.21853	0.583271	0.295666	0.949345	0.092083	20
1997	-1.43769	0.601877	0.237475	0.791411	0.071258	16
1998	-0.73688	0.64216	0.478603	1.728816	0.132496	11
1999	-0.98176	0.654528	0.374652	1.387213	0.101184	10
2000	-0.95927	0.565554	0.383171	1.187479	0.12364	26
2001	0.428344	0.557499	1.534715	4.680204	0.503258	30
2002	-0.40164	0.622654	0.669221	2.324878	0.192637	13
2003	0.43287	0.583271	1.541676	4.950122	0.480143	20
2004	1.240385	0.777695	3.456946	16.37532	0.729786	5
2005	0.609439	0.687392	1.839399	7.273387	0.465174	8
2006	-0.74956	0.687392	0.472576	1.868669	0.119512	8

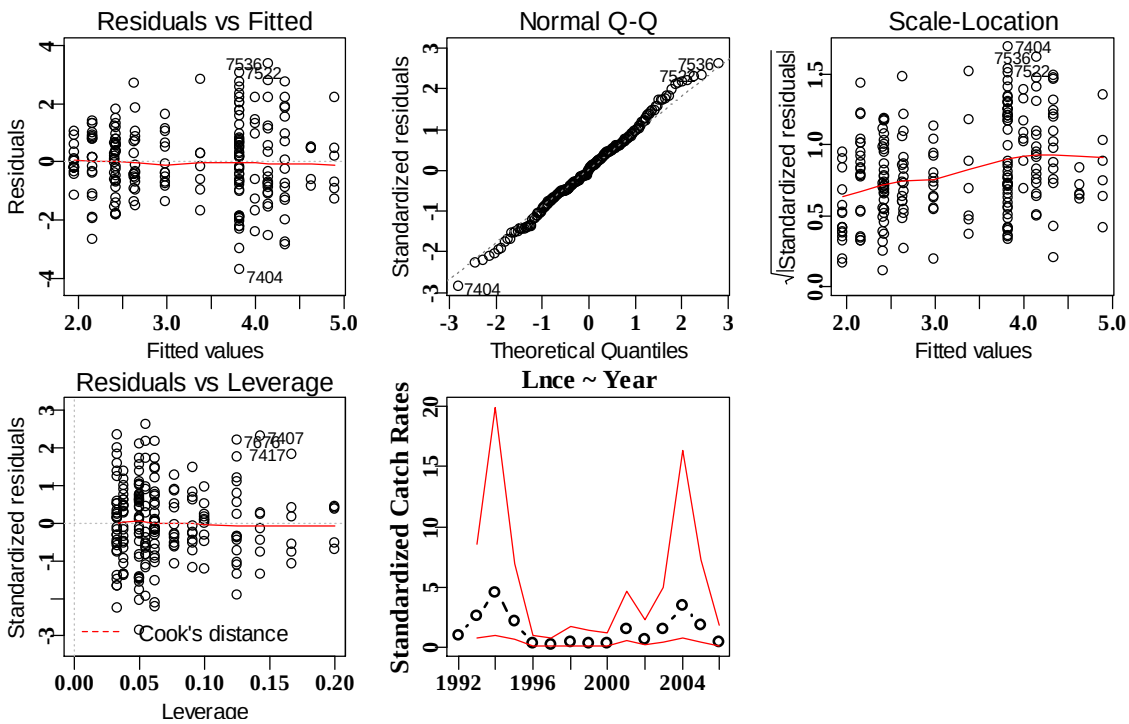


Figure 11.11. Diagnostic plots and depiction of the trend in geometric mean catch rates (relative to 1992) for the Port MacDonnell stratum.

11.6.2 Standardized Model LnCE = Year + Vessel + Month Port MacDonnell

Table 11.11. The standardized mean catch rates and standard errors for the eastern stratum at the Horse Shoe. Optimum model was LnCE = Year + Vessel + Month. 43 parameters with an R2 = 0.3106.West Prot MacDonnell. Standardized Model LnCE = Year + Vessel + Month

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1992	0	NA	1	NA	NA	7
1993	-0.21355	0.719693	0.807712	3.407012	0.191487	16
1994	1.173907	0.748596	3.234607	14.45584	0.723768	6
1995	0.723776	0.611618	2.062205	7.007713	0.606859	18
1996	-1.44567	0.604177	0.235588	0.788742	0.070368	20
1997	-1.523	0.643564	0.218056	0.789879	0.060197	16
1998	-0.81443	0.651363	0.442894	1.629543	0.120374	11
1999	-1.35601	0.656429	0.257687	0.957767	0.069331	10
2000	-1.12017	0.562631	0.326224	1.005102	0.105882	26
2001	0.168337	0.595609	1.183335	3.894458	0.359558	30
2002	-0.73537	0.63885	0.479328	1.72001	0.133578	13
2003	0.017866	0.605004	1.018026	3.413966	0.30357	20
2004	0.705464	0.803026	2.024786	10.08971	0.40633	5
2005	0.12714	0.710808	1.135576	4.70561	0.274041	8
2006	-1.45385	0.751727	0.23367	1.050859	0.051959	8

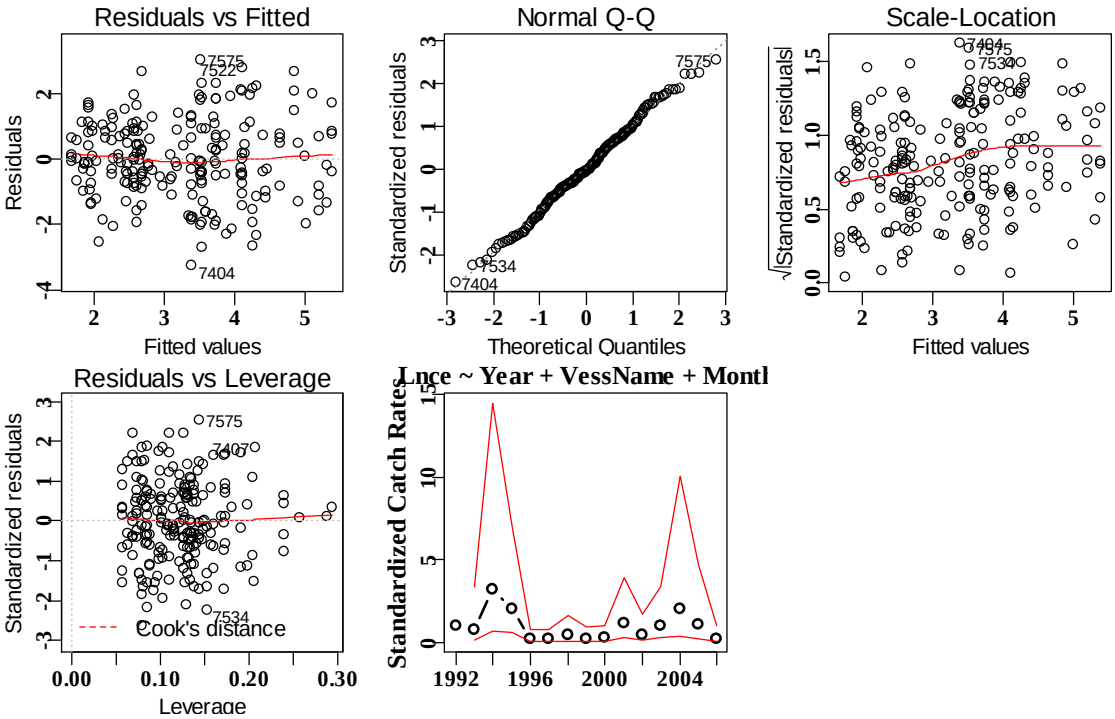


Figure 11.12. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1992) for the Port MacDonnell stratum. The optimal model was LnCE = Year + Vessel + Month.

11.6.3 Port MacDonnell restricted years 1992 – 1997

Table 11.12. Standardized mean catch rate series for the Port MacDonnell stratum over restricted years. R2 = 0.4068. Lnce ~ Year + VessName + Month

Year	LnCoeff	StErr	Coeff	C_USE	C_LSE	NObs
1992	0	NA	1	NA	NA	7
1993	0.003013	0.755464	1.003018	4.544607	0.221371	16
1994	0.760616	0.798831	2.139593	10.57273	0.432987	6
1995	0.68496	0.651773	1.983693	7.304617	0.538706	18
1996	-1.28235	0.643494	0.277385	1.00465	0.076586	20
1997	-1.18567	0.715495	0.305543	1.278037	0.073047	16
1998	-2.35736	0.875396	0.09467	0.545218	0.016438	8

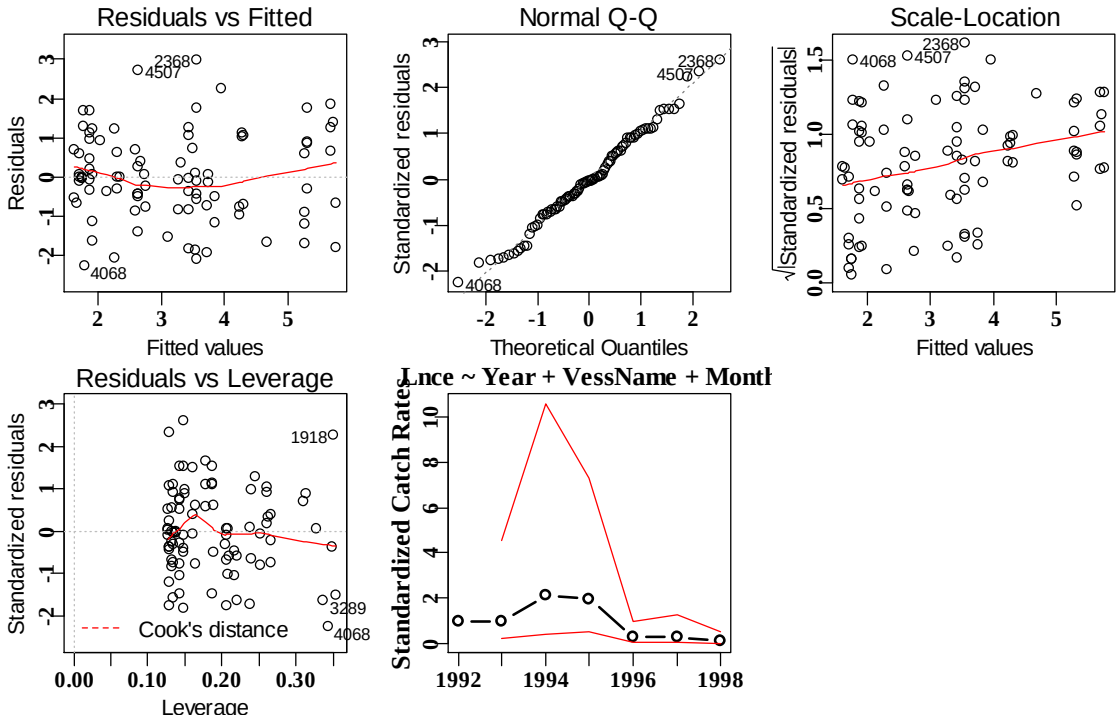


Figure 11.13. Diagnostic plots and depiction of the trend in standardized mean catch rates (relative to 1986) for the Port MacDonnell stratum over the restricted time series 1992 – 1997 (survey depicted as 1998). The optimal model was LnCE = Year + Vessel + Month.

11.7 Appendix 1. Stratum Definitions

Table A1. Longitude and latitude (in decimal degrees) of each stratum used in the 2005 blue warehou fishery independent survey. The stratum names correspond with those depicted in Figure 11.1. Port Mac is Port MacDonnell.

Stratum	Longitude	Latitude
Beachport	139.15517	37.37467
Beachport	139.30383	37.37467
Beachport	139.30383	37.54050
Beachport	139.15517	37.54050
Beachport	139.15517	37.37467
MainDrag	141.16200	38.51900
MainDrag	141.65817	38.75317
MainDrag	141.65183	38.82417
MainDrag	141.47467	38.82417
MainDrag	141.12650	38.58967
MainDrag	141.16200	38.51900
Port Mac	140.53167	38.26583
Port Mac	141.16200	38.51900
Port Mac	141.12650	38.58967
Port Mac	140.50000	38.33333
Port Mac	140.53167	38.26583
HorseShoe	148.28817	38.48133
HorseShoe	148.53167	38.17233
HorseShoe	149.33817	38.00000
HorseShoe	149.44250	38.20050
HorseShoe	148.65517	38.32183
HorseShoe	148.46983	38.59050
HorseShoe	148.28817	38.48133
Eden	149.96500	37.00000
Eden	150.20683	36.94967
Eden	150.29167	37.26000
Eden	150.18700	37.61350
Eden	149.80017	37.93683
Eden	149.68100	37.78300
Eden	150.00000	37.50150
Eden	150.07467	37.24717
Eden	149.96500	37.00000

11.8 Appendix 2. Shot by Shot data (vessel names omitted)

Table A2. Shot by shot details of the 2005 blue warehou fishery independent survey (quoted with permission). St_Long is the start longitude, St_Lat is the starting latitude, Effort is in hours, BW is kg blue warehou, AvDepth is the average depth in metres, CE is kg/hours, Lnce is the natural log of Ce.

Stratum	Year	Month	St_Long	St_Lat	Effort	BW	Avdepth	Ce	Lnce
E	1998	9	150.0167	-37.5333	2	1725	95.16	862.5	6.759835
E	1998	9	149.8667	-37.6333	2	265	93.33	132.5	4.886583
E	1998	9	149.8000	-37.7167	2	64	98.82	32	3.465736
E	1998	9	149.9667	-37.6333	2	175	100.65	87.5	4.471639
E	1998	9	150.0667	-37.5000	2	1426	100.65	713	6.569481
E	1998	9	149.9833	-37.5667	3	1388	100.65	462.6667	6.137007
E	1998	9	150.1000	-37.2333	2	156	102.48	78	4.356709
E	1998	9	150.0333	-37.3833	2	798	76.86	399	5.988961
E	1998	9	150.0667	-37.2333	2	63	76.86	31.5	3.449988
E	1998	10	150.0547	-37.5417	2.166667	5	175.68	2.307692	0.836248
E	1998	10	149.9919	-37.5614	2.25	180	162.87	80	4.382027
E	1998	10	149.8972	-37.6194	3	80	162.87	26.66667	3.283414
E	1998	10	150.0642	-37.3231	2.25	0	152.805	NA	NA
E	1998	10	150.0122	-37.0992	2	0	115.29	NA	NA
E	1998	10	150.0394	-36.9139	3.333333	0	128.1	NA	NA
E	1998	10	150.0833	-37.2167	4.5	2	124.44	0.444444	-0.81093
H	1998	9	149.2167	-38.0167	2.166667	3	137.25	1.384615	0.325422
H	1998	9	149.2333	-38.1333	2	1	165.615	0.5	-0.69315
H	1998	9	148.9167	-38.2333	2	0	166.53	NA	NA
H	1998	9	148.4167	-38.4667	1.666667	0	173.85	NA	NA
H	1998	10	149.2514	-37.9919	2	8	116.205	4	1.386294
H	1998	10	149.3000	-38.0667	1.25	0	175.68	NA	NA
H	1998	10	148.9894	-38.2286	2	0	160.125	NA	NA
H	1998	10	148.8667	-38.2333	2	3	121.695	1.5	0.405465
H	1998	10	148.4167	-38.3833	2	1	125.355	0.5	-0.69315
H	1998	10	148.4333	-38.4833	2	1	222.345	0.5	-0.69315
H	1998	10	148.6000	-38.2500	2	0	188.49	NA	NA
H	1998	10	148.9056	-38.1161	2	1	118.95	0.5	-0.69315
H	1998	10	149.2833	-37.9833	2	2	120.78	1	0
H	1998	10	149.2833	-38.1167	2	0	162.87	NA	NA
B	1998	8	139.3194	-37.5169	1.833333	4540	454.755	2476.364	7.814546
B	1998	8	139.2564	-37.4022	1.833333	0	258.03	NA	NA
B	1998	8	139.3206	-37.5272	2	2240	462.075	1120	7.021084
B	1998	8	139.2542	-37.5078	1.5	5280	494.1	3520	8.166216
B	1998	8	139.3081	-37.5175	2	295	549	147.5	4.993828
B	1998	8	139.3028	-37.5256	2.666667	3010	515.145	1128.75	7.028866
B	1998	8	139.3253	-37.5028	1.833333	2590	521.55	1412.727	7.253277
B	1998	9	139.2189	-37.5408	2	245	322.995	122.5	4.808111
B	1998	9	139.2150	-37.4594	0.866667	70	327.57	80.76923	4.391596
B	1998	9	139.2178	-37.4767	1.25	5	346.785	4	1.386294
B	1998	9	139.2267	-37.5347	2.166667	980	346.785	452.3077	6.114363
B	1998	9	139.2131	-37.4214	2.383333	1155	337.635	484.6154	6.183356
B	1998	9	139.3156	-37.5178	1.15	50	230.58	43.47826	3.772261
B	1998	9	139.3128	-37.5178	2.35	360	280.905	153.1915	5.031689
B	1998	9	139.3183	-37.5206	3	2480	300.12	826.6667	6.717402
B	1998	9	139.3167	-37.5197	3	560	292.8	186.6667	5.229324
M	1998	8	141.2386	-38.6206	2.033333	3042	279.075	1496.066	7.310594

Table A2 [cont.]

Stratum	Year	Month	St_Long	St_Lat	Effort	BW	Avdepth	Ce	Lnce
M	1998	8	141.2167	-38.6167	2.016667	484	292.8	240	5.480639
M	1998	8	141.2425	-38.6236	2.083333	705	260.775	338.4	5.824229
M	1998	8	141.2422	-38.6239	2	2170	265.35	1085	6.989335
M	1998	8	141.4789	-38.7586	2	2320	269.925	1160	7.056175
M	1998	8	141.3333	-38.6956	2	50	283.65	25	3.218876
M	1998	8	141.4200	-38.7197	2	230	274.5	115	4.744932
M	1998	8	141.2358	-38.6278	2	1785	283.65	892.5	6.794027
M	1998	9	141.2211	-38.6156	2.083333	3102	265.35	1488.96	7.305833
M	1998	9	141.2181	-38.6142	2.416667	3000	256.2	1241.379	7.123978
M	1998	9	141.2378	-38.6222	2.333333	1150	265.35	492.8571	6.200219
M	1998	9	141.2286	-38.6106	2.5	815	274.5	326	5.786897
M	1998	9	141.2297	-38.6114	2.666667	3300	274.5	1237.5	7.120848
P	1998	8	141.0856	-38.5247	2	17	198.555	8.5	2.140066
P	1998	8	140.6875	-38.3575	2	422	198.555	211	5.351858
P	1998	8	140.5589	-38.3008	2	37	186.66	18.5	2.917771
P	1998	8	140.6667	-38.3489	2	7	222.345	3.5	1.252763
P	1998	8	141.1414	-38.5433	2	18	205.875	9	2.197225
P	1998	8	141.0347	-38.4994	2	18	226.005	9	2.197225
P	1998	9	140.3228	-38.1758	2.133333	12	222.345	5.625	1.727221
P	1998	9	141.4717	-38.7592	1.833333	50	263.52	27.27273	3.305887

Table A3. Count of commercial catch and effort data from the five strata used in the fishery independent survey.

Year	Eden	HorseShoe	Beachport	Main Drag	Port MacDonnell
1986	125	3		2	8
1987	74	20		22	14
1988	131	23		57	36
1989	183	16			
1990	147	34		111	6
1991	192	25		204	1
1992	363	14		130	7
1993	330	3		90	16
1994	324	57	2	103	9
1995	230	78	2	126	30
1996	529	49	2	87	29
1997	180	89	12	42	18
1998	346	79	6	92	11
1999	156	66	14	170	10
2000	289	48	1	36	35
2001	80	32	19	87	33
2002	155	16	4	123	15
2003	72	10	6	55	20
2004	55	24	6	33	15
2005	65	17	22	55	19
Total	4026	703	96	1625	332

11.9 Appendix 3. R code for analyses (bwsurvey_stand.r).

```
# Procedures used to include survey data into blue warehou standardizations
 bw <- read.csv("BW_Survey.CSV", header=T,na.strings="NA")
names(bw)
levels(bw$Stratum)

startyr <- 1985
endyr <- 2006
bwa <- subset(bw,bw$Year > startyr)

bwa$VessName <- factor(bwa$VessName)
bwa$Year <- factor(bwa$Year)
bwa$Month <- factor(bwa$Month)
bwa$Depcat <- factor(bwa$Depcat)

suba <- subset(bwa,bwa$Ce != "NA")
subb <- subset(suba,suba$Avdepth != "NA")
sub1 <- subset(subb,subb$Stratum=="B")
sub2 <- subset(sub1,sub1$Count>2)
subbw <- subset(sub2,sub2$Median>500)  ## 300 for east 500 for west

freqbyyr <- by(subbw$Year,subbw$Year,length)

attach(subbw,warn.conflicts = FALSE)

levels(VessName)
levels(Year)
nyrs <- length(levels(Year))
levels(Month)
levels(Depcat)

Results <- matrix(nrow=nyrs,ncol=7,
            dimnames = list(NULL,
            c("Year", "LnCoeff", "StErr", "Coeff", "C_USE", "C_LSE", "NObs")))
Results[,7] <- as.numeric(freqbyyr)

par(mfrow=c(2,3))
par(mai=c(0.4,0.4,0.25,0.25))
par(cex=0.85, mgp=c(1.5,0.35,0), font.axis=7)

# model1 <- lm(Lnce ~ Year ,data=subbw)
# modtit <- "Lnce ~ Year"
 model1 <- lm(Lnce ~ Year + VessName + Month ,data=subbw)
 modtit <- "Lnce ~ Year + VessName + Month"

print(anova(model1))
print(summary(model1))
```

```
plot(model1)

yrs <- seq(startyr+1,endyr,1)
Results[,1] <- yrs
temp <- summary(model1)
Results[1,2] <- 0
Results[2:nyrs,2] <- temp$coefficients[2:nyrs,1]
Results[,4] <- exp(Results[,2])
Results[1,3] <- NA
Results[2:nyrs,3] <- temp$coefficients[2:nyrs,2]
Results[1,5:6] <- NA
Results[2:nyrs,5] <- exp(Results[2:nyrs,2]+2.0*Results[2:nyrs,3])
Results[2:nyrs,6] <- exp(Results[2:nyrs,2]-2.0*Results[2:nyrs,3])


##modtit <- "Lnce ~ Year"
OutText <- paste("Total Number of Parameters = ", unlist(model1[4]),sep="")
print(OutText)
print(modtit)
print(Results)
OutText <- paste("Adjusted R-squared = ", temp[9],sep="")
print(OutText)
ymax <- max(Results[2:nyrs,5])
plot(Results[,1],Results[,4], type="b", xlab="", ylab="", col="black", ylim=c(0,ymax),
    xlim=c(startyr+1,endyr), lwd=1.5)
points(Results[,1],Results[,5], type="l", col="red", lwd=1)
points(Results[,1],Results[,6], type="l", col="red", lwd=1)
   title(ylab=list("Standardized Catch Rates", cex=1.2, font=7),
        main=list(modtit,cex=1.2,font=7))
#ymax <- max(Results[2:nyrs,4])
#plot(Results[,1],Results[,4], type="b", xlab="", ylab="", col="black", ylim=c(0,ymax),
#     xlim=c(startyr+1,2006), lwd=1.5)
#points(Results[,1],Results[,6], type="l", col="red", lwd=1)
#    title(ylab=list("Standardized Catch Rates", cex=1.2, font=7),
#         main=list(modtit,cex=1.2,font=7))

## Cleanup
rm(bw,model1,modtit,suba,subb,freqbyyr, OutText)
rm(nyrs,Results,sub1, sub2, subbw, temp, ymax, yrs)
```

12. Updated Stock Assessment of Blue Warehou (*Seriolella brama*) Based on data up to 2006

André E. Punt[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

12.1 Summary

An assessment of the two stocks of blue warehou (eastern and western) is conducted using Stock Synthesis 2. The data on which the assessment is based differs from that on which the 2005 assessment was based because: a) data for 2005 are now available, b) the age-reading error matrix has been updated, c) consideration is given to using indices of abundance constructed using ISMP data, and d) the results of the 2005 industry-based survey are now available. In common with the 2005 assessment, discards are added to the landed catches when conducting the assessment for the western stock, but the model is fitted to the estimates of discard rate for the eastern stock.

The results for the eastern stock are qualitatively identical to those from the 2004 and 2005 assessments; the stock is depleted to well below the target reference point and there is no evidence for a recovery. In contrast to the situation for the eastern stock, the western stock recovered from below the overfished threshold of $0.2B_0$ to close to the B_{MSY} proxy of $0.4B_0$ in 2005, but has declined since owing primarily to lack of good recruitment. The model predicts that the western stock will drop below the overfished threshold by 2007 if the landed catches are as high as suggested by the industry members of SlopeRAG, and if recruitment is average. Under this projection, the RBC for the western stock is 0 for 2007. The change to the status of the western stock is also a consequence of the change from the assessment model used for the 2005 (and prior) assessments to SS2, specifically the removal of a penalty on fishing mortality and the ability to estimate B_0 within, rather than external to, the assessment.

12.2 Background and fishery

Blue warehou (*Seriolella brama*) are found in continental shelf and upper slope waters throughout south-eastern Australia (NSW, Victoria, Tasmania and South Australia). The species is also found in New Zealand waters. Adults are caught in depths to 500 m (Smith, 1994), although most commercial catches occur from 50 to 300 m. Spawning occurs during winter-spring in various locations throughout the adult distribution of the species (Knuckey and Sivakumaran, 2001) and larvae are widely distributed (Bruce *et al.*, 2001). Small juveniles are pelagic, commonly occurring in association with jellyfish in open coastal waters, and sub-adults often occur in the sheltered waters of large marine embayments. Growth is rapid, with a mean length of about 20 cm LCF being attained after one year. In Australia, the species has a maximum age of about 15 years although higher maximum ages have been recorded for blue warehou in New Zealand (Horn,

2001). Recent studies suggest that maturity occurs at 3–4 years of age (Knuckey and Sivakumaran, 2001).

Assessments priors to 2000 were based on the assumption that blue warehou form a single stock off southeast Australia, given an absence of evidence to support a more complicated stock structure. However, there was increasing, though indirect, evidence for separate stocks to the east and west of Bass Strait: (a) two main spawning areas, (b) differences in the size- and age-compositions of the catch east and west of Bass Strait, and (c) differences in growth between areas. Recently Talman *et al*. (2003) found that several techniques, including MtDNA, morphometrics, otolith microchemistry and otolith shape analysis indicated significant differences east and west of Bass Strait. Given this strong evidence for separate stocks east and west of Bass Strait, recent assessments have been based on the assumption of two stocks.

12.2.1 Previous assessments

Quantitative analyses based on fitting population dynamics models to catch, catch-rate and catch-at-age data have formed the basis for stock assessments since the establishment of the Blue Warehou Assessment Group (BWAG) in 1997. Prior to 1997, management advice was based on the results of a yield-per-recruit analysis (Smith *et al*., 1994) and from visual examination of trends in catch and in nominal and GLM-standardized catch-rates (Smith and Wayte, 2004).

The 1997 and 1998 assessments of blue warehou were based on the application of a fleet-disaggregated Virtual Population Analysis to catch-at-age and standardized fishing effort data (Punt, 1998). These assessments involved three fleets (‘west trawl’, ‘east trawl’ and ‘non-trawl’). From 1999 onwards, assessments of blue warehou (Punt, 1999, 2000; Punt and Smith, 2005; Punt, 2006) have been based on the ‘integrated analysis’ approach (e.g. Methot, 2006; Haist *et al*., 1993; Smith and Punt, 1998). This approach forms the basis for the bulk of the assessments of species in Australia’s South East and Southern Shark Fishery (Smith *et al*., 2001; Tuck and Smith, 2005). Information on catches, discard rates, catch-rates, and the length/age structure of the discards and the landed catch were included in the 1999, 2000, 2004 and 2005 assessments. The last four assessments of blue warehou were based on four (rather than three) fleets (‘west trawl’, ‘east trawl’, ‘non-trawl’ and the Tasmanian meshnet fishery).

12.2.2 Summary of the 2005 fishery

The landings east and west of Bass Strait during 2005 were 27t / 19t (Commonwealth / Tasmania) and 289t respectively. The landed catch in the east is the lowest since 1986 which reflects a pattern of declining catches that started in the late 1990s when catches in the east were close to 700t (excluding catches by the non-trawl fleet). The landings in the west during 2005 were the highest since 1998, although the total catch in the west (i.e. including discards) is less than for 2004, primarily because of a lower discard rate during 2005 (however, given the considerable uncertainty in estimates of discard rates, the discard rates for 2004 and 2005 are, in fact, not statistically different). The standardized catch-rates in the east continued their downward trend, with the standardized catch-rate for 2005 being the lowest on record. In contrast, the

standardized catch-rate in the west recovered to levels not seen since the mid-1990s. However, the given the lower discard rate for 2005, the catch-rate in the west for 2005, when expressed as total catch-per-unit-effort, is lower than that for 2004.

12.2.3 Modifications to the 2005 assessment

A number of modifications have been made to the data and model on which the 2005 assessment (Punt, 2006) was based.

a) The data for 2005 and some of the data for 2006 are included in the assessment (see Sections 12.3.1–12.3.4).
b) The age-reading error matrix has been updated (see Section 12.3.4).
c) Alternative indices of abundance based on the ISMP programme and the data from the 2005 industry-based survey are included in the assessment (see Sections 12.3.2.2 and 12.3.6).
d) The assessment is based on Stock Synthesis 2 rather than the model on which the 2005 assessment was based (see Sections 12.4.1 and 12.4.2 and Section 12.9, Appendix A).

12.3 Data available for assessment purposes

There are many sources of data for blue warehou. These include values for biological parameters, landed catches, discard rates (defined here as the ratio of the discard catch (in mass) to the total (i.e. discarded and landed) catch), catch-rates, length-frequencies for the landed and discarded catches, and age-length keys.

As was the case for the 1999, 2000, 2004 and 2005 assessments, the following four 'fleets' are considered in the assessment:

a) the otter trawl fishery in zones 10, 20 and 30 of the SESSF (denoted 'east trawl'),
b) the otter trawl fishery in zones 40, 50 and 60 of the SESSF (denoted 'west trawl'),
c) the meshnet fishery off Tasmania (denoted 'Tas meshnet'), and
d) the Commonwealth gill-net fishery (denoted 'non-trawl').

These four 'fleets' were selected by BWAG after consideration of their catch length-frequency distributions, and the likely impact of management measures (e.g. the Tasmanian meshnet fishery is not covered by the *TAC*s set by AFMA). The following sections outline the data available for assessment purposes. The bulk of the analyses are conducted assuming that the 'west trawl' fleet is fishing a different biological stock from the other three fleets.

Some of the previous assessments have been based on the assumption of a 'biological year' lifecycle (defined as 'May – April', based on spawning starting in winter) as well as that of a calendar year lifecycle (birth at the start of January each year). The results of assessments based on these two lifecycles have been qualitatively the same (e.g. Punt and Smith, 2005). In common with the 2005 assessment, therefore, this assessment only considers a calendar year lifecycle.

12.3.1 Catches

Information on catches is available from the SEF1 and GNO1 logbooks, the SEF2 and SAN2 catch validation databases, from State reporting systems, and from historical records (for the years prior to 1986 (SEF1) and 1997 (GNO1) – data for only a few months of 1985 are included in the SEF1 database). Blue warehou are closely related to spotted warehou and mixed catches do occur. Early catch statistics were recorded for all warehou species combined, commonly referred to as 'Tassie trevally'. Comparisons between logbook and 'verified' catch data in the late 1980s also indicated problems with correct recording of each species. However, consideration by SEFAG of the two data sets indicated that records in the SEF1 logbook gave the best data on individual species.

12.3.1.1 Trawl catches - Commonwealth

For the Commonwealth trawl fishery, the annual catches by fleet were extracted from the SEF1 database. These catches were then rescaled so that the total (over fleet) catch by species equals the total validated catch based on the SEF2 records, i.e.:

$$\tilde{C}_y^f = \tilde{C}_y^{f,\mathrm{SEF1}} \frac{\tilde{C}_y^{\mathrm{SEF2}}}{\sum_{f'} \tilde{C}_y^{f',\mathrm{SEF1}}} \tag{1}$$

where $\tilde{C}_y^f$ is the catch (in mass) by fleet *f* ('east trawl' and 'west trawl') during year *y* used in the analyses,

$\tilde{C}_y^{f,\mathrm{SEF1}}$ is the catch (in mass) by fleet *f* during year *y* recorded in the SEF1 database, and

$\tilde{C}_y^{\mathrm{SEF2}}$ is the catch (in mass) during year *y* recorded in the SEF2 database.

Ideally Equation 1 should have been applied by fleet. Unfortunately, it remains currently infeasible to link the SEF2 records with the SEF1 records to enable an appropriate comparison to be made (the SEF2 records are by port and vessel callsign whereas the SEF1 records are shot-by-shot).

SEF2 catches are only available from 1992. It is therefore not possible to apply Equation 1 directly for the years prior to 1992. For the purposes of the analyses of this report therefore, the catches prior to 1992 have been adjusted using the formula:

$$\tilde{C}_y^f = \tilde{C}_y^{f,\mathrm{SEF1}} \frac{\sum_{1992 \le y \le 1998} \tilde{C}_{y'}^{\mathrm{SEF2}}}{\sum_{1992 \le y \le 1998} \sum_{f'} \tilde{C}_{y'}^{f,\mathrm{SEF1}}} \tag{2}$$

The adjustment factor for the pre-1992 catches is 1.17.

12.3.1.2 Non-trawl catches

The catches by the non-trawl fleet for the years 1997–2005 were extracted from the GN01 logbook records. These catches were rescaled to match the SAN2 catches using Equation 1 and divided by 0.92 to account for an 8% discard rate (evident from the observer data). The non-trawl catches for 1986–96 were provided by Dr David Smith (CMAR, pers.commn).

12.3.1.3 State catches

Catches of blue warehou are made off the northwest and southeast of Tasmania, but the bulk of the catch is taken off the southeast (82% - 1996–2002; Figure 12.1). Given the lack of data on length-frequency for the Tasmanian catches, and the fact that most of the catch is taken from the southeast of Tasmania, all of the catches off Tasmania are assumed to be taken from the eastern stock.

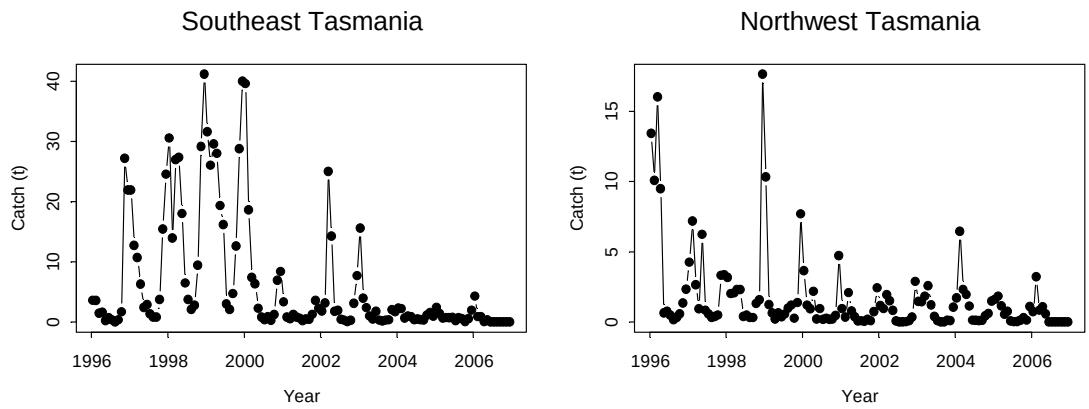


Figure 12.1. Catches of blue warehou recorded in Tasmanian State logbooks.

Catches of blue warehou are recorded in NSW state logbooks. However, the data in these logbooks prior to 2000 contained many fish taken in Commonwealth waters (K. Rowling, NSW Fisheries, pers. commn). The NSW state catches for 2001-5 are assumed not be recorded in the SEF1 logbook and are therefore added to the catch history for the 'east trawl' fleet calculated using Equation 2.

Year	*2001*	*2002*	*2003*	*2004*	*2005*
Catch (kg)	*265*	*303*	*323*	*1630*	*2322*

12.3.1.4 Catches used in the assessment

The catch for 2006 has been set to 600t (western stock) and 150t (eastern stock) based on the advice of the industry members of SlopeRAG (24-25 August 2006 meeting). The catch by the Tasmanian fleet has been set equal to that for 2005. Table 12.1 lists the catches by fleet included in the analyses. In common with the 2005 assessment, the catches by the 'west trawl' fleet are inflated by the observed discard rates.

12.3.2 Catch-rates

Catch-rate data constitute the primary source of information to determine trends in population size for the species in the South East and Southern Shark Fishery. However, the catch and effort data need to be standardized to (attempt to) eliminate the impact of factors other than changes in abundance on trends in catch-rates (Gavaris, 1980; Kimura, 1981; Vignaux, 1994).

12.3.2.1 Catch-rate indices based on logbook data

Catch-rate indices were developed for the 'east trawl', 'west trawl' and 'non-trawl' fleets by fitting a linear model (with normal error structure) to log-transformed catch rate data (Haddon, 2006). This approach has been used widely to standardize catch and

effort data for SESSF species (e.g. Klaer, 1994; Punt *et al*., 2001; Haddon and Thomson, 2005). Different models were selected as 'best' for the 'east trawl' and 'west trawl' fleets using AIC (Haddon, 2006). The 'best' model for the 'east trawl' fleet was:

Log(C/E) = Constant + Year + Boat_name + Month*Zone + Depth*Zone*Month

and that for the 'west trawl' fleet was:

Log(C/E) = Constant + Year + Zone*Boat_name + Zone*Depth + Zone*Month

where year, month, zone, and boat_name are categorical variables. The depth of the catch was transformed from a continuous variable to a discrete variable by dividing the range of depths into 50 m intervals (Haddon, 2006). Only those vessels active in the fishery for more than two years and with median annual catches greater than 4 tonnes were included in the analysis. Catches recorded to have been taken deeper than 400 m were ignored when standardizing the catch and effort data, as were records in which the catch or the effort was zero. These restrictions led to the catch-effort standardization being based 76.96% and 83.96% of the total catches since 1986 for the 'east trawl' and 'west trawl' fleets respectively (Haddon, 2006). The AIC-selected models explained 31.84% and 27.61% of the variance in the catch-effort data, with the bulk of the variance explained by year, vessel and month for the 'east trawl' fleet, and year and vessel for the 'west trawl' fleet. The resulting standardized indices are not markedly different from the geometric means of the catch rates (Figure 12.2).

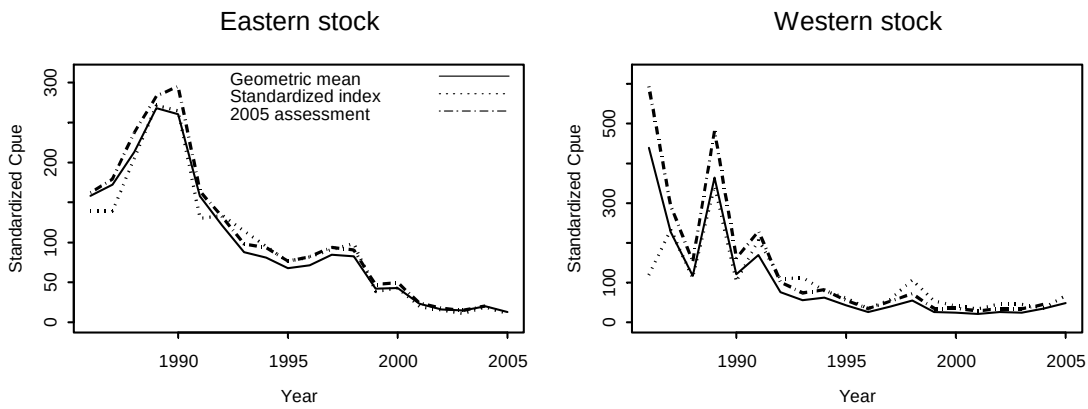


Figure 12.2. Standardized catch-rate indices, geometric mean catch-rates, and the catch-rate indices on which the 2005 assessment was based. Each index is standardized to its mean for improved clarity.

The non-trawl catch-rate indices were supplied by Dr David Smith (CMAR, pers. commn) based on the application of a GLM model to catch and effort data for a subset of the non-trawl fleet. The number of records drops over time. The analyses consequently ignore the data point for the last year of this index (1999).

The standardized catch-rate indices used in the analyses are listed in Table 12.1. The catch-rates indices for the 'west trawl' fleet are inflated by the discard-rates for this fleet because Punt (2006) showed that the discards for the western stock have essentially the same age- and size-structure as the landed catch (i.e. the selectivity ogive for the

discarded catch is the same as that for landed catch) while this is clearly not the case for the eastern stock.

12.3.2.2 Catch-rate indices based on the ISMP programme

Data on catch-rates of blue warehou are available from the ISMP programme. These data can be standardized by applying the delta method (Lo *et al*., 1992; Stefánsson, 1996). The probability of a non-zero catch was modeled using the binomial distribution while the non-zero catch rates were modeled assuming a log-gamma error structure.

The results of the catch-effort standardization (Figure 12.3; Table 12.2) suggest that there are too few targeted shots for the eastern stock to form the basis for a catch-effort standardization. There are sufficient data for the western stock to conduct an analysis (Table 12.2), but the results are fairly imprecise (approximate coefficient of variation of 74%)

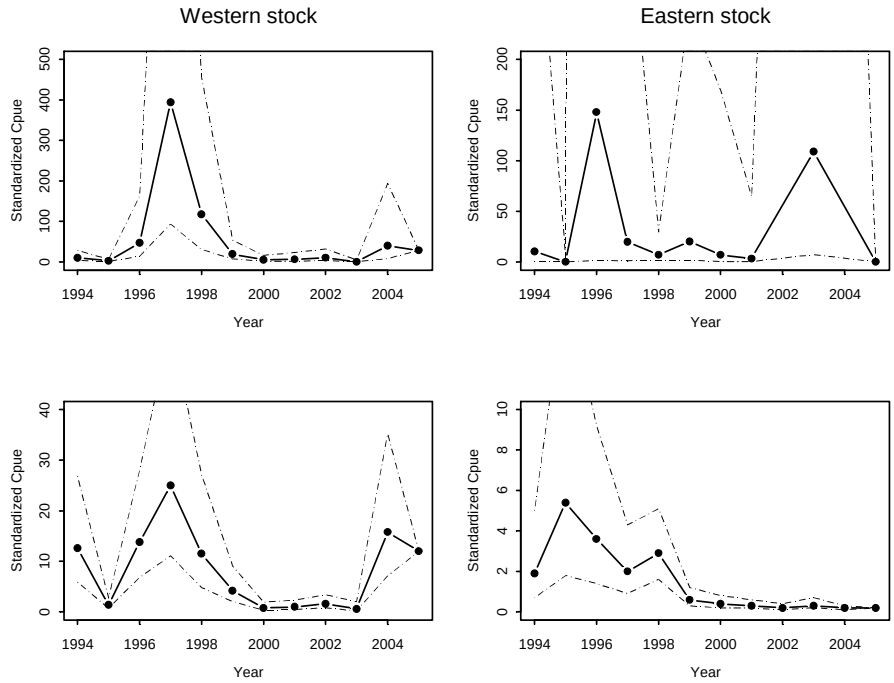


Figure 12.3. Standardized catch-rate indices based on the ISMP programme (estimates and approximate 95% confidence intervals). Results based on the targeted shots are shown in the upper panels and those based on all shots in the lower panels.

The time-trajectories of standardized catch-rate for the western stock from the logbook and ISMP programmes are similar for 1999-2005 when these indices are standardized to the catch-rate for 2005 (Figure 12.4).

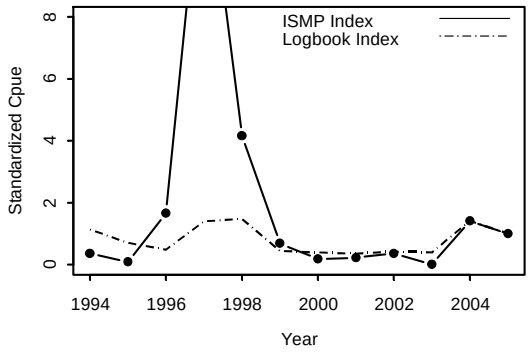


Figure 12.4. Comparison of the standardized catch-rate indices from standardization of the logbook catch and effort data from the standardization of the ISMP catch and effort data.

12.3.3 Discard rates

Information on the fraction of the catch (in mass) that is discarded annually is available from onboard observers. Two observer programmes, the SMP (Liggins, *et al.*, 1997) and the ISMP (Knuckey, *et al.*, 1999) have collected onboard data that can be used to estimate discard rates. The data collected by the observers are estimates by shot of the mass retained and the mass discarded. The discard rate used in this report is the ratio of the mass discarded (summed over all shots by a given fleet in a given year) to the total mass (retained plus discarded). Any records for which the gear code was not bottom trawl and in which the catch did not occur in one of SESSF zones 10, 20, 30, 40, 50 or 60 were ignored when determining discard rates for inclusion in the model. Discard rates by stock are computed by totaling the estimates of discard for each of the zones in which the stock is found (10, 20, and 30 for the eastern stock and 40, 50, and 60 for the western stock) and then dividing by the total (discarded and retained) catch from the stock. The boundary between zones 10 and 20 was set to $37^0$30S for the purposes of these calculations to avoid extrapolating discards between $37^0$15S and $37^0$30S to all of zone 20. The data prior to 1996 are not included in the analyses of this report due to small sample sizes.

The resultant discard rates are listed (by year and fleet) in Table 12.1 along with measures of their precision, expressed as coefficients of variation. The coefficients of variation in Table 12.1 are based on a bootstrap procedure; for each combination of year and stock, 1,000 pseudo data sets were generated by resampling shots at random and with replacement from the actual observer data for the fleet, year and stock under consideration.

12.3.4 Age- and length-frequency data

Length-frequency data are available from port measurers and from onboard sampling. The former generally involve much larger sample sizes than the latter (Table 12.3). In contrast, the onboard sampling programmes provide information on the length-frequencies of the discarded as well as the landed catch. As for the 2005 assessment, the length-frequency and age-composition data included in the assessment are restricted to

those based on at least 100 fish (Table 12.3 indicates the data omitted from the assessment owing to the sample sizes not satisfying this criterion by means of asterisks).

12.3.4.1 Port length-frequencies

The port length-frequencies for a given fleet are constructed from the raw data collected by the measurers using the equation:

$$N_{y,L}^{f} = \sum_{v} \tilde{N}_{y,L}^{f,v} / R_{y}^{f,v} \tag{3}$$

where $N_{y,L}^{f}$ is the number of animals in the component of the landed catch by fleet *f* during year *y* that was measured that are in length-class *L*,

$\tilde{N}_{y,L}^{f,v}$ is the number of animals in the vth sample collected from the landed catch by fleet *f* during year *y* that are in length-class *L*, and

$R_{y}^{f,v}$ is the fraction of the catch of the vth sample collected from the landed catch by fleet *f* during year *y* that was measured.

This approach to constructing catch length-frequencies is based on the assumption that the samples for a given fleet are a simple random sample of the catch of that fleet. In principle, this approach to constructing length-frequencies could be generalized so that, for example, port-specific length-frequencies are constructed and these then weighted by the port-specific contribution to the overall catch. Any reported catches of fish smaller than 24cm are assumed to be errors and are discarded.

Figure 12.5 plots the port-based length-frequencies from the ISMP database for 1991–2005. Results are shown in Figure 12.5 for the three key ports (Eden, Lakes Entrance, and Portland) and for three SESSF zones (East A, East B, and West). Eden, Lakes Entrance and Portland constitute the majority of the length-frequency records. The other ports for which notable amounts of data are available are Hobart, Beachport, and Bermagui. As expected, the length-frequencies for the western stock are based almost exclusively on the data for vessels from Portland. The picture in the east is less clear because: a) the length-frequencies for vessels based in Eden and those based in Lakes Entrance often differ substantially, and b) there is not a clear match between the port-based length-frequencies by port and the port-based length-frequencies by SESSF zone. The port-based length-frequencies on which the analyses of this report are based were constructed as follows: ‘west trawl’ – the port-based length-length-frequencies for vessels from Portland; ‘east trawl’ – the port-based length-frequencies for vessels from Eden (1998–2005) and data collected at sea and in port from Eden-based vessels (1994–97) by the SMP. The latter data are included in the assessment because the sample sizes prior to 1997 in Figure 12.5 are very small. In contrast, the SMP sample sizes for 1994–97 are 2889, 2260, 2833 and 3730 respectively (Table 12.3). The data set ‘west trawl’ starts in 1991 (Figure 12.5). However, data on length-frequency are also available for the western stock for 1987 and 1988 based on sampling during a research project (Smith *et al*., 1995).

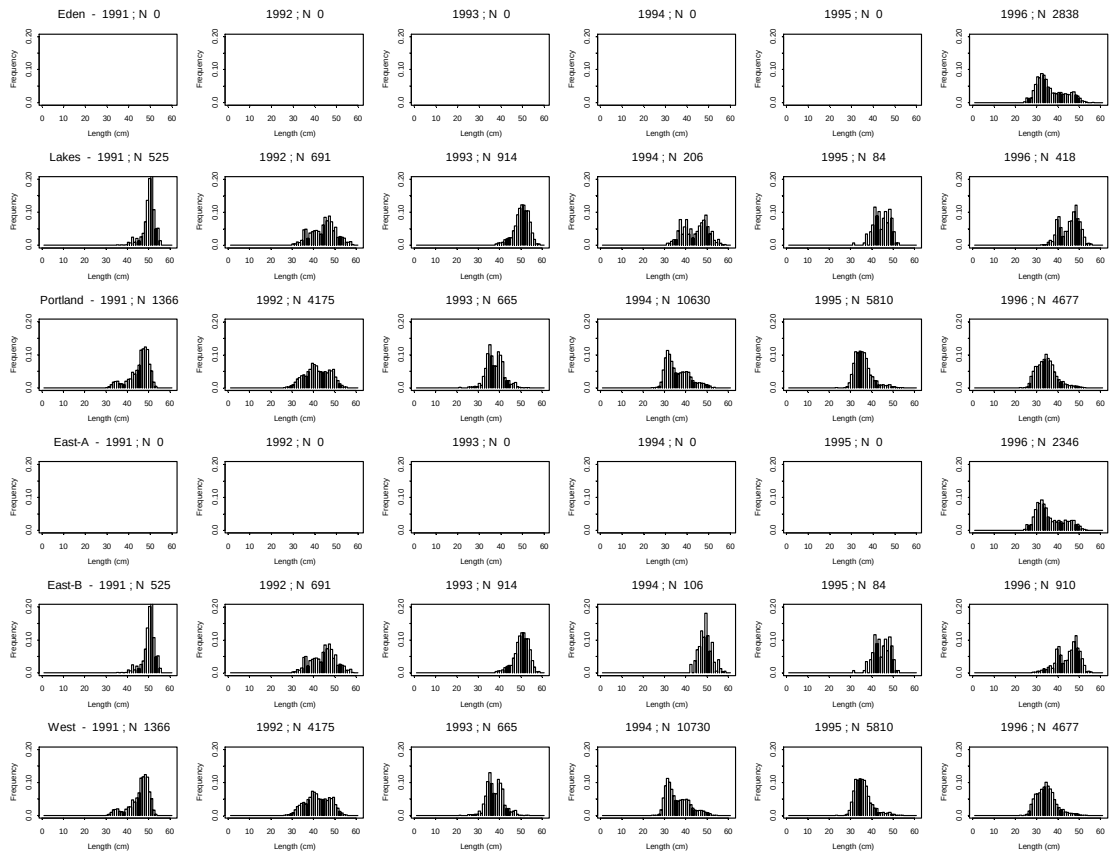


Figure 12.5a. Port-based length-frequency data from the SMP and ISMP for blue warehou. Results are shown by port of landing (Eden, Lake Entrance, Portland) and by SEF zone (East A, East B, and West).

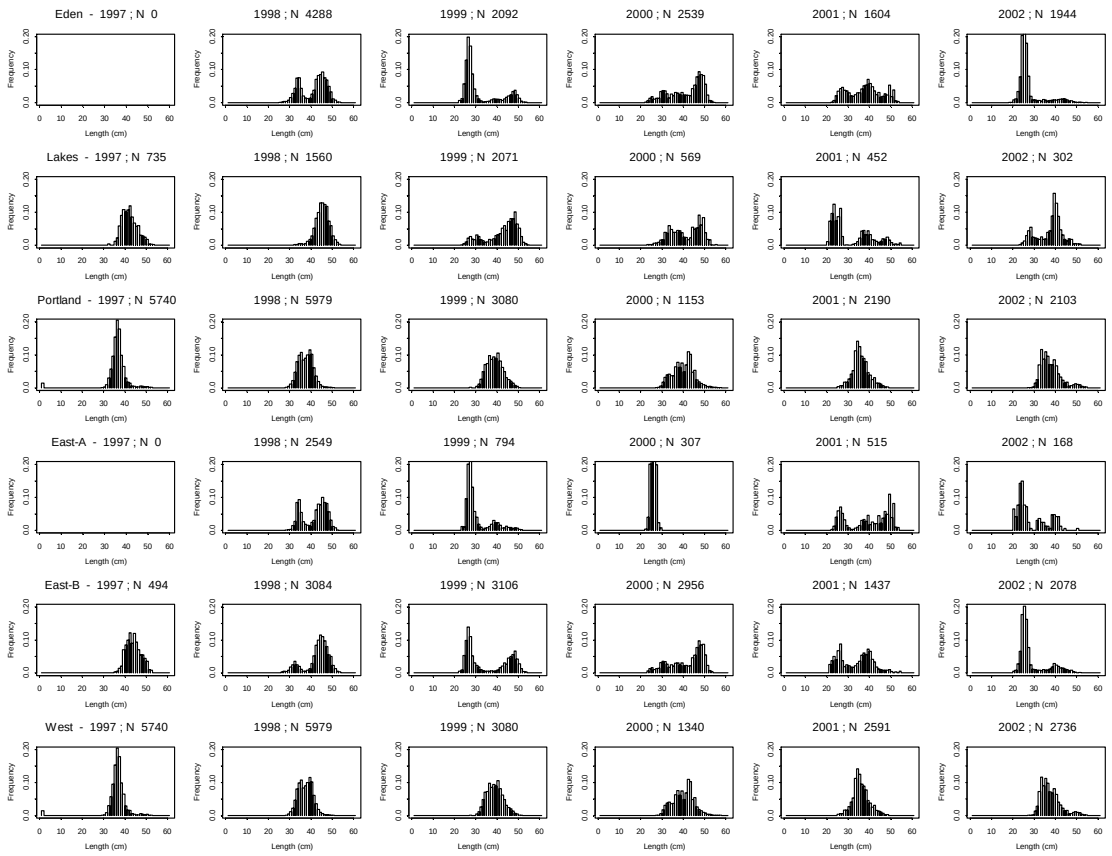


Figure 12.5b. Port-based length-frequency data from the SMP and ISMP for blue warehou. Results are shown by port of landing (Eden, Lake Entrance, Portland) and by SEF zone (East A, East B, and West).

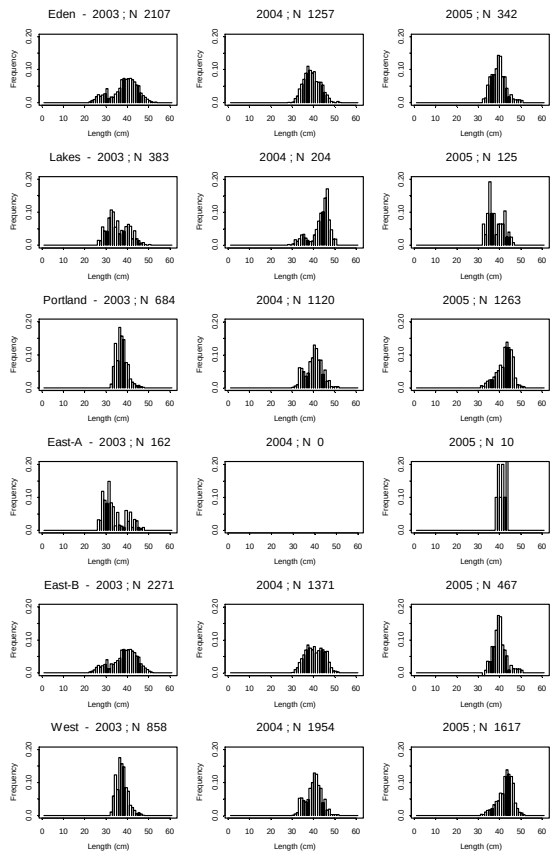


Figure 12.5c. Port-based length-frequency data from the SMP and ISMP for blue warehou. Results are shown by port of landing (Eden, Lake Entrance, Portland) and by SEF zone (East A, East B, and West).

The length-frequency data for Tasmania for 1997–99 were supplied by Jeremy Lyle (TAFI, pers. comm.). Table 12.3 lists the sample sizes on which the analyses are based and which are used when weighting the data during model fitting.

12.3.4.2 Discard length-frequencies

The proportion of the trawl catch which is discarded by length-class can be determined from the onboard length-frequency data using Equation 3. Information on discards is available for the years 1993–2005. However, the discard data (discard rates and length-frequencies) for the years 1993–95 are ignored (Table 12.1) because they are based on small sample sizes (Table 12.3), were collected from a pilot programme, and appear anomalous in several respects.

12.3.4.3 Age-composition data

Over 4,000 blue warehou have now been aged using sectioned (rather than whole) otoliths by the Central Ageing Facility in Queenscliff. Unlike results from ages estimated using whole otoliths, it now appears possible to track age classes between years. Table 12.3 lists the sample sizes for each year and stock.

Punt *et al.* (2005) developed an approach to estimate the extent of age-reading error by fitting a model based on the assumption that the coefficient of variation of age-reading error is quadratic in terms of age to the results of inter-reader calibration experiments (i.e. from the age-estimates for otoliths that were read by more than one reader or twice

by the same age-reader). For the purposes of this assessment, the model was fitted to two data sets in which otoliths (both stocks) were read multiple times (Kyne KrusicGolub (MAFRI, pers. commn)): a) 1122 otoliths read twice by the primary reader and b) 113 otoliths read once by the primary reader and once by the secondary reader. Simulations by Punt *et al.* (2005) suggest that 1122 otoliths is more than sufficient to determine the relationship between age and the coefficient of variation of age-reading error adequately while 113 otoliths is marginal in this regard. Figure 12.6 shows diagnostic plots based on the fit of this model to the two data sets: upper panels – coefficient of variation and standard deviation of age-reading error versus age; lower panels - observed number of animals for each combination of age based on the first age-reading and age based on the second age-reading with the model prediction. The model clearly fits the data well although uncertainty is very high for the smaller data set.

The results for the two data sets are remarkably similar suggesting that the age-reading error rates for the two age-readers are very similar. The result that the coefficient of variation of ageing error reduces after age 8 is inconsequential for this assessment because the oldest age in the assessment is age 7.

Table 12.4 lists the standard deviations of the age-reading errors. These standard deviations are based on the larger data set.

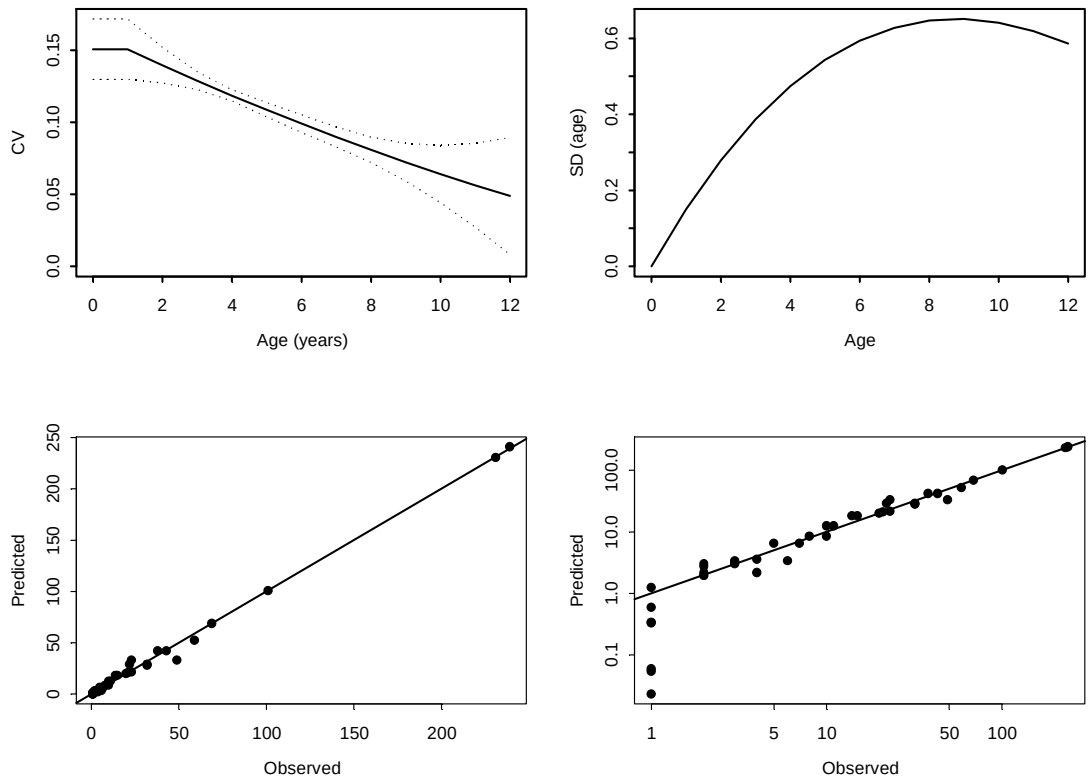


Figure 12.6a. Diagnostic plots for the fit of the age-reading error model of Punt *et al*. (2005) to the data for blue warehou (two readings by the primary reader).

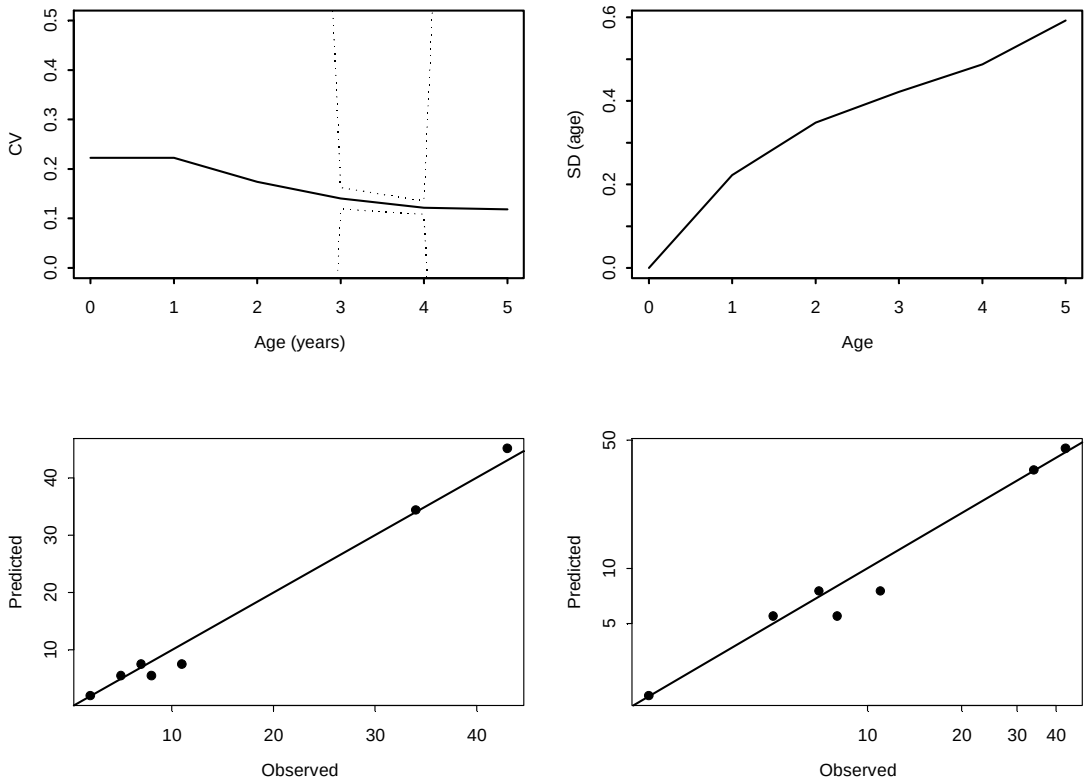


Figure 12.6b. Diagnostic plots for the fit of the age-reading error model of Punt *et al*. (2005) to the data for blue warehou (one reading by each of the primary and secondary reader).

12.3.5 Evaluation of the representatives of the onboard and port-based data

Assessments of the two stocks of blue warehou (particularly that of the eastern stock) have been very uncertain historically. The section therefore examines the length data on which the assessments are based to assess whether there is evidence for non-random sampling.

Figure 12.7 compares the SEF2 catches for the major ports of Eden, Portland, Lakes Entrance, and Hobart, and for all remaining ports with the weights of fish sampled during port-based and at-sea measuring. In general, there are no indications of major differences between the port-based and at-sea samples and the SEF2 catches, in that most of the samples are taken from the major ports. However, there is a suggestion that boats from Hobart and Lakes Entrance are under-represented in the on-board sampling compared to what would be expected given the amount of fish landed in these two ports. There are more port-based measurements in Lakes Entrance than would be expected given the landings there. Although the sampling is not exactly what would be expected given the SEF2 catches, the observations above are likely inconsequential for the assessment because the assessment is based on data from Portland and Eden only.

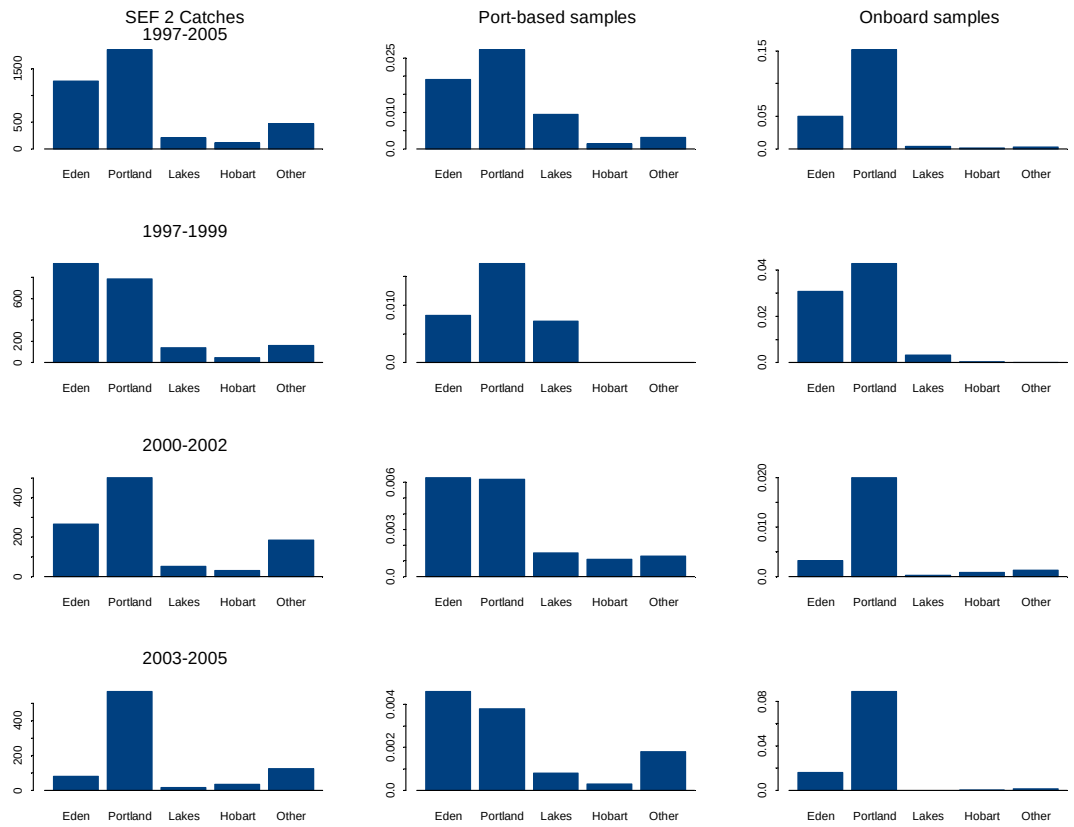


Figure 12.7. SEF2 catches, weight of blue warehou measured in port and weight of blue warehou measured by onboard observers. Results are shown for the period 1997-2005.

Figure 12.8 explores the data further by plotting the fraction of the SEF2 catch by port (Eden and Portland) that is measured by three-month period. There is again little evidence for major discrepancies between the sampling and catches. A final comparison is shown in Figure 12.9. This figure plots the spatial distribution of the catches (based on SEF1 records) and the location of the onboard samples that collected data on blue warehou.

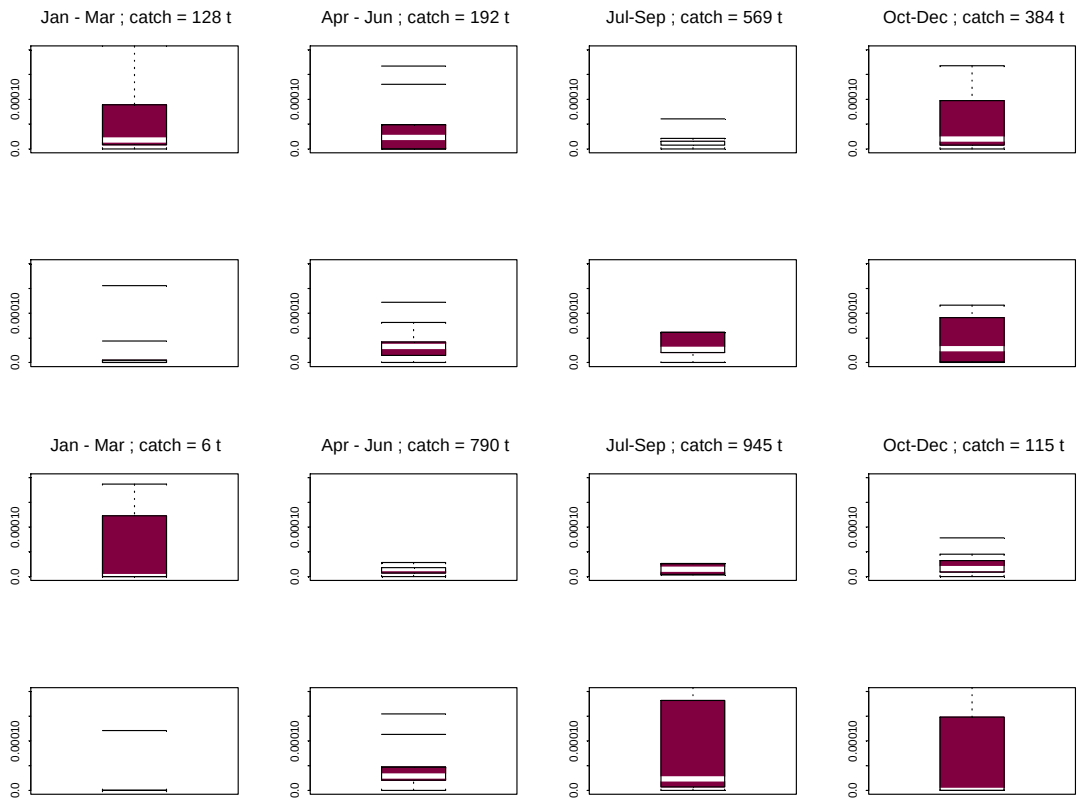


Figure 12.8. Fraction of the total SEF2 catch that is measured in-port and at-sea by three-month period. Results are shown for Eden in the upper panels and in Portland in the lower panels.

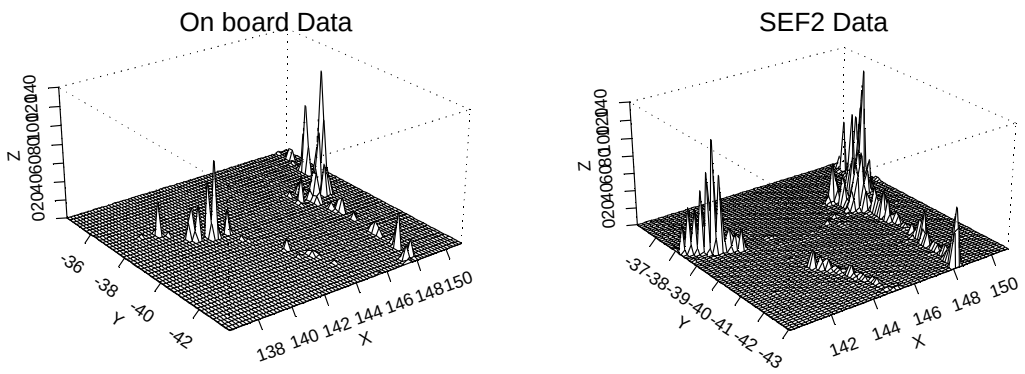


Figure 12.9. Spatial distribution of the observed shots in which blue warehou were recorded and the spatial distribution of the shots in SEF1 logbook that recorded blue warehou. The data plotted cover the years 1997-2005.

12.3.6 2005 Industry-based survey

An industry-based survey was conducted to the west and east of Bass Strait during August-October 2005 (Hudson and Knuckey, 2006). This survey was designed to be similar to that which was conducted in the Great Australia Bight Fishery. It was conducted over three months in five strata (three in the west and two in the east) with the aim that 10 shots would be conducted in each of two months. In principle, the results from this survey could be compared with past catch rates (Hudson and Knuckey, 2006). However, the survey was designed with the aim of optimizing areas and times when the availability/catchability of blue warehou was at its peak. Therefore, it is ideally considered to be the first in a new time-series, rather than a basis to compare with the results of past commercial catch-rates. However, it is possible to include the data from the survey in the assessment if the survey data can be standardized to make these data comparable with past catch rates (to the extent that this is possible).

Haddon (pers. commn) standardized the catch and effort and survey data for four of the five strata (the data for the Beachport stratum could not be used) by fitting a linear model to the logarithms of the catch-rates that occurred in the survey strata. The model fitted was log(C/E)= Year + Vessel + Month. It was impossible to include depth as a covariate in the analysis owing to lack of data. Table 12.5 lists the resulting indices of relative abundance (and their associated coefficients of variation). These indices are fairly imprecise and perhaps even contradictory to some extent. The survey data were included in the stock assessment by treating the indices for the two strata as alternative indices of abundance to that those based on the logbook cpue analysis (i.e. the assessment was conducted without the logbook catch-rate series, but with the indices from the two strata). Indices of abundance are presented in Table 12.5 when the commercial catch and effort after 1997 are ignored. However, assessment results are not reported for these short series because their inclusion in the assessment led to lack of stability in the outputs and problems with model convergence.

12.4 Stock assessment method

12.4.1 Overview of the model and the likelihood function

The 2006 assessment of blue warehou is based on the age-length model Stock Synthesis 2 (Methot, 2006). Stock Synthesis 2 (SS2) is a generalized assessment package based on the integrated analysis paradigm. SS2 can allow for multiple seasons, areas and fleets although most applications are based on a single season and area. Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterized in terms of the steepness of the stock-recruitment (h), the average recruitment in an unfished state (R_0), and the extent of variability in recruitment relationship (σ_R). SS2 allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS2 are estimated by fitting it to data on catches, catch-rates, catch length-frequencies, survey length-frequencies, mean lengths-at-age, and conditional age-at-length data. The model on which the 2004 and 2005 assessments of blue warehou were based is, in many ways, a special case of SS2. Appendix A (Section 12.9) compares SS2 and the model on which the 2005 assessment

was based. The runs in Appendix A (Section 12.9) are not meant to be definitive, but rather to provide the basis for identifying the differences between SS2 and the 2005 assessment.

Appendix A (Section 12.9) does not explore a major difference between the model on which the 2005 assessment was based and SS2, namely that SS2 includes a stock-recruitment relationship and hence explicitly estimates the virgin spawning biomass, B_0. In contrast, B_0 had to be estimated externally to the model during the 2005 assessment. Punt (2006) noted that the lack of a stock-recruitment relationship and hence a unique estimate of B_0 was potentially a major problem when applying the Tier 1 rules to blue warehou. However, a potential concern with SS2 is that it requires estimates of catches for the years before 1986 (see Table 12.6).

Table 12.6 outlines the structural assumptions of the assessments for the two stocks. These assumptions mimic those on which the 2005 assessment was based, but reflect the nature of SS2 (see Table A1 of Appendix A, Section 12.9).

12.4.2 Parameter estimation

In principle, it is possible to estimate the values for all of the parameters of the model, but paucity of data precludes this in practice (see Table 12.7 for the list of estimated parameters). Thus, for example, the rate of natural mortality, *M*, is pre-specified rather than being estimated. The value for *M* in the reference case assessment is set equal to 0.45yr^{-1} and sensitivity is explored to choices for *M* of 0.35yr^{-1}, and 0.55yr^{-1}. Similarly, the extent of variation in recruitment, σ_r, is taken to be 1 and the steepness of the stock-recruitment relationship is set to 1, both for consistency with assumptions made during the 2005 assessment. Sensitivity tests explore the impact of different values for these parameters. Maturity is assumed to be related to length by a logistic curve with 50 and 95%iles of 33.4 and 42.9 cm (Knuckey and Sivakumuran, 2001).

The multinomial sample sizes for the length-frequency data are tuned so that these match (on average) the effective sample sizes. Within each data series, years are weighted in proportion to the number of fish actually measured. The sample sizes for the age-length keys are set to 0.05 of the number of animals actually aged.

12.4.3 Calculating the RBC

The steps involved in computing the Recommended Biological Catch for 2007 (by stock) using the Tier 1 rules are:

a) Determine the relationship between exploitation rate and spawning biomass, where the relative exploitation rates among the various fleets are based on the exploitation rates estimated for 2006.
b) Find the exploitation rates so that spawning biomass is a pre-specified fraction of that in an unfished state.
c) Determine the depletion of the spawning biomass at the start of 2007.
d) Determine the correction factor (if needed), and multiply the exploitation rates calculated at step 2 by this correction factor.

e) Multiply the numbers-at-age in the middle of 2007 (i.e. the numbers at age at the start of 2007 less half of natural mortality) by the exploitation rates calculated at step d).

Three variants of the Tier 1 rules are applied depending on specifications for the target spawning biomass and the depletion at which the exploitation rate begins to be reduced to zero (all variants set the exploitation rate to zero if the stock is assessed to be depleted to be 20% of B_0):

a) 20-48-48; a target stock size of 48% of B_0, with the exploitation rate dropping off once the stock drops below the target level.
b) 20-40-48; a target stock size of 48% of B_0, with the exploitation rate dropping off once the stock drops below 0.4 B_0.
c) 20-40-40; a target stock size of 40% of B_0, with the exploitation rate dropping off once the stock drops below the target level.

12.5 Results and discussion

12.5.1 Model selection

The first step in the assessment is to determine the implications of the changes to the data, and hence the selection of a "reference case" analysis. Figure 12.10 shows the time-trajectories of spawning biomass (in absolute terms and relative to B_0) and recruitment for an assessment based on the data used in the 2005 assessment ("2005 data" in Figure 12.10), an assessment in which the 2005 data are added to the assessment[5] ("New data" in Figure 12.10), a variant of "New data" in which account is taken of age-reading error using the standard deviations in
Table 12.4 ("Ageing error" in Figure 12.10), and an analysis with the 2005 data, the revised age-reading error model, and a maximum age of 12 years ("Ref" in Figure 12.10).

The results in Figure 12.10 show that allowing for ageing error, adding the 2005 data, and extending the maximum age from age 7 to age 12 has no major impact on the results of the assessment. The fits of the two "reference case" models to the catch-rate data are good, as would be expected given the high weight assigned to these data (Figure 12.11). However, the fit to the discard data for the eastern stock remains poor and the effective sample sizes for the length-frequency data are much larger than the input sample sizes (Figure 12.11). The input sample sizes were therefore adjusted (tuned) until the effective sample sizes were roughly comparable with the input sample sizes (Figure 12.12). Although the effective sample sizes for these tuned assessments are more comparable with the input sample sizes, the results of the tuned assessments, in terms of time-trajectories of spawning biomass and recruitment, are qualitatively identical to those for the "reference case" assessments (Figure 12.13).

[5] The 2005 age, length and commercial catch-rate data – not the ISMP indices or the survey data.

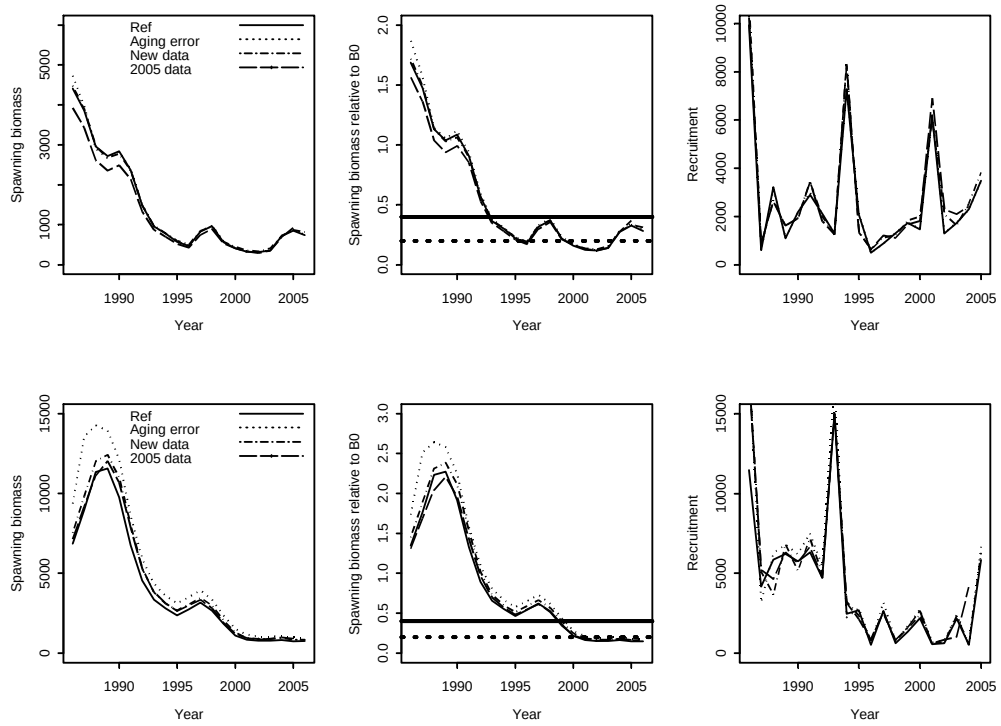


Figure 12.10. Time-trajectories of spawning biomass (in absolute terms and expressed relative to B_0) and recruitment for four assessments. The results for the western stock are shown in the upper panels and those for the eastern stock in the lower panels.

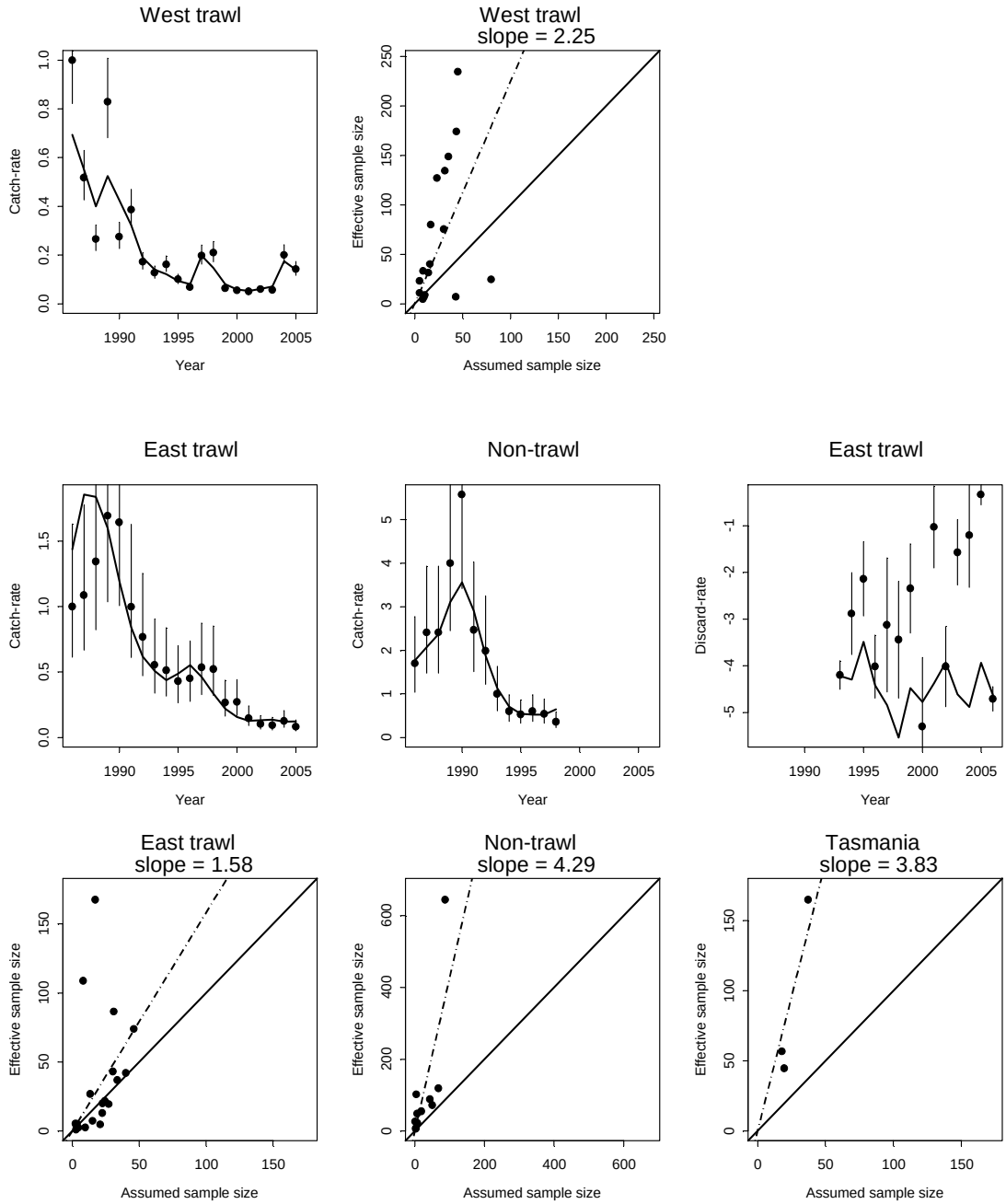


Figure 12.11. Diagnostic statistics (fits to the catch-rate and discard data and the relationship between the effective and input sample sizes for the length-frequency data) for the "reference case" analysis of Figure 12.10

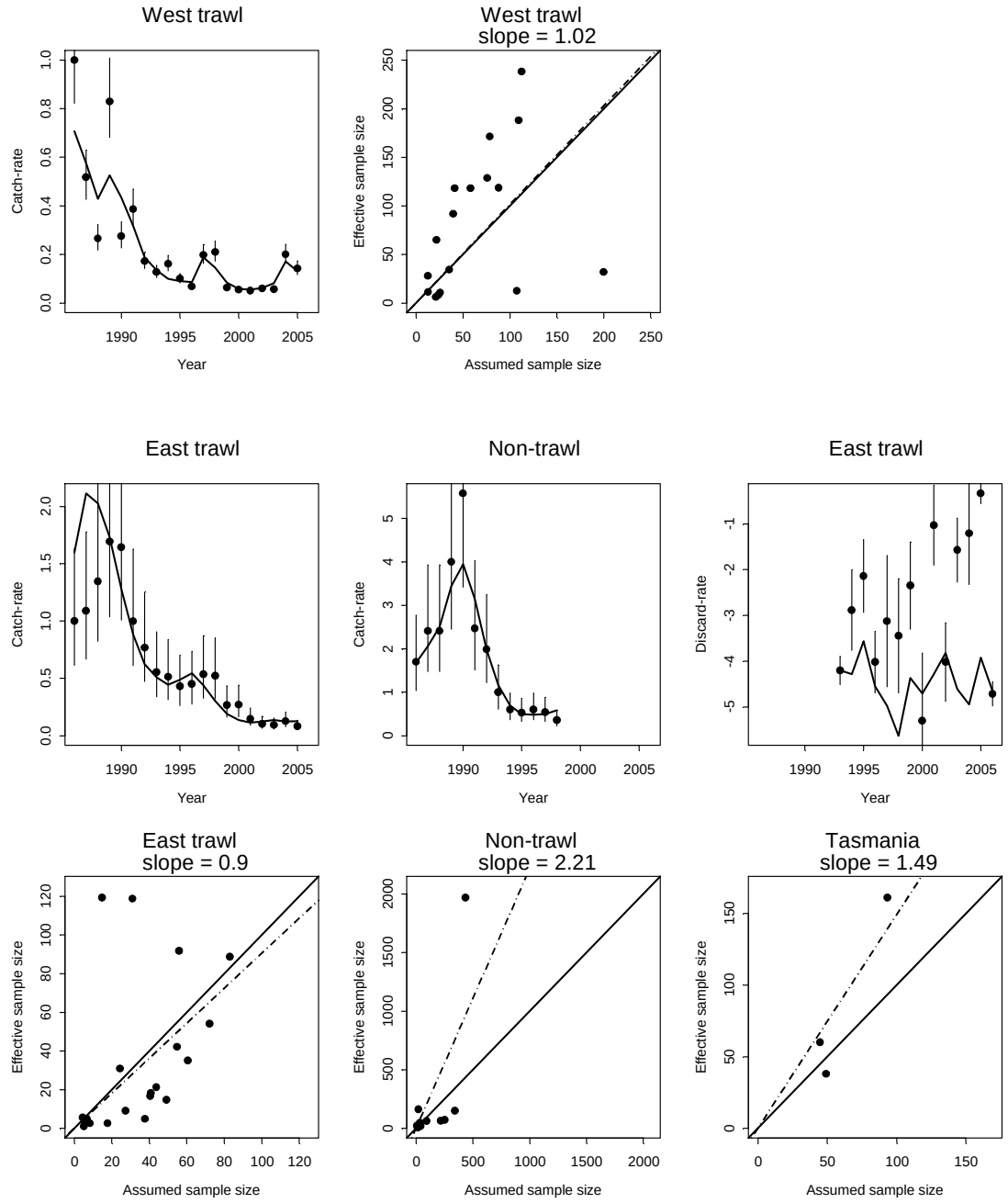


Figure 12.12. Diagnostic statistics (fits to the catch-rate and discard data and the relationship between the effective and input sample sizes for the length-frequency data) for the "tuned reference case" assessment.

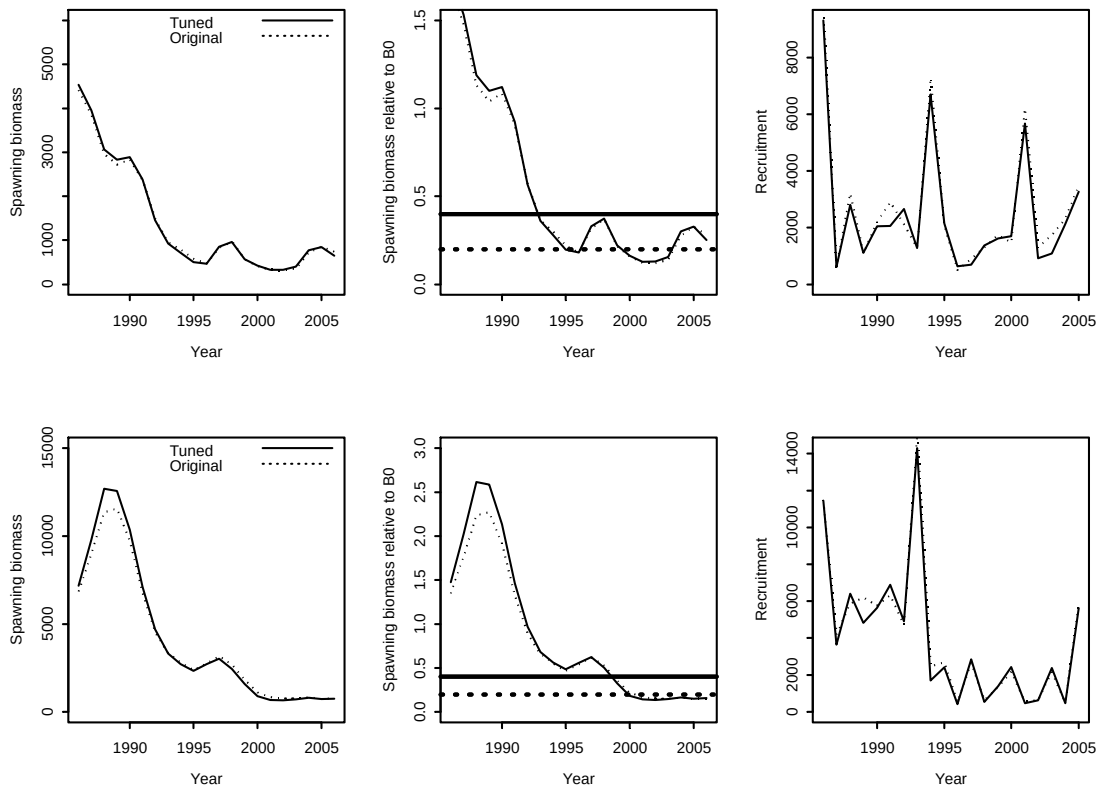


Figure 12.13. Time-trajectories of spawning biomass (in absolute terms and expressed relative to B_0) and recruitment for the "reference case" assessment and a variant of this assessment in which the input sample sizes are tuned. The results for the western stock are shown in the upper panels and those for the eastern stock in the lower panels.

12.5.2 Including alternative indices of abundance

Figure 12.14 examines the sensitivity of the results to including the index of abundance based on the ISMP programme (western stock only) and to replacing the trawl catch-rate series by catch-rate series in which the 2005 data point is based on the results of the 2005 industry-based survey (both stocks). Including the index based on the ISMP programme in the assessment of the western stock has no noticeable impact on the results of the assessment. This is not surprising because this index is imprecise (Table 12.2) and because it mimics the commercial catch-rate series for the 'west trawl' fleet closely in recent years (Figure 12.4). The results for the eastern stock do not change markedly if the 'survey index' is included in the assessment, although there is a slight upward trend in abundance due to a strong 2003 cohort (Figure 12.14).

In contrast to the situation for the eastern stock, including the 'survey index' in the assessment for the western stock changes the trend in abundance for recent years quite noticeably. Figure 12.15 shows the fit of the model to the two survey indices ('Main Drag' and 'Port MacDonell') for the western stock. The model is not able to mimic the marked increase in abundance implied by the survey catch-rate for the 'Main Drag' stratum, nor the reduction in abundance implied by the survey catch-rate for the 'Port MacDonell' stratum.

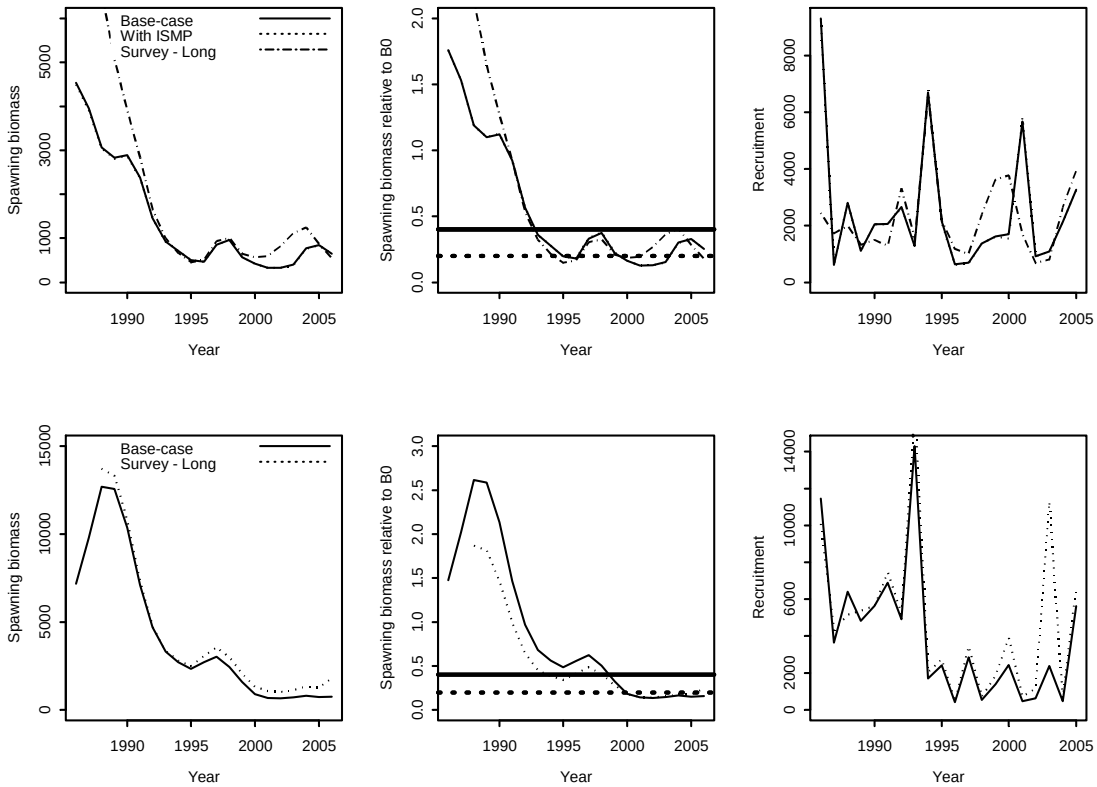


Figure 12.14. Time-trajectories of spawning biomass (in absolute terms and expressed relative to B_0) and recruitment for the "reference case" assessment and variants of this assessment in which the index of abundance included in the assessment is changed.

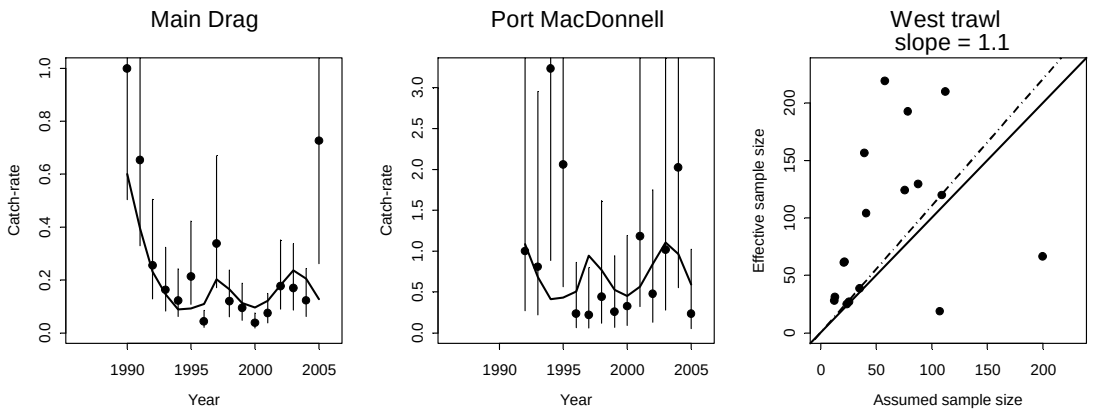


Figure 12.15. Diagnostic statistics (fits to the catch-rate data and the relationship between the effective and input sample sizes for the length-frequency data) for the variant of the assessment for the western stock in which the 'survey index' data are included in the assessment rather than the commercial catch-rate data.

One reason for the downward trajectory of population size after 2004 for the western stock for the 'with survey index' assessment is because this trend is more comparable with the length-frequency data. As the results for the 'reference' analysis and the 'with survey index' analysis are qualitatively different, results are shown for both analyses in the remainder of this document (unless the results for the two analyses are qualitatively – and quantitatively – identical). The two 'reference case' analyses and the 'with survey index' analysis for the western stock are henceforth referred to as the 'base-line' analyses.

12.5.3 The base-line analyses

12.5.3.1 Diagnostic statistics

The model mimics the discard rates for trawl fishery in the east poorly (Figure 12.12). The plots of the fits to the length-frequency data are particularly voluminous. These fits are therefore shown in Section 12.10, Appendix B ('reference case' only) rather than in the main text. The fits to the landed length-frequency data are adequate for the Tasmania meshnet fishery, and for the non-trawl fishery for the years during which the catch by this fleet was substantial. The fits to the data for the east trawl fishery are much poorer than those to the data for west trawl fishery. It is perhaps noteworthy that the fits to the length-frequency data for the west trawl fishery are quite poor in recent years and that the model predictions for 2005 are actually more comparable with the length-frequency distribution obtained during the 2005 industry-based survey.

Figure 12.16 plots the overall selectivity patterns and the probability of a fish being retained as a function of length for the two 'reference case' analyses. The probability of discarding for the Tasmanian meshnet and non-trawl fleets within the model is zero (discard is added to the catches by the non-trawl fleet before the catches are included in the assessment). The Tasmanian meshnet selectivity pattern is dome-shaped whereas that for the non-trawl fleet is focused exclusively on large animals. The difference in selectivity pattern between the Tasmanian and non-trawl fleets is not unexpected given the length-frequencies in Appendix B (Section 12.10) which show that the Tasmanian fleet catches somewhat smaller animals than the non-trawl fleet.

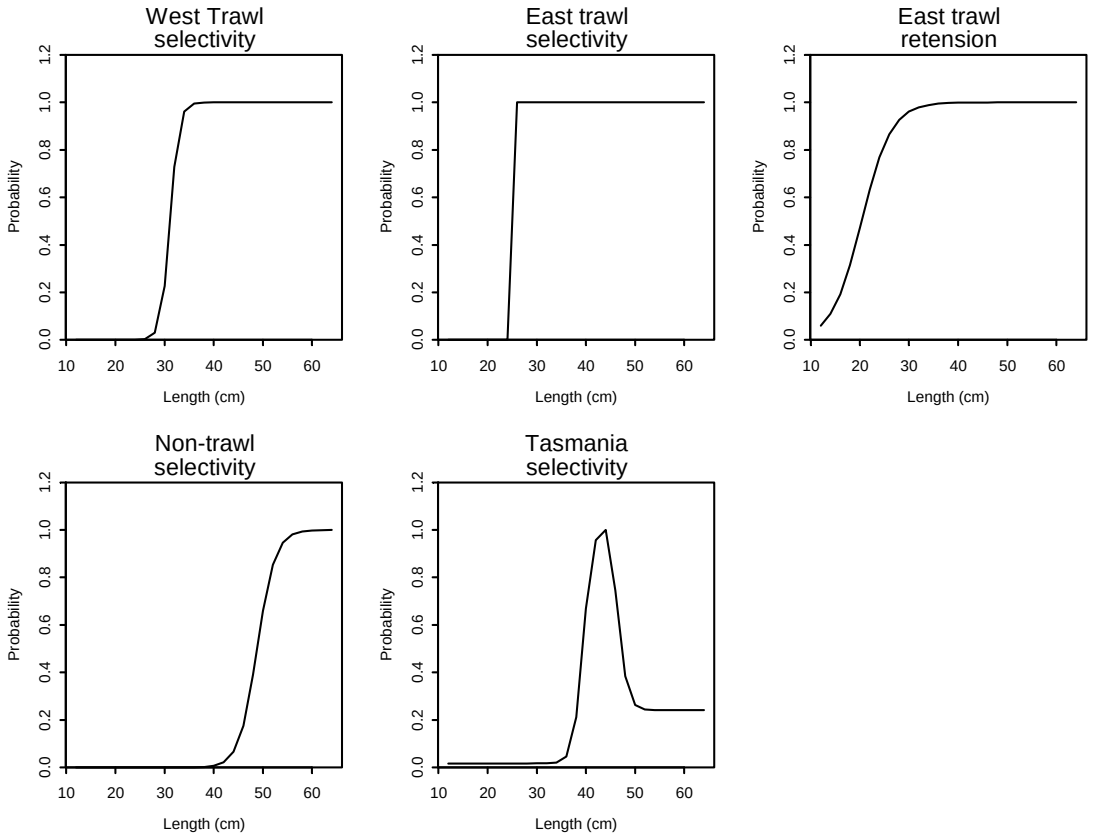


Figure 12.16. Length-specific selectivity patterns and, for the east trawl fishery, the probability of being retained as function of length. The results in this Figure are based on the "tuned reference case" analysis.

12.5.3.2 Assessment outcomes

Figure 12.17 summarizes the results of the two reference case assessments (the results for the 'with survey index' assessments are qualitatively identical) in terms of phase plots. The results of the two 'reference case' assessment are qualitatively identical to the expectations based on the 2005 assessment. Specifically, the 2005 assessment estimated the spawning biomass of the western stock to be depleted in the early 2000s, to have recovered somewhat because of strong recruitment after 2002, and to decline again owing to additional poor recruitment. It also estimated that the eastern stock continues to be at a small fraction of its average unfished level, with no sign of recovery evident. All of these results are supported by the results of the two 'reference case' assessments. The western stock was predicted last year to decline somewhat during 2006 (and 2007). This is supported in the present assessment because of lower catch-rates in 2006 (Figure 12.12) and a lack of evidence for additional good recruitment in the landed length-frequencies (Section 12.10, Appendix B). Sensitivity analyses (not shown here) in which the weight assigned to be landed length-frequencies for the western stock in 2004 and 2005 is increased lead to even more pessimist results for the western stock.

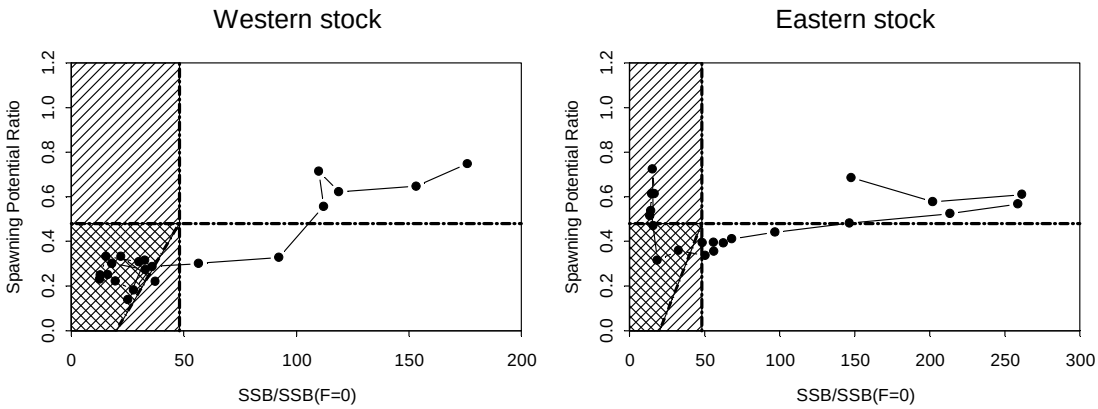


Figure 12.17. Phase plots for the two reference case assessments. The dots denote the annual depletion of the spawning biomass (x-axis) and the spawning biomass-per-recruit corresponding to the fishing mortality rates during the year concerned (y-axis). The lightly shaded area denotes depletion to below the target level (48% of B_0 for this plot) while the heavily shaded area denotes being depleted to below the target level and with a exploitation rate that is predicted not to lead to recovery.

A key difference between the results for the 2005 assessment of the western stock and those of the 2006 assessment is that the western stock is now estimated to be depleted to below the (2005) target level of 40% of the unfished spawning biomass. There are several reasons for this, including the move from the assessment model on which the 2005 assessment was based to SS2 which led to a penalty on fishing mortality being dropped (see Section 12.9, Appendix A), and a more formal basis for estimating B_0. A noted by Punt (2006) "*A potentially major problem associated with applying the Tier 1 rules to blue warehou occurs because the assessment does not include a stock-recruitment relationship and hence does not explicitly estimate* B_0". As a result, three fairly *ad hoc* methods were developed to estimate B_0 for the 2005 assessment and results were presented for each as part of the 2005 assessment. The estimates of B_0 in the present assessment differ noticeably from those based on these three fairly *ad hoc* methods. The following table expresses the B_0 from SS2 as a percentage of those based on two of the three methods used for the 2005 assessment (as the latter are applied to the SS2 output; the third method cannot be applied to SS2 output).

Stock	***"1991"***	***"Recent B_0"***
Western stock		
Reference case	*108.4*	*136.5*
With survey	*108.6*	*202.0*
Eastern stock		
Reference case	*68.2*	*89.7*

For the western stock, the estimate of B_0 from SS2 is similar to the 1991 spawning biomass, but the recent B_0 approach leads to an estimate of B_0 which is much higher than that which is produced by SS2. In contrast, the estimate of B_0 from SS2 for the eastern stock is markedly lower than the estimates based on either of the "recent B_0" or the "1991" approaches.

12.5.3.3 Calculation of the RBC

The RBCs for both stocks for 2007 from the three analyses are 0 because both stocks are assessed to be below $0.2B_0$ (western stock: $0.126/0.106B_0$; eastern stock: $0.156B_0$) (Table 12.8). Given the short lifespan (and high (potential) productivity) of blue warehou, the 2008 RBCs are 146-226t and 54-80t for the western and eastern stocks respectively. The short lifespan and high variation in recruitment for blue warehou implies that a stock can move from above the target level to below the overfished threshold and *vice versa* in a small number (1-2) of years. The likely magnitude of this effect should be examined using a MSE.

It is necessary to place these results for the western stock in context (the results for the eastern stock have been, and remain, very uncertain). The RBCs for 2008 are sensitive to how the Tier 1 rule is specified (Table 12.8). As expected, the RBCs are higher if there was no 48-20 adjustment and if a target level of $0.4B_0$ rather $0.48B_0$ was adopted.

SS2 can be used to estimate F_{MSY} and hence B_{MSY}, rather than relying on proxies for B_{MSY}. The estimate of B_{MSY}/B_0 from the 'reference case' assessment is 0.05. However, this estimate should be interpreted with caution because it is based on the assumption that steepness is 1 and allows animals younger than 2 to be mature. The value of steepness at which B_{MSY}/B_0 is 0.4 is 0.64, which would appear to be low for a species such as blue warehou.

12.5.4 Sensitivity tests

The sensitivity of the results for the three base-line analyses to a variety of modifications to the assumptions of the assessment is examined in Table 12.8. Table 12.8 lists the values for several quantities of potential interest to management:

1. B_0 – the average unfished spawning biomass
2. B_{06} – the spawning biomass at the start of 2006
3. B_{06}/B_0 - the ratio of the spawning biomass at the start of 2006 to B_0.
4. B_{07}/B_0 - the ratio of the spawning biomass at the start of 2007 to B_0.
5. RBC 2007 – the RBC for 2007 based on the Tier 1 rules.
6. ABC 2007 – the RBC for 2007 based on the Tier 1 rules when the adjustment for being depleted is ignored.
7. RBC 2008 – the RBC for 2008 based on the Tier 1 rules if the catch for 2007 is based on the RBC estimated for 2007.
8. ABC 2008 – the RBC for 2008 based on the Tier 1 rules when the adjustment for being depleted is ignored and the catch for 2007 is based on the RBC estimated for 2007.
9. Likelihood – the objective function (the negative of the logarithm of the likelihood function plus any penalty terms) corresponding to the estimates provided.

The results of the assessment are more optimistic (less depleted with a higher 2007 RBC) if natural mortality exceeds the reference case value of $0.45yr^{-1}$, if the extent of variation in recruitment is lower than assumed for the reference case analysis, and if the catches prior to 1986 were twice the values assumed for the reference case analysis. The

results are less optimistic if natural mortality is lower than the reference case value of $0.45yr^{-1}$, if the extent of variation in recruitment is higher than assumed for the reference case analysis, and if the catches prior to 1986 were half those assumed for the reference case analysis and particularly if the steepness is less than 1. Better fits to the data are achieved for the western stock for lower steepness and lower historical catches, but the effect is small (a difference in log-likelihood less than 1). In contrast, a lower value for *M* and steepness leads to significantly better fits to the data for the eastern stock. Both of these sensitivity tests lead to less optimistic results and a 0 RBC for both 2007 and 2008 for the eastern stock.

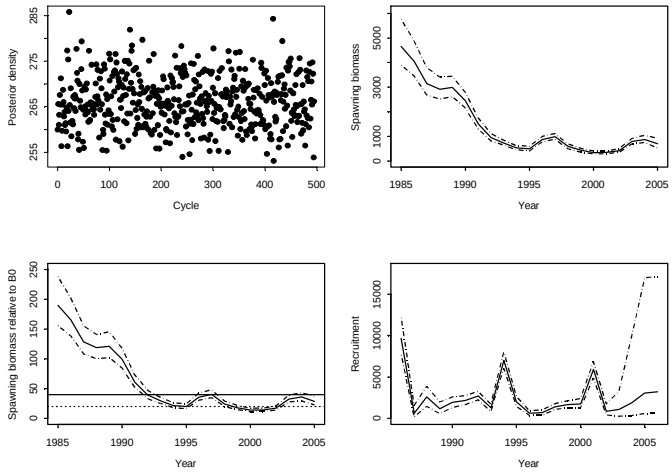
Table 12.8 examines whether the status of the western stock is due to the use of both survey strata when conducting the 'with survey index' assessment or whether this is due to the inclusion of the length-frequency data for 2005. The results suggest that a non-zero RBC for 2007 occurs only if the data for the 'Port MacDonell' stratum and the length-frequency data for 2004 and 2005 are ignored (row 'Main Drag Only; No 2004&05 LF" in Table 12.8).

Figure 12.17 shows the Bayesian posterior distributions for the time-trajectories of spawning biomass (in absolute terms and relative to B_0) and recruitment, and the trace for the objective function. These posterior distributions were determined by applying the MCMC algorithm with 1,000,000 cycles, ignoring the first 500,000 as a burn-in period and thinning the remaining chain by selecting every 1000th parameter vector from the posterior.

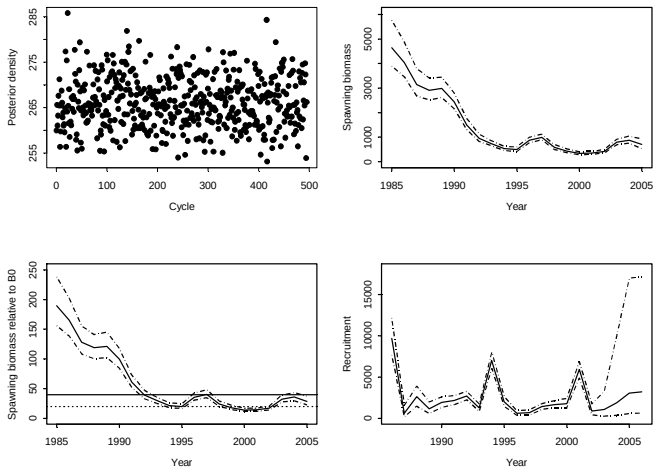
There is evidence for lack of convergence of the MCMC algorithm for the eastern stock (Figure 12.18c). Problems with convergence of the MCMC algorithm when SS2 is applied in which the model includes dome-shaped selectivity are, however, not uncommon. Given the trace in Figure 12.18c, there is no way that a reliable posterior can be obtained without simplifying the model (perhaps substantially).

In contrast to the situation for the eastern stock, the traces of the posteriors for the western stock (Figure 12.18a and Figure 12.18b) do not show evidence for a lack of convergence. The posteriors show that there is considerable uncertainty regarding recent recruitment and that current biomass remains very imprecisely determined. For example, even though the best estimate of 2007 depletion is less than 0.2, the probability is non-zero that the spawning biomass is above $0.4B_0$.

(a) Western stock (reference case)



(b) Western stock (‘with survey index’)



(c) Eastern stock

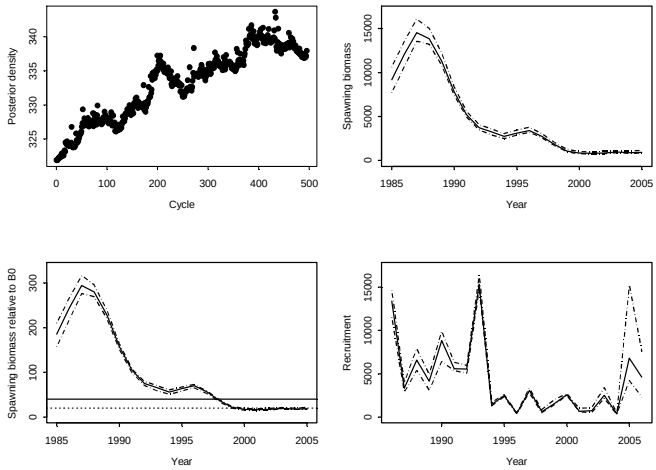


Figure 12.18. Posterior distributions for the time-trajectories of spawning biomass and recruitment and the trace for the objective function

Figure 12.19 highlights the uncertainty associated with the assessment further. This figure shows the posterior distributions for B_0 and the spawning biomasses in 1991, 2006 and 2007. The results in Figure 12.19 indicate, as expected, that the spawning biomass is estimated best for the years for which data are available (1991 and 2006) while projections that rely on as yet unmonitored recruitments, are very imprecise. One result of the imprecision associated the 2007 abundance is that the posterior distribution for the 2007 RBC includes a non-zero probability of an RBC of 200t and higher, even for the most conservative of the variants of the Tier 1 rule (20-48-48). A set of projections under the 20-48-48 variant of the Tier 1 rule was conducted (2007-12). The posterior distributions for 2012 spawning stock biomass, depletion and RBC are extremely broad. This is not unexpected given that there are only a few age-classes in the stock of blue warehou, so the spawning stock biomass in 2012 consists almost completely of year-classes that have yet to be spawned.

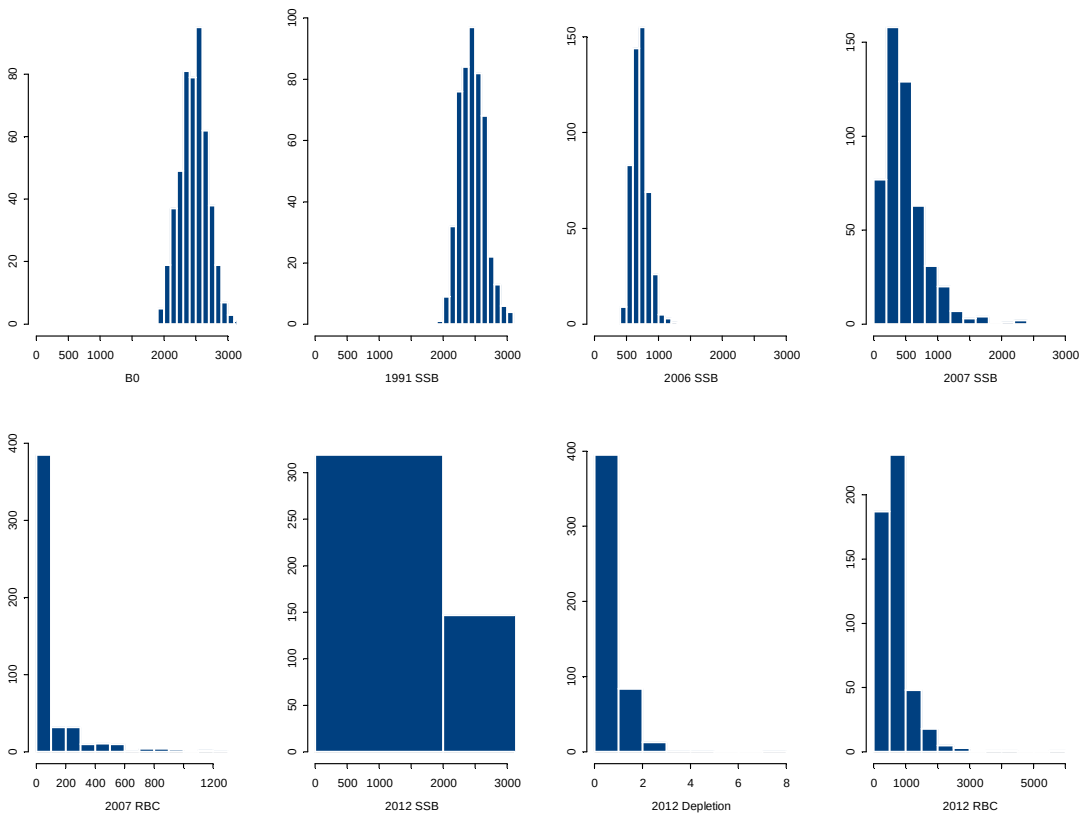


Figure 12.19. Posterior distributions for B_0, the spawning biomasses for 1991, 2006, and 2007, and the 2007 RBC under the 20-48-48 variant of the Tier 1 rule. The results of projections under the 20-48-48 variant of the Tier 1 rule are summarised by the posterior distributions for spawning biomass in 2012, the 2012 depletion and the 2012 RBC.

12.6 Further work

a) Consideration should be given to including sex-structure into the population dynamics model. Although the length-frequency data are not sex-specific, much of the recent ageing data include the sex of the animal.
b) The fishery catches are very low at present. This leads to lower sample sizes for length-frequency and further concern regarding the validity of catch-rates as indices of abundance.
c) Consideration should be given to evaluating objective methods for detecting resource recovery. Such methods may also be of value for several of the other species in the SESSF (e.g. eastern gemfish).
d) There is a need to collect additional length-frequency data for the Tasmanian component of the fishery (owing to the present size of this sector relative to the rest of the fishery in the east).
e) The impact of the catches from northwestern Tasmania coming from the western rather than the eastern stock should be examined. Such an examination requires information on the length-composition of the catches from northwestern Tasmania.
f) The possibility that maturity is age- and length-specific should be explicitly included in the assessment in common with previous assessments which have imposed the constraint that blue warehou cannot mature before age 2. Unfortunately, although the SS2 package allows for length- and age-specific selectivity, it presently cannot allow maturity to be age- and length-specific.
g) There is a data source that is currently ignored when conducting assessments of blue warehou. In principle, the ages obtained from reading of whole (rather than sectioned) otoliths can be included in the assessment by calculating an age-reading error matrix that allows for ageing bias. There are sufficient data to estimate such a matrix (see Figure 12.20), but whether inclusion of ages based on readings of whole otoliths will improve the assessment is unclear because the relationship between ages based on whole and sectioned otoliths is clearly fairly imprecise.
h) The 2005 industry-based survey could only be included in the present assessment in a fairly *ad hoc* manner. There are several ways in which the utility of an industry-based survey could be improved as a source of data for stock assessment for blue warehou. Initial thoughts in this regard are: a) the shots in the each stratum must be completed even if catch-rates are low, b) depth information should be recorded and used when standardizing the data, c) the length-frequency data should be captured and included in the assessment, d) consideration should be given to how to combine data for different spatial and temporal strata, and e) the results from the 2005 survey should be used to determine the ideal number of shots in each stratum – the selection of the number of shots should be based on desired levels of precision for the resulting indices.
i) The approach used to derive the standardized indices of abundance based on the logbook data ignores zero catches (and particularly trends in zero catches). There is value in examining the potential for the use of “delta” methods (Maunder and

Punt, 2004) and/or techniques that select which shots should have been capable of capturing blue warehou (e.g. Stephens and MacCall (2004)).

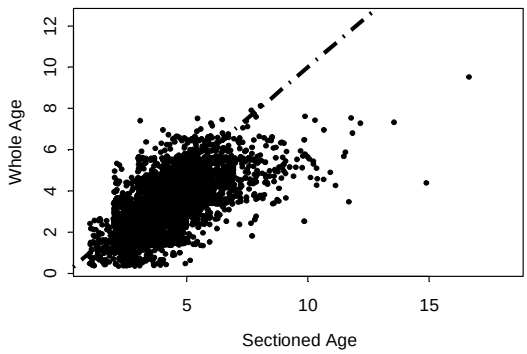


Figure 12.20. Sectioned versus whole ages for blue warehou (Kyne KrusicGolub, pers. Commn). The data points have been "jittered" for improved clarity.

12.7 Acknowledgements

Kyne KrusicGolub and Matt Koopman (Primary Industries Vic), Phillipe Ziegler (University of Tasmania), Ian Kunckey (Fishwell Consulting), and Neil Klaer (CSIRO) are thanked for providing the data on which the analyses of the assessment are based. Rick Methot (NWFSC, NOAA) is thanked for advice regarding some of the options of SS2.

12.8 References

Bruce, B.D., Neira, F.J. and R.W. Bradford. 2001. Larval distribution and abundance of blue and spotted warehouse (*Seriolella brama* and *S. punctata*: Centrophidae) in south-eastern Australia. *Marine and Freshwater Research* 52: 631–636.

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. *Canadian Journal of Fisheries and Aquatic Sciences* 37: 2272–2275.

Haddon, M. 2006. Standardized commercial catch-effort data for selected shelf and slope assessment group species. Document submitted to the 24-25 July 2006 meeting of SlopeRAG. 55 pp.

Haddon, M. and R. Thomson. 2005. Standardized commercial catch-effort data for selected shelf and slope assessment group species. Document submitted to the 30 June and 1 July 2005 meetings of SlopeRAG. 32 pp.

Haist, V., Fournier, D.A. and J.F. Schweigert. 1993. Estimation of density-dependent natural mortality in British Columbia herring stocks through SSPA and its impact on sustainable harvesting strategies. p. 269–282 *in* S.J. Smith, J.J. Hunt and D. Rivard, editors. Risk evaluation and biological reference points for fisheries management. *Canadian Journal of Fisheries and Aquatic Sciences Special Publication* 120.

Horn, P.L. 2001. Validated ageing methods for blue warehou (*Seriolella brama*) and white warehou (*S. caerulea*) in New Zealand waters. *Marine and Freshwater Research* 52: 297–309.

Hudson, R. and I. Knuckey. 2006. Fishery independent survey for blue warehou in the South East Fishery. Fishwell Consulting, Queenscliff. iii+21pp.

Kimura, D.K. 1981. Standardized measures of relative abundance based on modelling log(c.p.u.e.), and the application to Pacific ocean perch (Sebastes alutus). *Journal du Conseil International pour l'Exploration de la Mer* 39: 211–218.

Klaer, N.L. 1994. Methods for standardization of catch/effort and data requirements. p. 86–90 *in* D.A. Hancock, editor. *Population Dynamics for Fisheries Management*. Australian Government Publishing Service, Canberra.

Knuckey, I.A. and K.P. Sivakumuran. 2001. Reproductive characteristics and per-recruit analyses of blue warehou (*Seriolella brama*): implications for the South East Fishery of Australia. *Marine and Freshwater Research* 52: 575–587.

Knuckey, I.A., Grieve, C. and D.C. Smith. 1999. Evolution of the integrated scientific monitoring programme in Australia's South East Fishery. p. 231–248 *in* C.P. Nolan, editor. *Proceedings of the International Conference on Integrated Fisheries Monitoring*. FAO, Rome

Liggins, G.W., Bradley, M.J. and S.J. Kennelly. 1997. Detection of bias in observer-based estimates of retained and discarded catches from multi species trawl fishery. *Fisheries Research* 32: 133–147.

Lo, N.C., Jacobson, L.D. and J.L. Squires. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 2515–2526.

Maunder, M.N. and A.E. Punt. 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141–159.

Methot, R., 2006. User Manual for the Integrated Analysis Program Stock Synthesis 2 (SS2). Model Version 1.23a.

Punt, A.E. 1998. *Ad hoc* tuned VPA analyses for the blue warehou resource off southern Australia for 1998. Document submitted to the 30 – 31 May 1998 meeting of BWAG.

Punt, A.E. 1999. An assessment of blue warehou for 1999 based on integrated analysis. Document submitted to the 7-8 June 1999 meeting of BWAG.

Punt, A.E. 2000. An assessment of blue warehou for 2000 based on integrated analysis. Document submitted to the 22-23 May 2000 meeting of BWAG.

Punt, A.E. 2006. Updated stock assessment of blue warehou (*Seriolella brama*) based on data up to 2005. In: Tuck, G.N. (Ed.). Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2005-2006. AFMA and CSIRO Marine and Atmospheric Research, Hobart. p107–141.

Punt, A.E. and D.C. Smith. 2005. Stock assessment of blue warehou (*Seriolella brama*) based on data up to 2003. In: Tuck and A.D.M. Smith (Eds.). Stock Assessment for the South East and Southern Shark Fishery. Final report of FRDC Project 2001/005. CSIRO Marine and Atmospheric Research, Hobart. p49–120.

Punt, A.E., Smith, D.C. and M.T. Koopman. 2005. Using information for 'data-rich' species to inform assessments of 'data-poor' species through Bayesian stock assessment methods. Final report of FRDC Project 2002/094. Primary Industries Research Victoria, Queenscliff.

Punt, A.E., Smith, D.C., Thomson, R.B., Haddon, M., He, X. and J.M. Lyle. 2001. Stock assessment of the blue grenadier *Macruronus novaezelandiae* resource off south-eastern Australia. *Marine and Freshwater Research* 52: 701–717.

Punt, A.E., Smith, D.C., Tuck, G.N. and R.D. Methot. 2006. Including discard data in fisheries stock assessments: Two case studies from South-eastern Australia. *Fisheries Research* 79:239–250.

Smith, D.C. 1994. Blue warehou. p. 189–197 in R.D.J. Tilzey, editor. *The South East Trawl Fishery – A Scientific Review with Particular Reference to Quota Management*. Bureau of Resource Sciences, Canberra.

Smith, A.D.M. and A.E. Punt. 1998. Stock assessment of gemfish (*Rexea solandri*) in eastern Australia using maximum likelihood and Bayesian methods. p. 245–286 *in* T.J. Quinn II, F. Funk, J. Heifetz, J.N. Ianelli, J.E. Powers, J.F. Schweigert, P.J. Sullivan and C-I Zhang, editors. *Fisheries Stock Assessment Models*, Alaska Sea Grant College Program, AK-SG-98-01.

Smith, A.D.M. and S.E. Wayte (eds) 2004. The South East Fishery 2003. Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Smith, D.C., Huber, D., Woolcock, J., Withel, A.F. and J.W.J. Wankowski. 1995. Western Bass Strait trawl fishery assessment program. Final report of FRDC Project 86/39, MAFRI, Queenscliff.

Smith D.C., McCoy, P. and J. Cottier. 1994. Assessment of the trawl and gillnet fisheries for warehous. Final Report of FRDC Project 90/11. Victorian Fisheries Research Institute, Queenscliff.

Smith, D.C., Smith, A.D.M. and A.E. Punt. 2001. Approach and process for stock assessment in the South East Fishery, Australia: A perspective. *Marine and Freshwater Research* 52: 671–681.

Stephens, A. and A. MacCall. 2004. A multispecies approach to subsetting logbook data for purposes of estimating CPUE. *Fisheries Research* 70: 299–310.

Stefánsson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. *ICES Journal of Marine Science* 53: 577–588.

Talman, S., Hamer, P., Robertson, S., Robinson, N., Skinner, A. and D.C. Smith. 2003. Stock structure and spatial dynamics of the warehous: a pilot study. Final report of FRDC Project 2001/004, Primary Industries Research Victoria, Marine and Freshwater Systems, Queenscliff.

Tuck, G.N. and A.D.M. Smith. 2005. Stock assessment for the south east and southern shark fishery. FRDC report 2001/005. 412pp.

Vignaux, M. 1994. Catch per unit effort (CPUE) analysis of west coast South Island Cook Strait spawning hoki fisheries, 1987-93. *New Zealand Fisheries Assessment Research Document* 94/11.

Table 12.1. Reported catches (tonnes), discard rates (with coefficients of variation in parenthesis) and catch-rates by fleet. The catches for the 'east trawl' fleet include NSW State catches after 2000. The discard rates indicated by asterisks are included in these tables but not in the calculations owing to low sample sizes. The 1999 catch-rate for the non-trawl fishery (indicated by the ampersand) is excluded from the analyses. The catches and catch-rates in parenthesis for the western stock are the values after correction for discarding. A '+' indicates an assumed value and a '*' indicates an estimate based on limited data for 2006.

Year	Catches				Discard rates		Catch-rates		
	East	West	Non-trawl	Tas	East	West	East	West	Non-trawl
1986	160	83	254	165	-	-	1.000	1.000	1.700
1987	210	263	1033	278	-	-	1.088	0.518	2.410
1988	397	237	835	170	-	-	1.345	0.266	2.410
1989	785	116	1061	52	-	-	1.694	0.830	4.000
1990	642	370	1746	172	-	-	1.644	0.275	5.580
1991	652	851	1386	154	-	-	0.998	0.386	2.470
1992	518	571	842	249	0.000*	-	0.768	0.172	1.990
1993	542	437	487	168	0.015 (0.157)*	-	0.555	0.127	1.000
1994	555	518 (590)	389	257	0.056 (0.448)*	0.123 (0.693)	0.513	0.142 (0.161)	0.600
1995	563	397 (411)	199	138	0.118 (0.405)*	0.034 (0.449)	0.430	0.097 (0.100)	0.530
1996	632	222 (254)	213	119	0.018 (0.344)	0.124 (0.608)	0.451	0.059 (0.068)	0.600
1997	497	293 (646)	317	127	0.044 (0.733)	0.546 (0.468)	0.535	0.090 (0.198)	0.540
1998	524	408 (680)	87	246	0.032 (0.638)	0.399 (0.545)	0.522	0.126 (0.210)	0.360
1999	154	200 (217)	312	268	0.096 (0.487)	0.077 (0.003)	0.267	0.059 (0.063)	1.000[&]
2000	207	225 (226)	87	108	0.005 (0.753)	0.001 (0.619)	0.271	0.055 (0.055)	-
2001	70	228 (238)	32	24	0.358 (0.447)	0.043 (0.637)	0.147	0.048 (0.050)	-
2002	69	238 (240)	4	70	0.018 (0.438)	0.009 (0.776)	0.103	0.059 (0.060)	-
2003	48	202 (208)	2	41	0.208 (0.358)	0.027 (0.829)	0.094	0.055 (0.056)	-
2004	63	199 (496)	2	29	0.300 (0.569)	0.598 (0.264)	0.126	0.080 (0.200)	-
2005	27	289 (372)	1	19	0.718 (0.115)	0.224 (0.319)	0.082	0.110 (0.142)	-
2006	150[+]	600[+]	1[+]	19[+]	0.009 (0.134)[*]	0.385 (0.268)[*]	-	-	-

Table 12.2. Standardized catch-rate indices based on the ISMP programme. Results are shown for indices based on targeted and all shots (source: Anne Gason, PirVic, pers. Commn). The column "# obs" indicates the number of shots included in the catch-effort standardization.

Western stock						Eastern stock					
Targeted shots			All shots			Targeted shots			All shots		
Year	Index	# obs	Year	Index	# obs	Year	Index	# obs	Year	Index	# obs
1994	10.2	40	1994	12.6	122	1994	10.3	8	1994	1.9	101
1995	2.6	30	1995	1.4	188	1995	0.0	2	1995	5.4	66
1996	47.2	18	1996	13.8	152	1996	148.0	10	1996	3.6	101
1997	394.3	13	1997	25.0	151	1997	19.8	1	1997	2.0	218
1998	118.1	13	1998	11.5	194	1998	7.0	30	1998	2.9	374
1999	19.5	22	1999	4.2	178	1999	20.2	6	1999	0.6	640
2000	5.2	20	2000	0.8	117	2000	6.9	2	2000	0.4	517
2001	6.3	22	2001	1.0	137	2001	3.2	2	2001	0.3	658
2002	10.3	13	2002	1.6	219	2003	108.9	3	2002	0.2	486
2003	0.3	5	2003	0.6	151	2005	0.1	36	2003	0.3	606
2004	40.0	11	2004	15.8	141				2004	0.2	560
2005	28.4	70	2005	12.0	244				2005	0.2	578

Table 12.3. Sample sizes for age-length keys and length-frequencies for the landed / discarded catches. Values annotated by an asterisk are samples sizes that are too low for inclusion in the assessment.

Year	Age-length keys		Landed length-frequencies				Discard length-frequencies	
	East	West	East	West	Non-trawl	Tas	East	West
1986	-	-	-	-	-	-	-	-
1987	0	139	0	4031	-	-	-	-
1988	0	238	0	1882	-	-	-	-
1989	0	0	0	0	-	-	-	-
1990	0	0	0	0	-	-	-	-
1991	192	0	0	1366	6920	-	-	-
1992	90*	0	0	4175	3475	-	-	-
1993	0	173	0	665	5442	-	26*	-
1994	0	120	2889	10630	630	-	102*	-
1995	0	139	2260	5810	110	-	73*	-
1996	113	74*	2833	4677	312	-	17*	-
1997	68*	58*	3730	5708	1478	1325	134	241
1998	-	-	4288	5979	561	2758	191	184
1999	153	-	2092	3080	4038	1456	117	-
2000	389	366	2539	1153	410	-	0	59
2001	435	484	1604	2190	284	-	342	336
2002	318	432	1944	2103	244	-	26*	10
2003	96*	189	2107	684	18*	-	631	-
2004	125	673	1257	1120	-	-	409	2608
2005	72*	617	342	1263	-	-	1400	1675
2006	-	-	-	-	-	-	-	298

Table 12.4. The data used to construct the age-reading error matrix.

	Estimated Age						
Age	1	2	3	4	5	6	7+
SD	0.151	0.279	0.387	0.474	0.543	0.594	0.628

Table 12.5. Indices of relative abundance based on commercial catch-rates and survey data. Results are shown for two strata in each of the western and eastern stocks. The average coefficient of the variation for the years for which the annual index is based on commercial data is given in the row 'CV – non survey', while the coefficient of variation for the survey index is given in the row 'CV – survey'.

	Eastern stock				Western stock			
	Eden		Horseshoe		Main drag		Port McDonell	
CV - non-survey	0.207	0.148	1.086	0.904	0.349	0.354	0.661	0.715
CV - survey	0.438	0.430	1.095	1.200	0.522	0.543	0.752	0.875
1986	1.000	1.000	1.000	1.000				
1987	1.853	1.804	34.082	53.904				
1988	1.339	1.291	19.589	28.908				
1989	1.828	1.705	3.920	5.678				
1990	1.290	1.292	12.546	18.756	1.000	1.000		
1991	0.557	0.560	1.568	2.355	0.654	0.658		
1992	0.647	0.673	1.908	2.411	0.255	0.247	1.000	1.000
1993	0.487	0.508	0.503	0.670	0.163	0.162	0.808	1.003
1994	0.463	0.487	1.363	2.074	0.122	0.115	3.235	2.140
1995	0.386	0.395	0.796	1.126	0.213	0.198	2.062	1.984
1996	0.574	0.593	1.401	1.747	0.043	0.037	0.236	0.277
1997	0.656	0.651	0.593	0.850	0.338	0.324	0.218	0.306
1998	0.786		1.458		0.120		0.443	
1999	0.400		0.809		0.095		0.258	
2000	0.307		0.176		0.038		0.326	
2001	0.093		0.681		0.075		1.183	
2002	0.166		0.142		0.177		0.479	
2003	0.234		0.084		0.170		1.018	
2004	0.086		6.538		0.123		2.025	
2005 *	0.252		0.294		0.353		1.136	
2005 Survey	1.102	1.189	0.077	0.100	0.727	0.575	0.234	0.095

* Data replaced by the survey index when included in the stock assessment.

Table 12.6. Key structural assumptions made when conducting the reference case assessments for the two stocks of blue warehou. Quantities annotated by an asterisk denote aspects of the reference case analysis varied in the tests of sensitivity

Assumption	Eastern Stock	Western Stock
Biological parameters		
Sex-structure	No, single sex	
Age classes	Ages 0-12	
Length-classes	12 - 64 cm (2cm length-classes)	
Natural mortality *	Age-independent; pre-specified (reference M = 0.45yr^{-1})	
Length-weight regression	$W = 0.00003\ L^{2.90}$	
Variation in length-at-age	Linear increase with age; estimated	
Length-specific maturity	See Section 12.4.2	
Stock-recruitment relationship		
Steepness *	Pre-specified (reference h=1)	
σ_R *	Pre-specified (reference σ_R=1)	
Recruitments estimated for	1980-2004	
Catches and discards		
Equilibrium (pre-1986) catch*	East: 150t Non-trawl: 200t Tasmania: 100t	West: 200t
Length-specific selectivity	East: logistic Non-trawl: logistic Tasmania: double-logistc	West: logistic
Discards	East: fitted to Non-trawl: added to catches Tasmania: none	West: added to catches
Length-specific discarding	East: logistic Non-trawl; Tasmania: N/A	West: N/A
Initial state	Exploited non-equilibrium age-structure (1986)	
Data utilized		
Catch-rates	East: CV = 0.25 Non-trawl: CV=0.25 Tasmania: N/A	West: CV=0.1
Discard rates	East: CV = see Table 12.1 Non-trawl; Tasmania: N/A	West: N/A
Landed length-frequency	East, non-trawl, Tasmania: Yes	West: Yes
Discarded LF	East: Yes Non-trawl; Tasmania: No	West: No
Age-length keys	Weight is 5% of the numbers aged	

Table 12.7. The estimable parameters of the model. The number associated with each stock denotes the number of estimable parameters of each type.

Parameter	Eastern Stock	Western Stock
Virgin recruitment	1	1
Recruitment deviations	25	25
Length-at-age	5	5
Fishing mortality pre-1986	3	1
Catchability*	2	1
Selectivity	10	2
Retention	2	0
Total estimated	46	34

* Estimated analytically so not included in the total number of estimable parameters

Table 12.8. Quantities of management interest for the base-line analyses and the sensitivity tests.

(a) Western stock

					20-48-48		20-40-48		20-40-40		20-48-48		20-40-48		20-40-40		
	B_0	B_{06}	B_{06}/B_0	B_{07}/B_0	RBC 2007	ABC 2007	RBC 2007	ABC 2007	RBC 2007	ABC 2007	RBC 2008	ABC 2008	RBC 2008	ABC 2008	RBC 2008	ABC 2008	Likelihood
Reference case																	
Base case	2578	648	0.251	0.126	0	151	0	151	0	195	146	306	171	306	221	396	237.307
M=0.35yr^{-1}	2944	571	0.194	0.083	0	100	0	100	0	129	10	216	11	216	14	280	235.066
M=0.55yr^{-1}	2480	765	0.308	0.179	0	230	0	230	0	297	322	434	376	434	485	559	239.827
h=0.75	3038	630	0.207	0.094	0	120	0	120	0	152	37	251	43	251	55	318	236.734
$\sigma_R = 0.6$	2052	682	0.332	0.202	3	180	3	180	4	233	230	296	268	295	346	382	229.383*
$\sigma_R = 1.2$	3093	636	0.205	0.095	0	143	0	143	0	184	92	332	108	332	139	429	242.490*
Higher hist catches	2670	659	0.247	0.137	0	171	0	171	0	221	181	330	211	330	272	427	238.734
Lower hist catches	2549	646	0.253	0.123	0	147	0	147	0	190	139	300	162	300	209	388	236.816
No 2005 LF	2706	772	0.286	0.197	0	217	0	217	0	280	258	366	301	366	389	473	221.236*
With ‘ survey index’																	
Base case	3080	548	0.178	0.106	0	161	0	161	0	210	149	354	173	354	226	462	159.738
M=0.35yr^{-1}	3349	522	0.156	0.080	0	108	0	108	0	140	9	240	10	240	13	313	154.931
M=0.55yr^{-1}	3343	616	0.184	0.130	0	255	0	255	0	333	360	560	419	560	549	733	165.334
h=0.75	3608	530	0.147	0.091	0	141	0	141	0	180	45	293	52	293	67	374	159.157
$\sigma_R = 0.6$	2456	718	0.292	0.192	0	202	0	202	0	264	259	346	303	346	395	453	151.185*
$\sigma_R = 1.2$	3769	517	0.137	0.089	0	168	0	168	0	220	119	405	139	405	181	529	164.825*
Higher hist catches	3324	579	0.174	0.110	0	180	0	180	0	236	176	390	205	390	268	510	161.050
Lower hist catches	3059	544	0.178	0.105	0	158	0	158	0	206	143	350	167	350	218	456	159.231
No 2005 LF	3283	724	0.221	0.175	0	242	0	242	0	316	283	432	331	432	432	564	153.202*
Main Drag Only	3105	594	0.191	0.107	0	162	0	162	0	212	150	357	175	357	228	466	150.745*
Main Drag Only; No 2004&05 LF	3408	1065	0.312	0.274	165	355	192	355	251	465	388	490	438	483	532	614	139.811*

* Not comparable to the negative log-likelihood for the base case case analysis.

(b) Eastern stock

					20-48-48		20-40-48		20-40-40		20-48-48		20-40-48		20-40-40		
	B_0	B_{06}	B_{06}/B_0	B_{07}/B_0	RBC 2007	ABC 2007	RBC 2007	ABC 2007	RBC 2007	ABC 2007	RBC 2008	ABC 2008	RBC 2008	ABC 2008	RBC 2008	ABC 2008	Likelihood
Base case	4855	765	0.158	0.156	0	255	0	255	0	325	54	417	63	417	80	531	320.418
M=0.35yr^{-1}	5014	635	0.127	0.128	0	171	0	171	0	219	0	276	0	276	0	352	311.454
M=0.55yr^{-1}	5157	1021	0.198	0.191	0	393	0	393	0	498	248	646	290	646	367	819	329.504
h=0.75	5357	702	0.131	0.127	0	186	0	186	0	234	0	281	0	281	0	352	316.994
$\sigma_R = 0.6$	4141	1077	0.260	0.271	150	333	175	333	222	424	248	427	278	423	325	526	326.370*
$\sigma_R = 1.2$	5603	719	0.128	0.126	0	255	0	255	0	325	0	448	0	448	0	570	322.423*
Higher hist catches	6597	1318	0.200	0.214	51	444	60	444	76	564	282	643	325	641	402	812	327.675
Lower hist catches	4646	768	0.165	0.162	0	252	0	252	0	320	71	406	83	406	105	516	319.809

* Not comparable to the negative log-likelihood for the base case analysis.

12.9 Appendix A: Comparison of assessment models based on the data used for the 2005 assessment

The 2005 assessment of blue warehou (Punt, 2006) was based on an age-length model fitted to data on catches, catch-rates, catch length-frequencies and catch age-composition data. Philosophically, the assessment model used for the 2005 assessment is similar to that of Stock Synthesis 2 (SS2). In particular, both models are based on estimating the growth curve (and variation in length-at-age) by fitting to conditional age-length data (Punt *et al*., 2006). However, there are some technical differences between SS2 and the model used by Punt (2006). The following steps were therefore conducted to confirm that the changes in assessment method would not lead to unexpected changes in key model outputs:

(1) Identify where the assumptions in SS2 differ from those underlying the 2005 assessment.
(2) Conduct assessment runs based on varying the specifications of the 2005 assessment to determine what is needed to force the base-case model used for the 2005 assessment to mimic the results from SS2.

A.1 Differences in assumptions

The model underlying the 2005 assessment and SS2 differ in several ways (see Table A.1). However, as will be shown in Section A.2, only one of these differences has an impact on the qualitative conclusions of the assessment (the penalty on fishing mortality). The penalty on fishing mortality was introduced into the assessment when it began to be based on Integrated Analysis rather than on Virtual Population Analysis. This penalty was needed because the data for blue warehou were very sparse at that time and the model was very unstable – adding this penalty stabilized the model. The data set for blue warehou (although still somewhat uninformative) is no longer so small that a penalty of this type is needed.

Table A.1. Differences between SS2 and the model used for the 2005 assessment.

Specification	2005 assessment	SS2
Maturity	Function of age and length	Function of length only
Likelihood function for the age and length data	Log-normal	Multinomial
Variation in length-at-age	Log-normal	Normal
Sampling variation in discard rates	Log-normal	Normal
Penalty on fishing mortality	Yes	No

A.2 Results of alternative assessment runs

A base-case run of SS2 was conducted and various variants of the 2005 assessment constructed in an attempt to mimic the results from SS2. Three versions of the method used for the 2005 assessment were considered: a) the base-case specifications for the 2005 assessment, b) as for a) except that the likelihood function is assumed to be multinomial, variation in length-at-age is assumed to be normal, and sampling variation in discard rates is assumed to be normal, and c) as for b) except that the penalty on fishing mortality is dropped. The plots for each comparison show the fit to the catch-rate indices, the time-trajectory of the spawning biomass (in absolute terms and expressed relative to the mean spawning biomass), and the time-trajectory of vulnerable biomass (in absolute terms and expressed relative to the mean vulnerable biomass). For the eastern stock, results are only shown for the trawl and non-trawl fleets. The plots for the western stock also show the ratios of the time-series of exploitable biomass from the two models while the plots for the eastern stock also show the time-trajectory of recruitment.

All three variants of the 2005 assessment model mimic the time-trajectories of exploitable biomass from SS2 when exploitable biomass is expressed relative to the mean exploitable biomass between 1986 and 2005. All four models also mimic the catch-rate indices well. However, the estimates of spawning stock biomass and exploitable biomass (in absolute terms) from the model on which the 2005 assessment was based are higher than those from SS2 unless the penalty on fishing mortality is dropped (compare the results in Figures A1(a), A1(b), A2(a) and A2(b) with those in Figures A1(c) and A2(c)). Some differences in spawning stock biomass at the start of the assessment period remain between SS2 and the model on which the 2005 assessment was based even if the penalty on fishing mortality is dropped. However, there are few data for these years so whether this is unexpected / important or not is unclear.

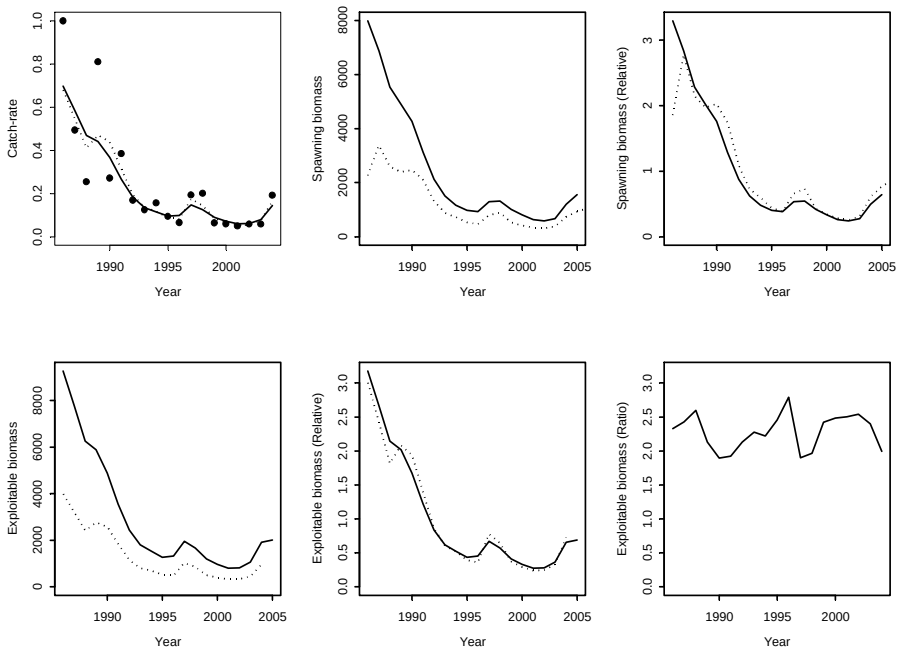


Figure A.1(a): Comparison of the results from SS2 (dotted lines) and the base-case model on which the 2005 assessment was based (solid lines) for the western stock of blue warehou.

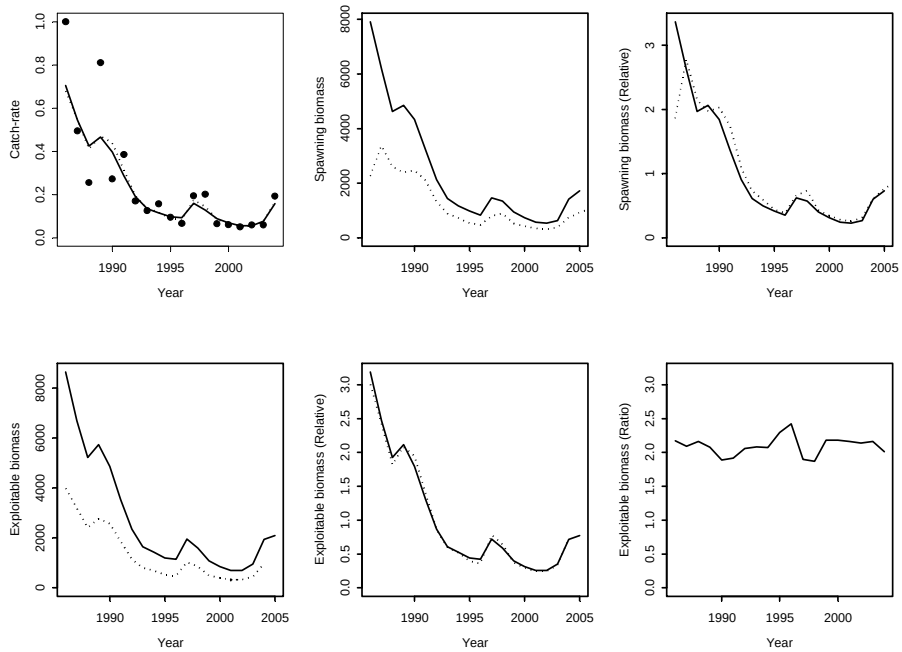


Figure A.1(b): Comparison of the results from SS2 (dotted lines) and a variant of the base-case model on which the 2005 assessment was based in which the assumptions regarding the likelihood function, the distribution of length-at-age, and the sampling distribution for discard rate are changed to mimic SS2 (solid lines) for the western stock of blue warehou.

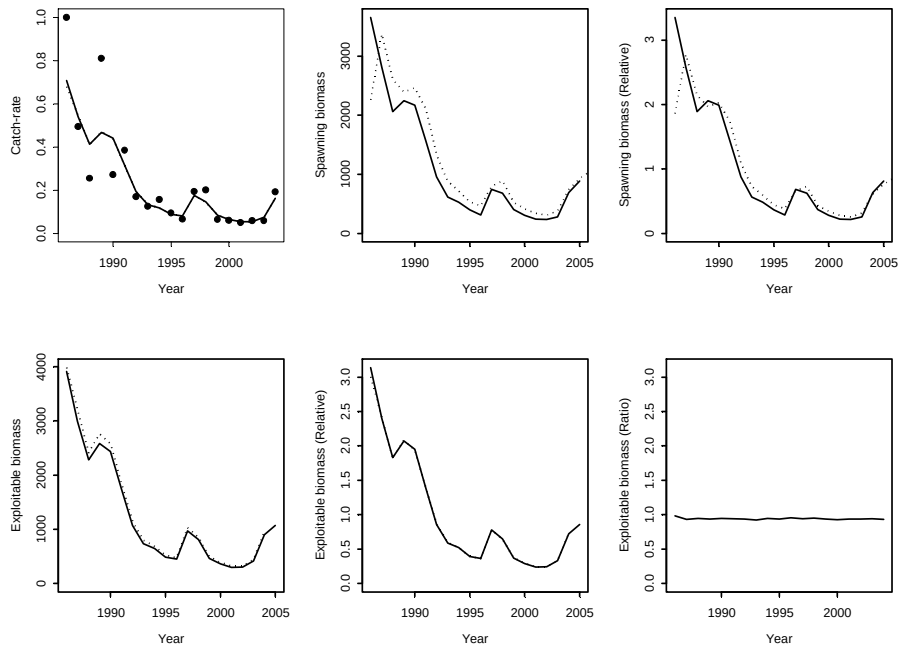


Figure A.1(c): As for Figure A.1(b) except that the penalty on fishing mortality is ignored.

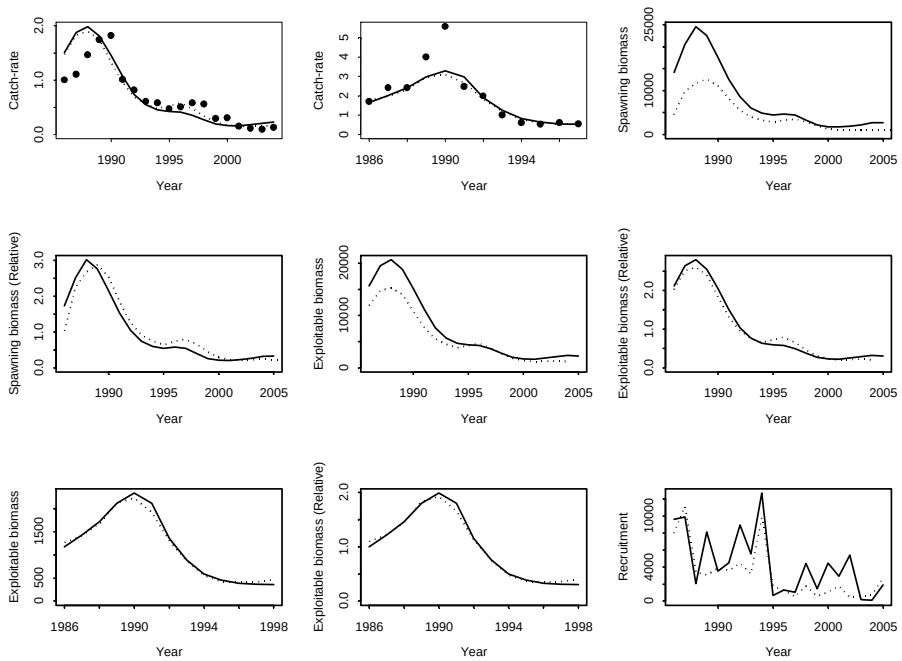


Figure A.2(a): Comparison of the results from SS2 (dotted lines) and the base-case model on which the 2005 assessment was based (solid lines) for the eastern stock of blue warehou.

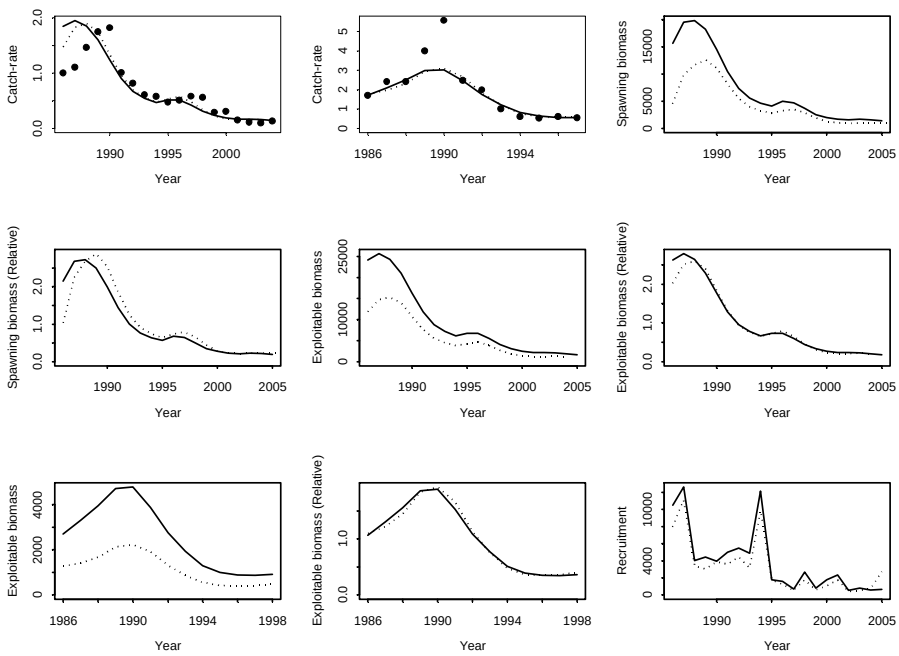


Figure A.2(b): Comparison of the results from SS2 (dotted lines) and a variant of the base-case model on which the 2005 assessment was based in which the assumptions regarding the likelihood function, the distribution of length-at-age, and the sampling distribution for discard rate are changed to mimic SS2 (solid lines) for the eastern stock of blue warehou.

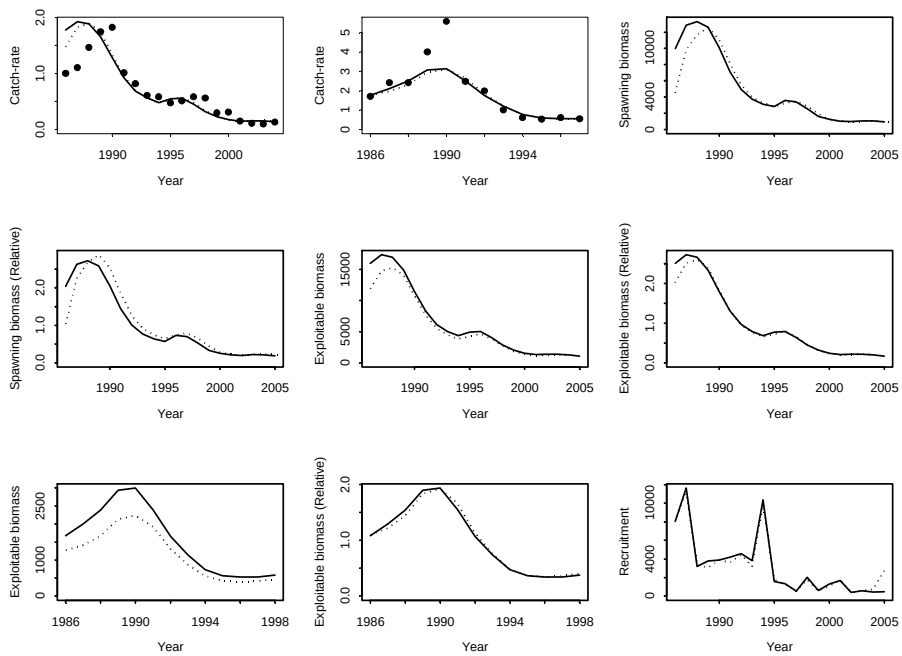
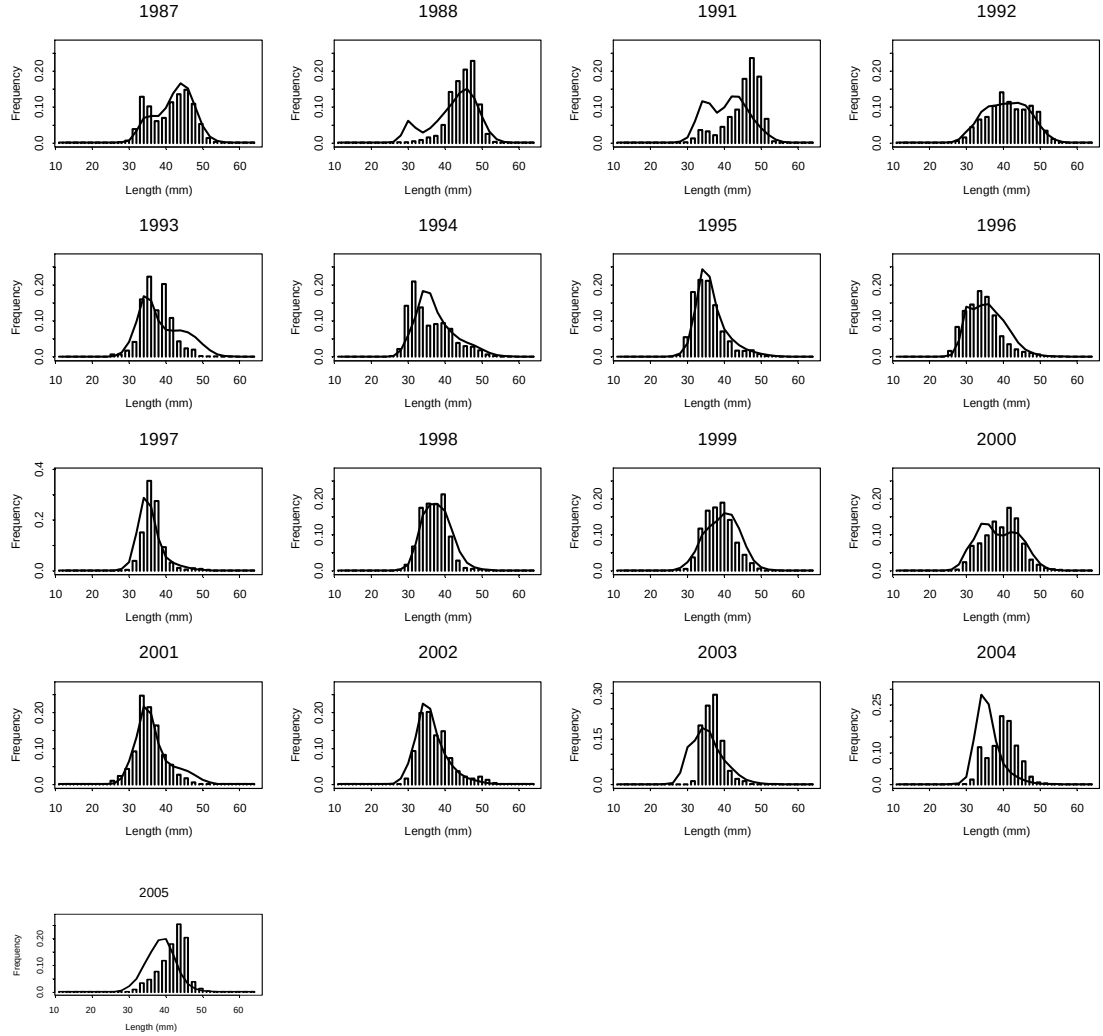


Figure A.2(c): As for Figure A.2(b) except that the penalty on fishing mortality is ignored.

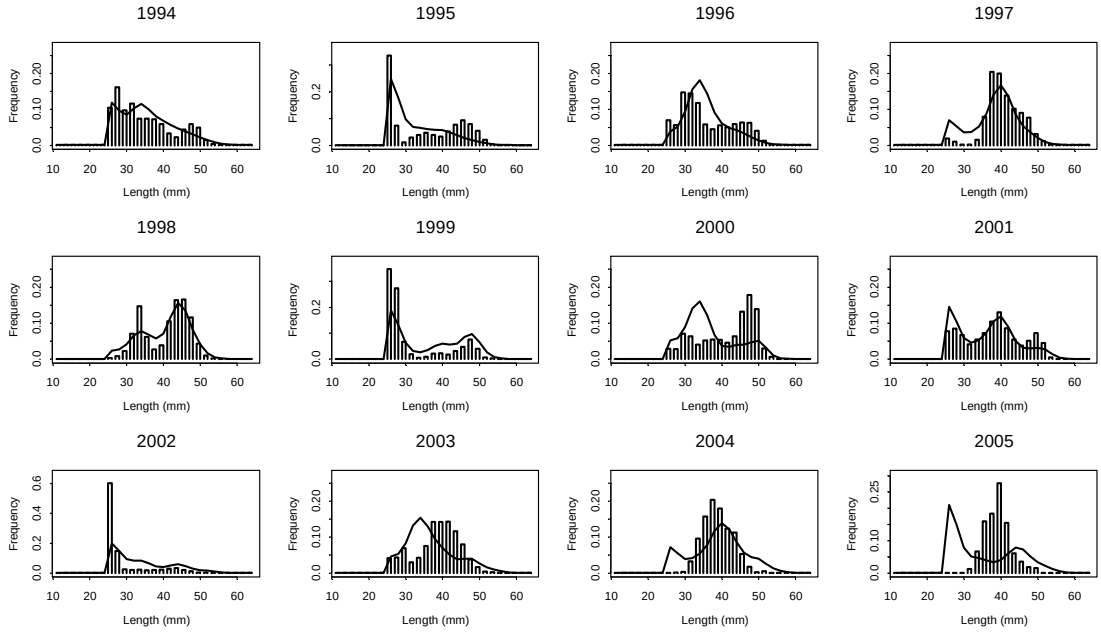
12.10 Appendix B: Fits to the length-frequency data

(a) Western stock

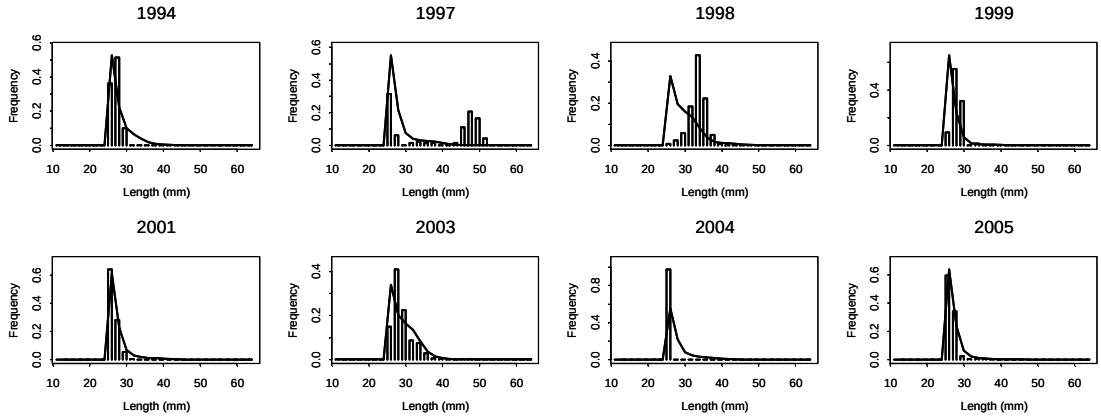


(b) Eastern stock

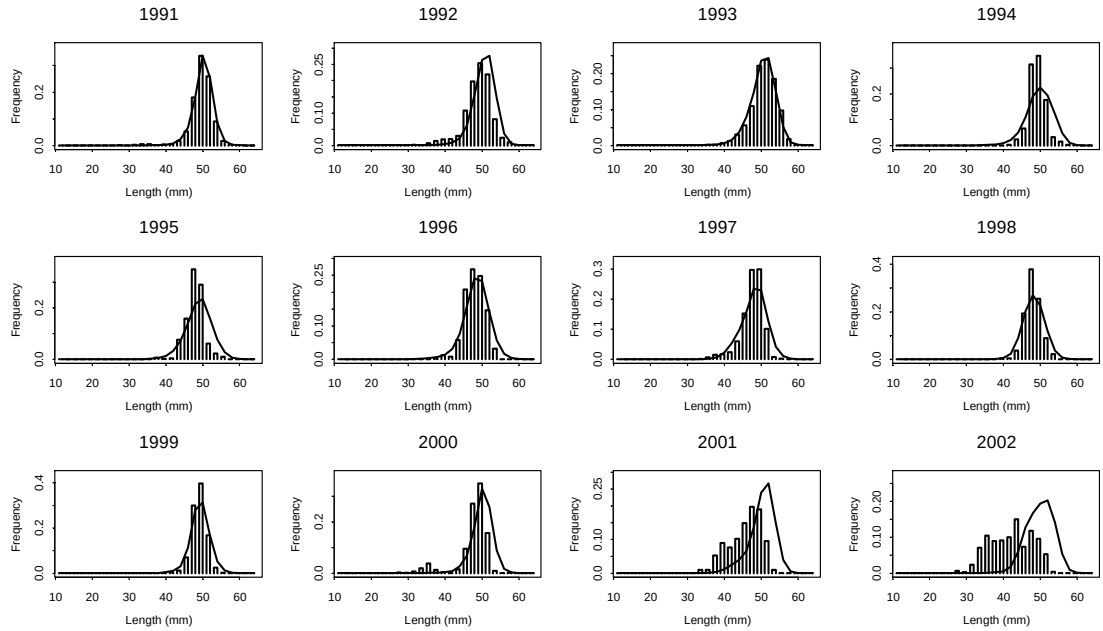
(b-i) East trawl (landed)



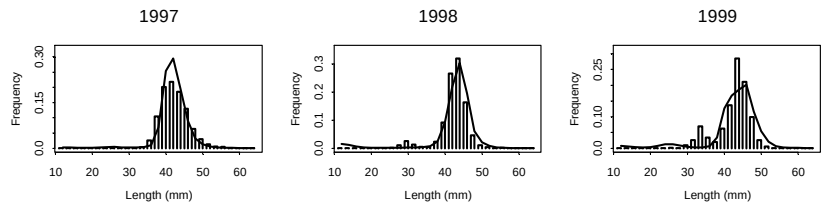
(b-ii) East trawl (discarded)



(b-iii) Non-trawl



(b-iv) Tasmanian meshnet



13. Addendum: Updated Stock Assessment of Blue Warehou (*Seriolella Brama*) Based on Data up to 2006

André E. Punt[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

Figure 13.1 and Figure 13.2 show time-trajectories of depletion (spawning biomass relative to B_0) for the western stock of blue warehou based on deterministic projections (steepness = 1) under catches from 2007 of 0 to 600t (dashed lines). Results are shown in Figure 13.1 for the 'reference case' analysis and in Figure 13.2 for the 'with survey index' analysis. Figure 13.1 and Figure 13.2 also show time-trajectories of depletion under the 20-40-40, 20-40-48 and 20-48-48 variants of the Tier 1 rules (bold lines). Table 13.1 lists the year in which the western stock of blue warehou is predicted to recover to the 40% of B_0 and 48% of B_0 (a "-1" indicates the stock does not recover to the level concerned).

The results in this addendum should be interpreted with caution because the projections ignore parameter uncertainty and variation in recruitment. The results are based on the assumption that steepness equals 1, an optimistic assumption, but not one that is inconsistent with the data.

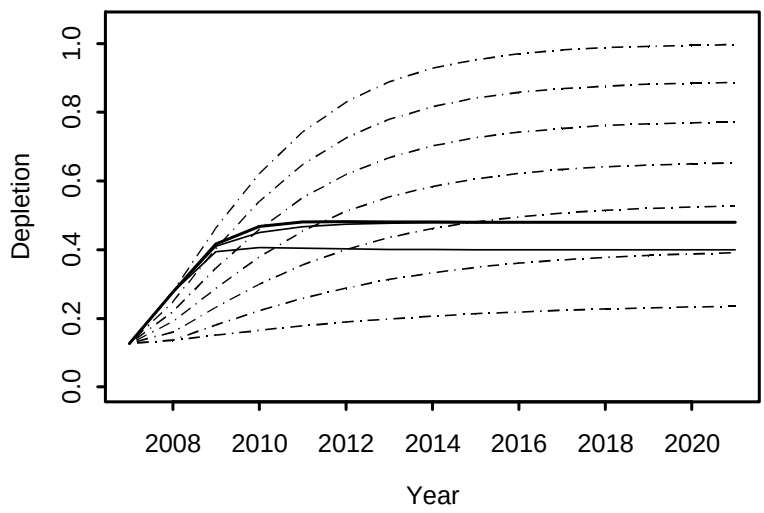


Figure 13.1. Time-trajectories of depletion for the western stock of blue warehou. The bold lines are the results for the three variants of the Tier 1 rules and the dashed lines are the results for the seven levels of constant catch. The results in this figure are based on the "reference case" analysis.

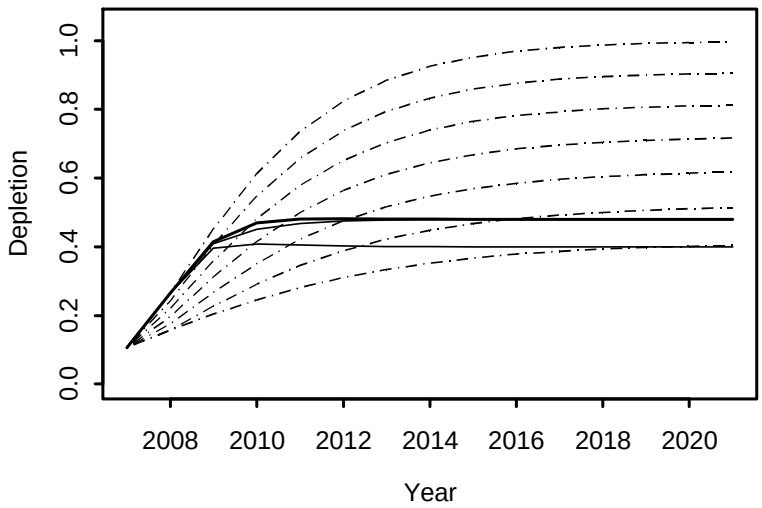


Figure 13.2. Time-trajectories of depletion for the western stock of blue warehou. The bold lines are the results for the three variants of the Tier 1 rules and the dashed lines are the results for the seven levels of constant catch. The results in this figure are based on the "with survey index" analysis.

Table 13.1. Years in which recovery to $0.4B_0$ and $0.48\ B_0$ are predicted to occur under ten scenarios and two assessment models. A "-1" indicate that recovery does not occur.

	20-48-48	20-40-48	20-40-40	C=0	C=100*t*	C=200*t*	C=300*t*	C=400*t*	C=500*t*	C=600*t*
				Reference case analysis						
$0.40B_0$	2009	2009	2010	2009	2009	2010	2011	2012	-1	-1
$0.48B_0$	2011	2015	-1	2010	2010	2011	2012	2015	-1	-1
				"With survey index" analysis						
$0.40B_0$	2009	2009	2010	2009	2009	2010	2010	2011	2013	2020
$0.48B_0$	2011	2014	-1	2010	2010	2010	2011	2013	2016	-1

14. Updated Stock Assessment of Pink Ling (*Genypterus blacodes*) in the South East Fishery, August 2006

Bruce Taylor[1]

[1]Primary Industries Research Victoria, Queenscliff, Victoria, 3225, Australia

14.1 Summary

The 2006 stock assessment has been updated following advice from the 24-25 July Slope RAG meeting. The 2006 Pink Ling assessment model has been run in Stock Synthesis 2 (SS2) and has assumed separate stocks in the east and west of the fishery. The data had been updated to include 2005 data, catches from 1977-1984 and catch rates for the non-trawl fishery. It had also included length frequency data for years where no age length keys were available. This updated assessment includes estimates of growth parameters, use of conditional length at age data, revised standardisation of catch rates, revised length at maturity and, in the east, the inclusion of data from Kapala surveys.

The new reference case estimates the spawning biomass at the end of 2006 at 15% of the virgin spawning biomass in the east and 40% in the west. The 2005 assessment estimated the spawning biomass in 2004 as 39% of the virgin spawning biomass. The current assessment estimates the 2004 spawning biomass as 23% in the east and 60% in the west.

The RBC for 2007 and 2008, using the new 20:48:48 Tier 1 rule, is 215 tonnes (0t from the east and 215t from the west) and 224 tonnes. With a 20:40:48 rule, the RBC is 251 and 255 tonnes and with a 20:40:40 rule, it is 315 and 304 tonnes. Projections under the 20:48:48 rule suggest a long term sustainable yield of almost 950t.

14.2 Method

14.2.1 Previous Assessments

In 2005, the base case Pink Ling assessment model (Klaer 2003a, 2003b) was run with updated 2003 and 2004 data (Taylor, 2005). This model was developed in Coleraine (Hilborn, 2000), a generalised age structured stock assessment model. It assumed the fishery was a single stock and used unstandardised trawl catch-rates. An alternative run used standardised catch-rates from the trawl fishery. This was then run in SS2 (Taylor, 2006a) and 2005 data added and run as east and west fisheries (Taylor, 2006b).

14.2.2 Data

Catch: From 1986 for trawl fleet and 1997 for the non-trawl fleet, most of the catch is reported to the Commonwealth. When available, the total annual landings from SEF2 and SAN2 are used for the estimated total catch and SEF1 and GN01 are used to

estimate the relative catch taken by zone and gear type. The estimated catches reported by zone are listed in Table 2 and shown in Figure 14.1.

Before 1986 (and 1997 for the non-trawl fishery), catches were reported to the states and data from these sources have been included this year. These are shown in Table 1. The total catches were based on Pearce (1995), PIRVic Catch and Effort data, Wayte and Smith (2003) and Klaer (2003b). The 2006 projected catch was set equal to the quota (1200 tonnes), with the same gear type and east/west split as in 2005. The catches by gear type that were used in the assessment are listed in Table 1 and shown in Figure 14.1.

Catch-rate: The otter trawl was standardised for vessels that had caught ling for more than 2 years, and had a mean annual catch of greater than 10 tonnes (Klaer, 2003a). The model fitted to the data (records with a ling catch and with effort data) in this assessment was:

Log(C/E) = constant + Year*Region + BoatName + Month*Zone + Depth_Zone*Zone + Zone

where Region refers to East and West.

In 2006, a preliminary analysis of catch and effort from the auto long line vessels was made. The catch-rates for the auto long line vessels were standardised for vessels that had been in the fishery for more than 2 years (this removed 4 vessel having greater than 5 days fishing each year, and 2 other vessels fishing less than 5 days in one of the years) and had a mean annual catch of greater than 10 tonnes (removed 1 more vessel). This left 4 vessels in the east and 2 in the west. Effort data was not available before 1995, and 2002 was the first year there was more than 1 vessel fishing. The model fitted to the data (records with a ling catch and with effort data) was:

Log(C/E) = constant + Year*Region + BoatName + Month*Zone + Depth_Zone*Zone + Zone

where Region refers to East and West.

The raw and standardised catch-rates are shown in Figure 14.4 and the fitted catch-rates in Figure 14.6.

Age and length frequency data: The length frequency data were taken from the port samples (Figure 14.5). In the east, Sydney Fish Market trawl length frequency data from 1986-90 and from three Kapala surveys were also used. Samples less than 80 were dropped. The length at age data was aggregated into 5 cm bins. The values of the sample sizes used in the model were reduced to more closely reflect the effective sample sizes in SS2. The changes are listed in Table 3.

Maturity: The maturity ogive was set at a 72cm infection point (Wayte & Smith, 2003) and a slope of -3 was assigned to approximate the knife-edge selection of previous assessments.

Ageing error:

Standard deviations for ageing error were estimated from the data and set at:

Age	1	2	3	4	5 and above
sd	0.42	0.42	0.5	0.7	0.9

14.2.3 The 2006 Assessment

The 2006 assessment is run within the age-length model Stock Synthesis 2 (Methot, 2006). The data is fitted by maximum likelihood, and the RBC is estimated within the model.

Fixed parameters: As in previous assessments (Taylor, 2005, Klaer, 2003a, 2003b), natural mortality (0.2), recruitment steepness (0.75), the weight at length coefficients and maturity at age (Figure 14.3) were fixed. The values used are given in Table 3.

Selectivity: Selectivity at length for each gear type in each of the east and west was estimated in the model (Figure 14.2). The trawl selectivity (fishing fleet and Kapala) used a double logistic function while the non-trawl selectivity used a logistic curve. The selectivity function also includes an availability component, so can be different in the west to the east. In past assessments, the selectivities were age based and fixed.

14.3 Results and Discussion

The catch in 2005 was 1372 tonnes (Table 1). It followed catches of 1600, 1607 and 1608 tonnes in the previous 3 years, and was lower due to a reduction in quota. There has been a transfer in 2004 and 2005 from trawl to nontrawl catches (Table 1). The non-trawl catch was 619 tonnes in 2005, down from 851 tonnes in 2004. Catches were lower in both the east and the west in 2005 (Figure 14.1). A catch of 1200 tonnes (based on the quota), in proportion to catches by gear type and zone, was used in 2006 for the projections.

The catch-rates, and the fits to them, are shown in Figure 14.4 and Figure 14.6. The model fits the trawl cpue well, but the non-trawl cpue has more variability. All cpue series show a decline in recent years although the decline appears to have stabilised in the eastern trawl fishery.

14.3.1 Reference case

The fishery was modelled on a reference case (Table 3) and then assumptions or data were tested by varying the parameters or data in turn from the reference values. The summary of the outcomes of these sensitivity tests is listed in Table 5. Outputs from the reference case are shown in Figure 14.1 to Figure 14.13.

For the reference case in the east, the estimated value of the virgin spawning stock biomass (SSB) is 8,956t and the 2005 SSB is 1,859t. The SSB level at the end of 2005 as a proportion of virgin is 19% (23% in 2004 and projected to be 15% in 2006 under the current quota). The RBC for 2007 under the 20:48:48 rule is 0 tonnes and 0 tonnes in 2008.

In the west, the estimated value of the virgin SSB is 7,999t and the 2005 SSB is 3,926t. The SSB level at the end of 2005 as a proportion of virgin is 49% (60% in 2004 and projected to be 40% in 2006 under the current quota). The RBC for 2007 is 215 tonnes and 224 tonnes in 2008.

For the fishery, the RBC for 2007 is 215 tonnes and the RBC for 2008 is 224 tonnes. With a 48% target and a 20:40 rule, the RBC for 2007 and 2008 is 251 and 255 tonnes and with a 40% target and a 20:40 rule, the RBC is 315 and 304 tonnes (Table 4a -c).

Projections and depletion beyond 2008 for each of the above rules are listed in Table 4a-c. These suggest a long term sustainable yield of almost 950t (roughly 50:50 east and west). The east is currently more depleted than the west because it has had higher catches in the past.

The 2005 assessment estimated the spawning biomass in 2004 as 39% of the virgin spawning biomass. The current assessment estimates the 2004 spawning biomass as 23% in the east and 60% in the west. With the previous 40% biomass target, the long term sustainable yield is about 1020 tonnes.

Overall, the fits to the data are quite good, thought the eastern assessment does not predict the recent stabilisation of trawl cpue. Both zones had relatively high recruitment during the 1990s, which has subsequently declined. The dome shaped selectivity for the east (both for trawl and Kapala) is very pronounced. While trawl catches predominated, this would have allowed a partial refuge in size for larger ling, but this refuge is increasingly removed as non-trawl catches increase.

14.3.2 Sensitivity tests

The model was run with variations from the reference case. These included excluding the trawl catch-rates, excluding the nontrawl catch-rates and, in the east, changing the steepness term and changing the weighting on length and age data. These are summarised in Table 5. The exclusion of the trawl data had the greatest effect on the current level of depletion.

14.4 Acknowledgements

Kyne KrusicGolub, Matt Koopman, Paula Baker and Anne Gason (PIRVic), Malcolm Haddon and Jeremy Lyle (University of Tasmania), Kevin Rowling (NSW Fisheries) and Neil Klaer (CSIRO) are thanked for providing the data on which the analyses of the assessment are based.

14.5 References

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and Starr, P. 2000. Coleraine – A generalized age structured stock assessment model.

Klaer N. 2003a. Data summary and assessment update for Pink Ling (*Genypterus blacodes*) in the South East Fishery. Ling Workshop 2003, Hobart, Tasmania. .

Klaer N. 2003b. Post workshop assessment update for Pink Ling (*Genypterus blacodes*) in the South East Fishery. June 2003.

Methot, R., 2006. User Manual for the Integrated Analysis Program Stock Synthesis 2 (SS2). Model Version 1.23a.

Pease, B.C. & Grinberg,A. 1995. NSW Commercial Fisheries Statistics1940-92, NSW Fisheries, Sydney.

Punt A. 2006. Updated Stock assessment of Blue Warehou (*Seriolella Brama*) based on data up to 2006. Slope Resource Assessment Group. July 2006.

Taylor, B.L. 2005. Updated stock assessment of Pink Ling (Genypterus blacodes) in the South East Fishery. Slope Resource Assessment Group. August 2005.

Taylor, B.L. 2006a. Comparisons for Pink Ling from Coleraine and SS2 using raw CPUE and 2004 data. Slope Resource Assessment Group. May 2005.

Taylor, B.L. 2006b. Updated stock assessment of Pink Ling (Genypterus blacodes) in the South East Fishery. Slope Resource Assessment Group. July 2006.

Thompson, R. 2000. Report of the workshop on pink ling in the South East Fishery for the South East Fishery Assessment Group.

Thompson, R.B. 2002. South East Fishery data for stock assessment purposes. Draft version. May 2002.

Wayte, S.E. and Smith A.D.M. 2003. South East Fishery species report 2003.

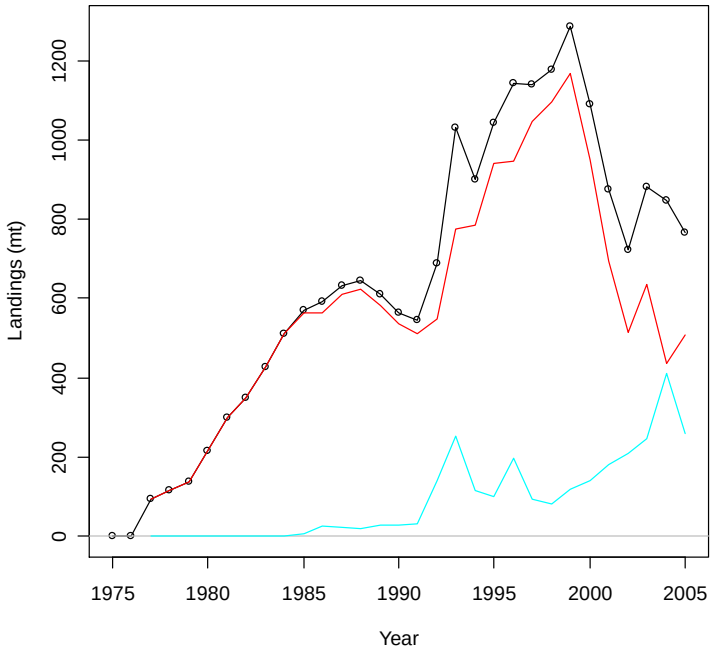


Figure 14.1a. Landed catch for the period 1977 – 2005 for the Eastern Zone. Black (upper) is total catch, red (middle) is trawl catch and blue (lower) is non trawl catch. Some discards are included for 1997 – 2001.

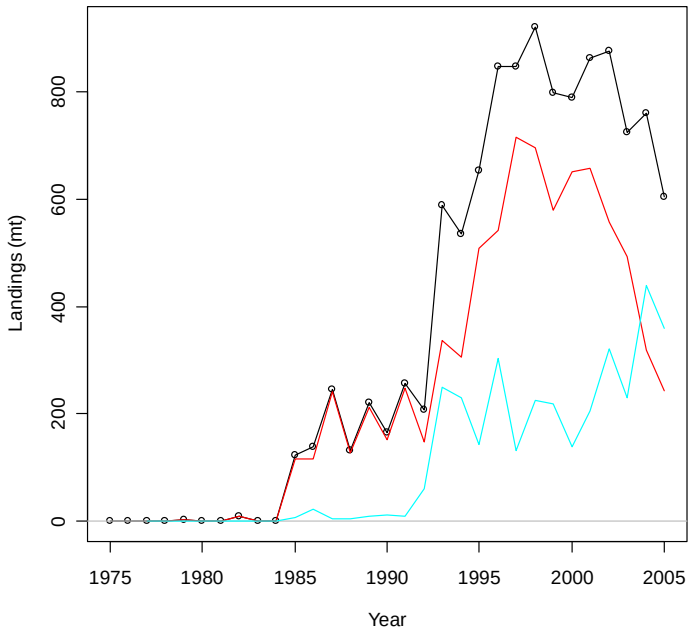


Figure 14.1b. Landed catch for the period 1979 – 2005 for the Western Zone. Black (upper) is total catch, red (middle) is trawl catch and blue (lower) is non trawl catch. Some discards are included for 1997 – 2001.

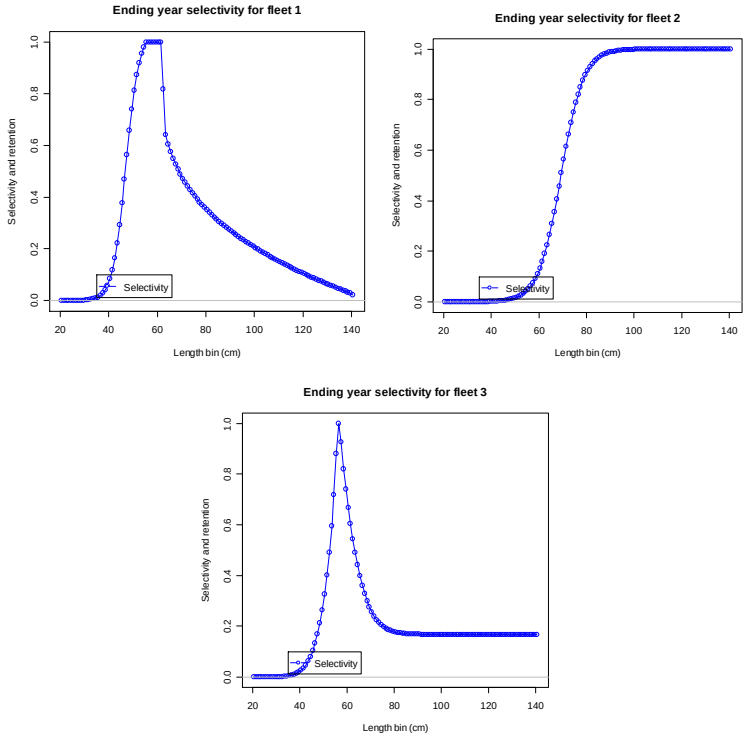


Figure 14.2a. Estimated selectivity at length for trawl (left), non trawl (centre) and Kapala (right) for the Eastern Zone.

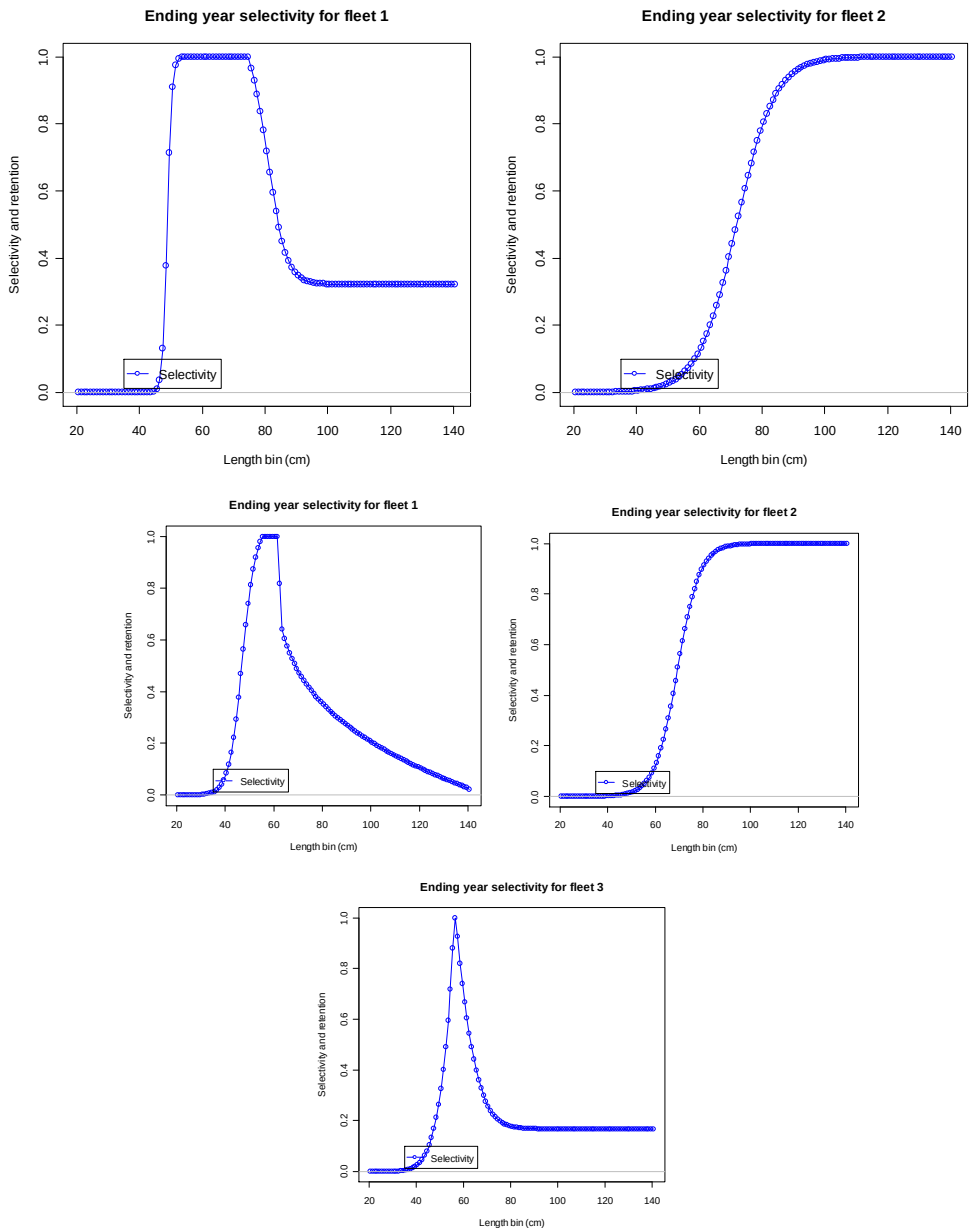


Figure 14.2b. Estimated selectivity at length for trawl (left) and non trawl (right) for the Western Zone.

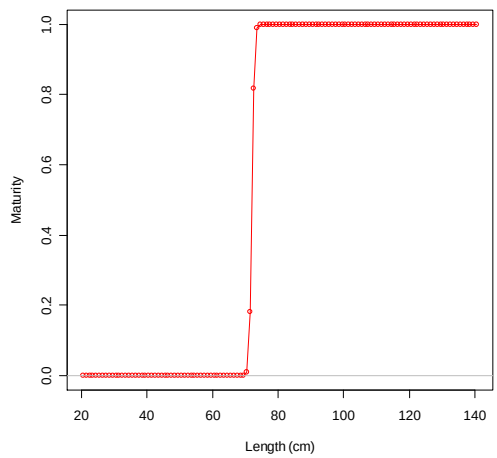


Figure 14.3. Maturity at length.

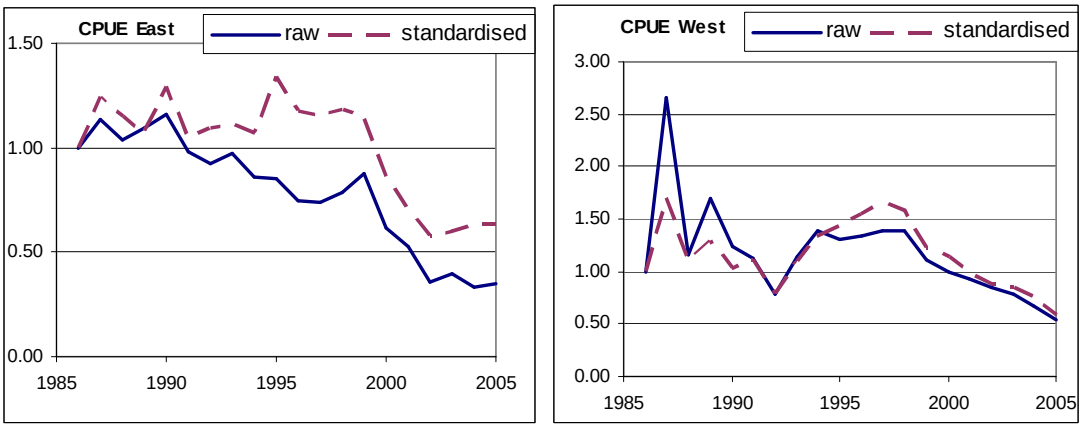


Figure 14.4a. Raw and standardised trawl catch rates for the east (left) and west (right).

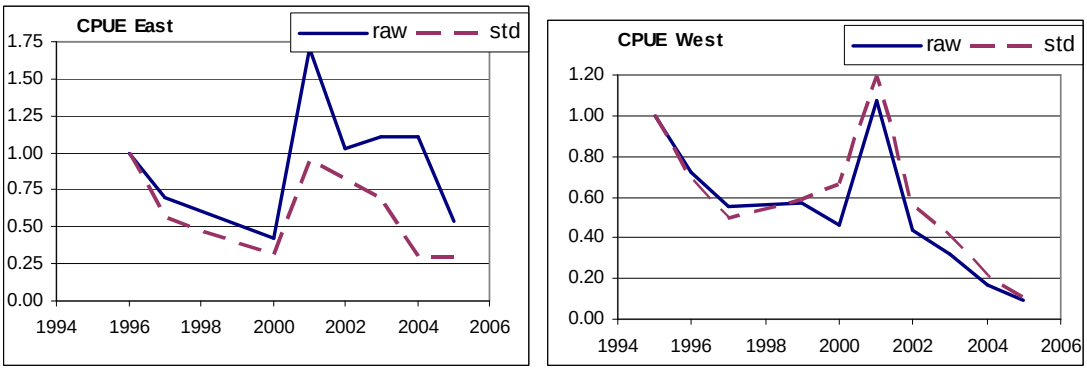


Figure 14.4b. Raw and standardised non-trawl catch rates for the east (left) and west (right).

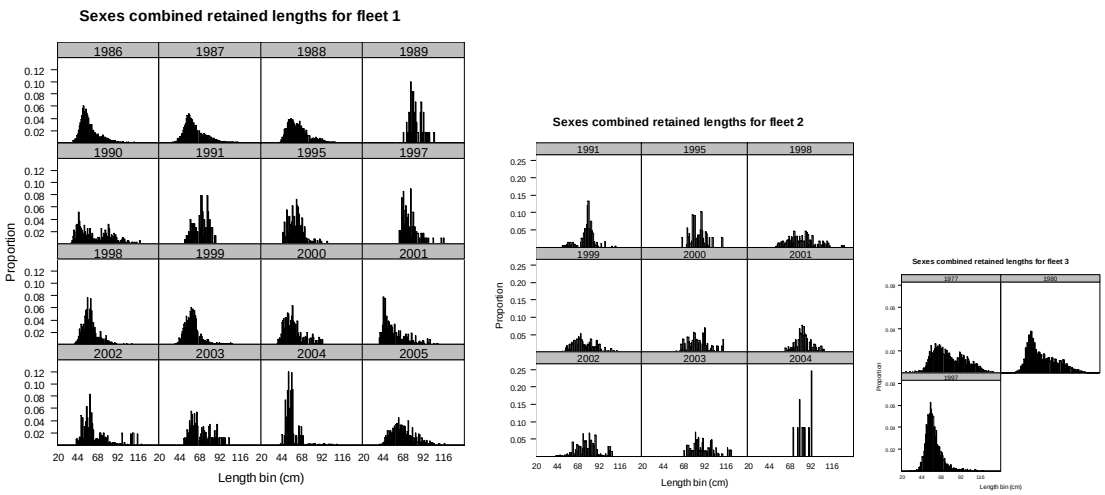


Figure 14.5a.Sydney Fish Market length-frequency composition (1986-90) and port-based trawl data from 1991 (left), port based length-frequency data for non-trawl (centre) and Kapala length-frequency data for the Eastern Zone.

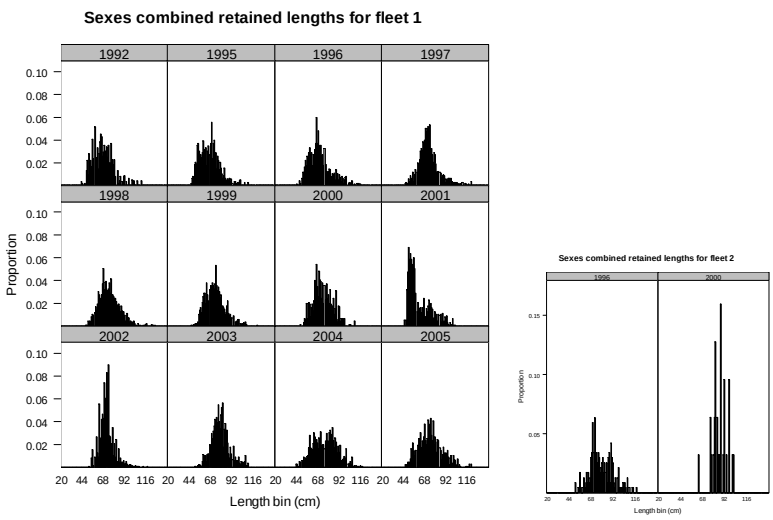


Figure 14.5b. Port based length-frequency composition for trawl (left) and port based length-frequency data for non-trawl (right) in the Western Zone.

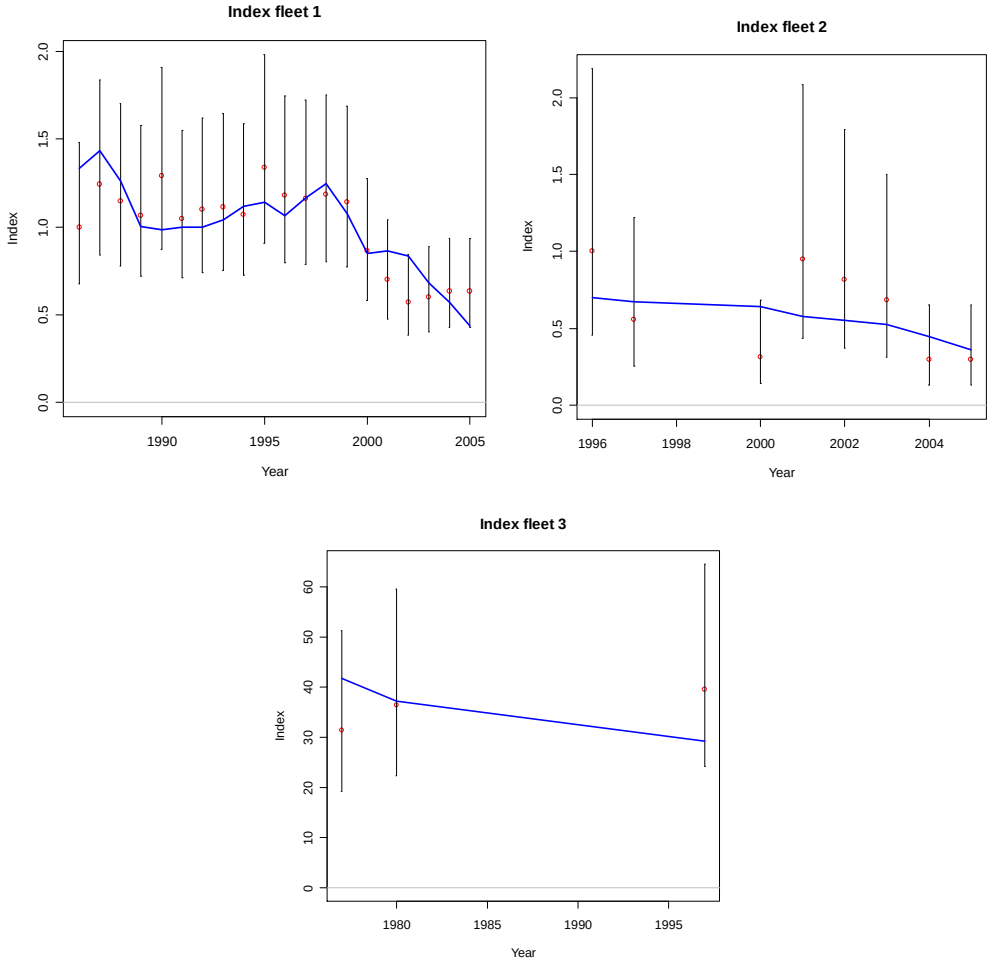


Figure 14.6a. Observed and estimated catch rates for trawl (left), non-trawl (right) and Kapala (below) for the Eastern Zone.

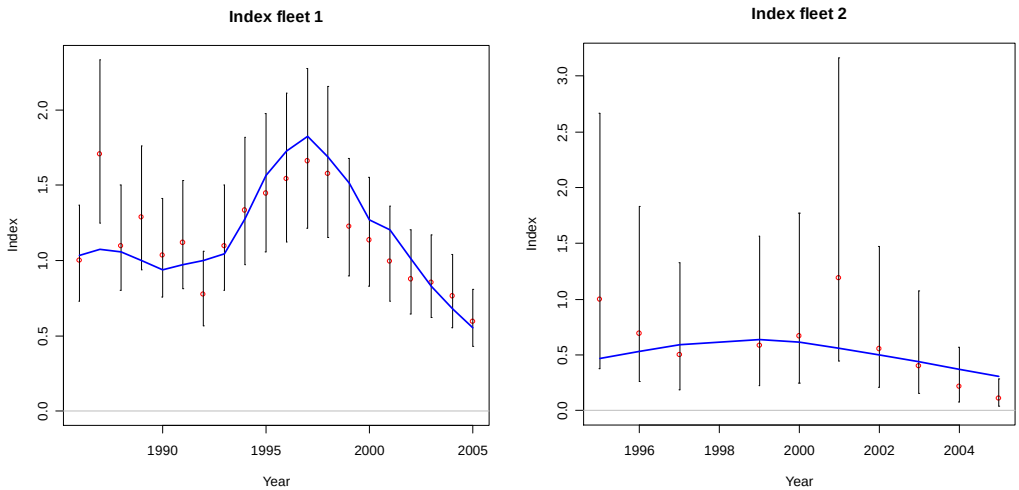


Figure 14.6b. Observed and estimated catch rates for trawl (left) and non trawl (right) for the Western Zone

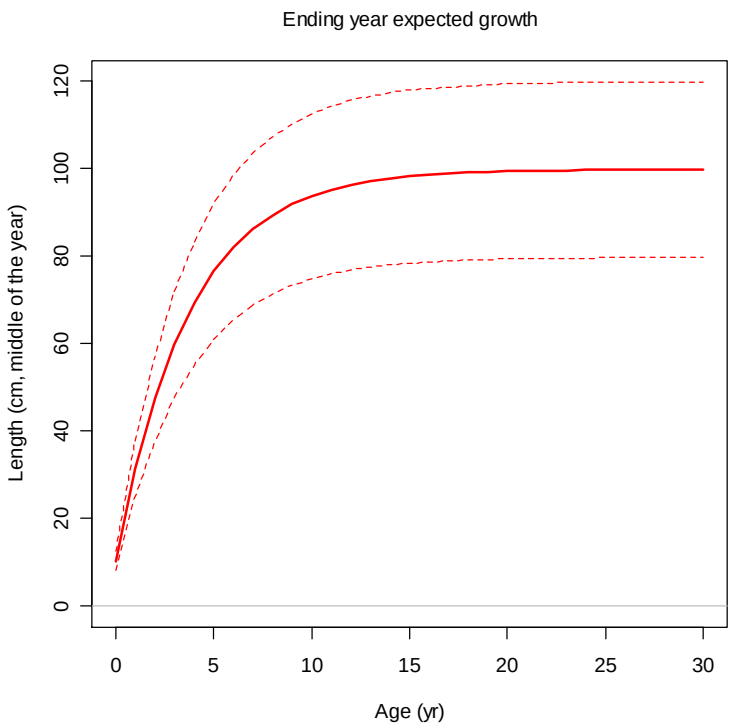


Figure 14.7a. Estimated growth curve for the Eastern Zone.

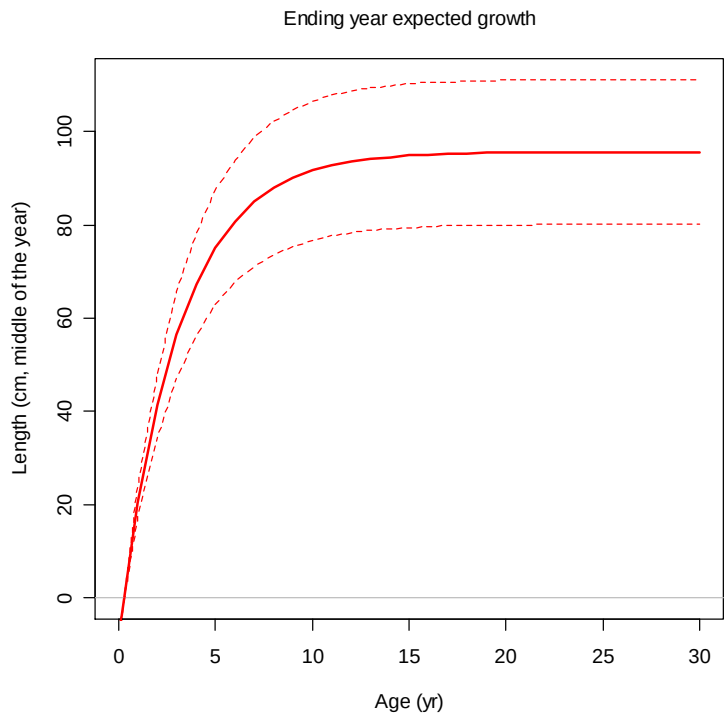


Figure 14.7b. Estimated growth curve for the Western Zone.

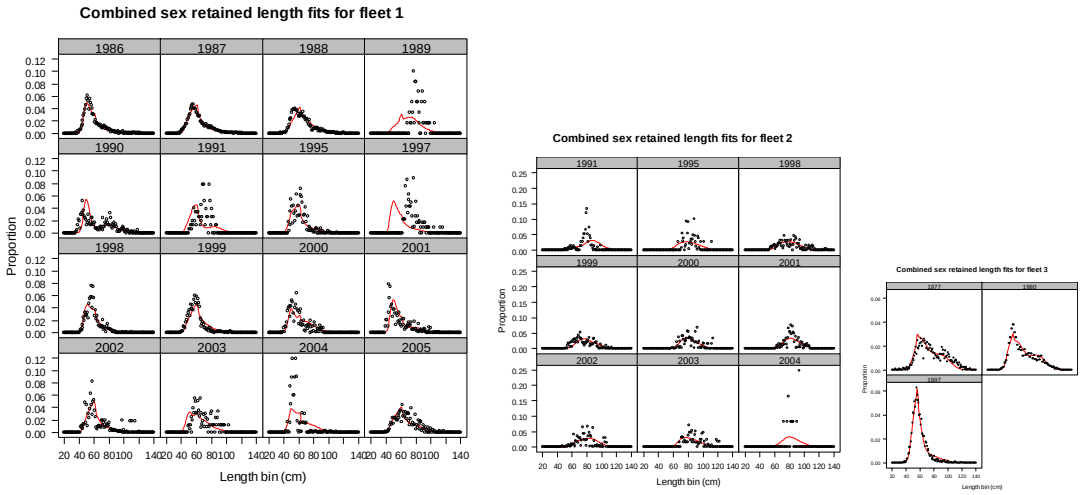


Figure 14.8a. Observed and estimated Sydney Fish Market length-frequency data during 1986 – 1990 and port-based data from 1991 for trawl (left), port based length-frequency composition from 1991 for non-trawl (centre) and Kapala length-frequency data (right) in the Eastern Zone.

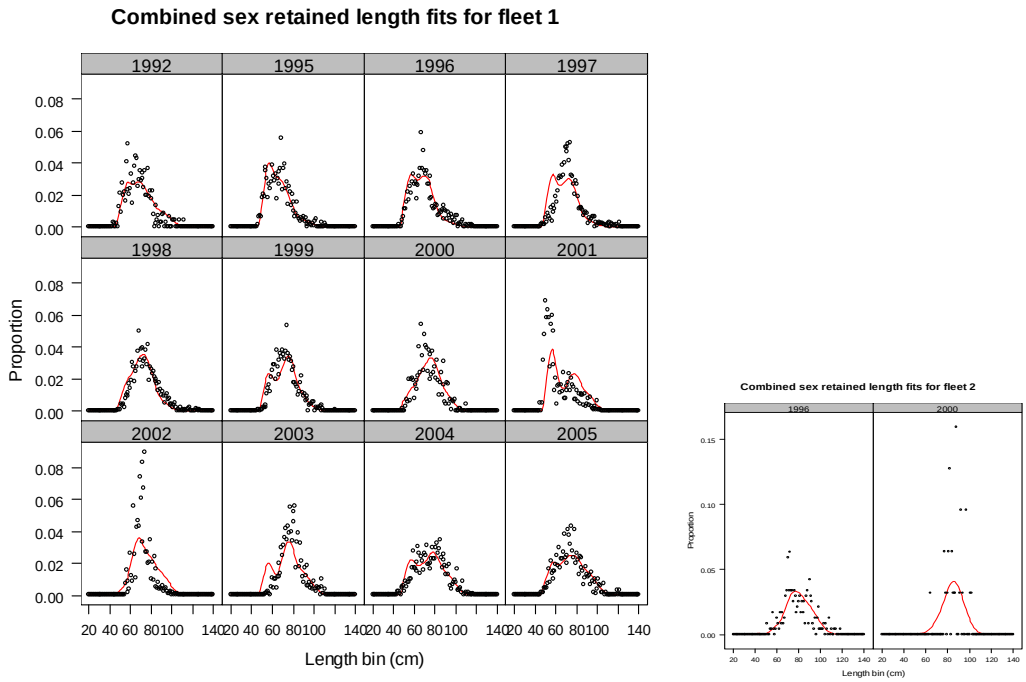


Figure 14.8b. Observed and estimated length-frequency data from 1992 for trawl (left) and for non-trawl (right) in the Western Zone.

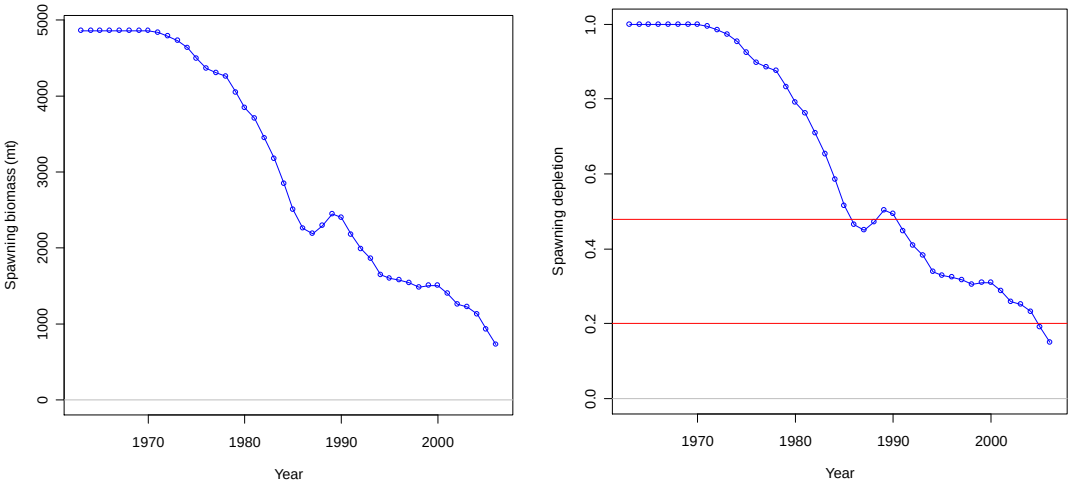


Figure 14.9a. Estimated female spawning biomass (left) and spawning biomass depletion (right) for the Eastern Zone.

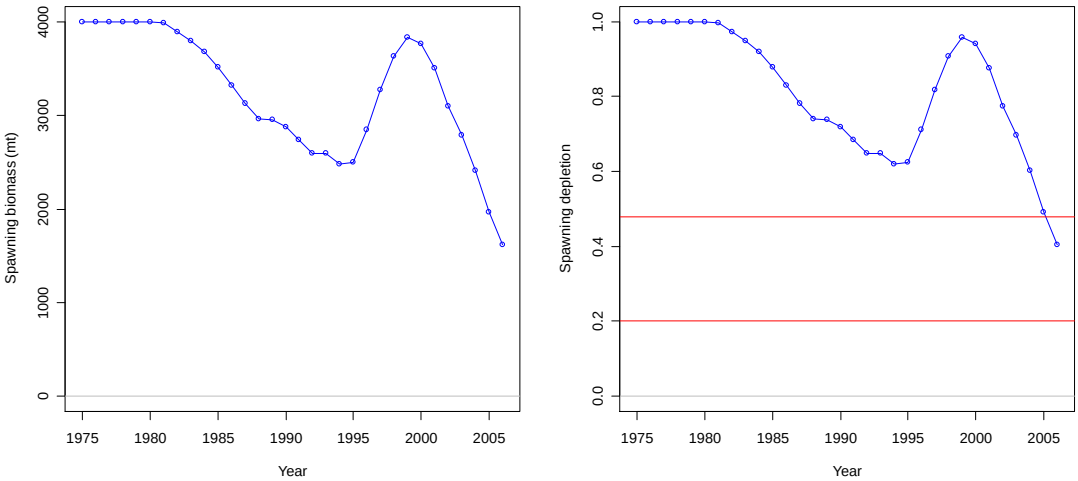


Figure 14.9b. Estimated female spawning biomass (left) and spawning biomass depletion (right) for the Western Zone.

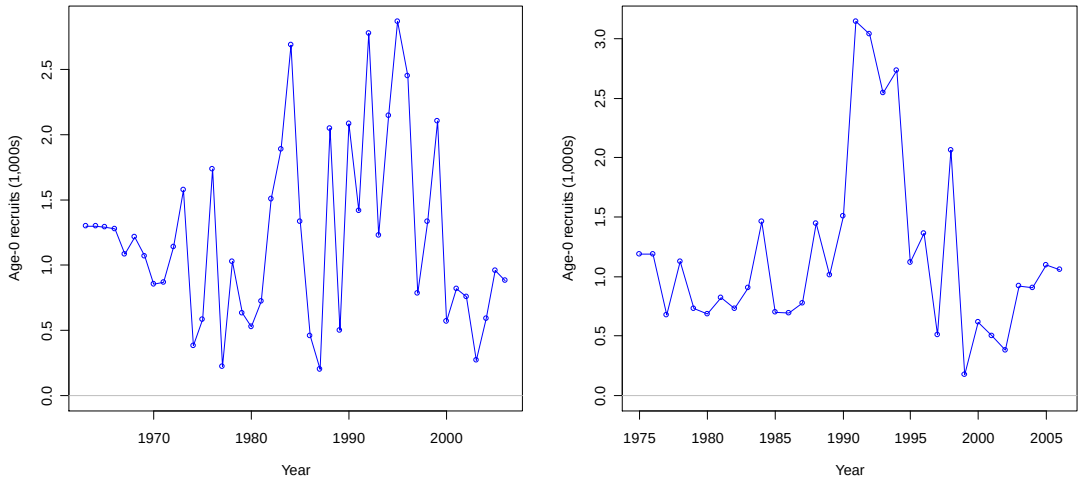


Figure 14.10 Annual recruitment for the Eastern Zone (left) and the Western Zone (right).

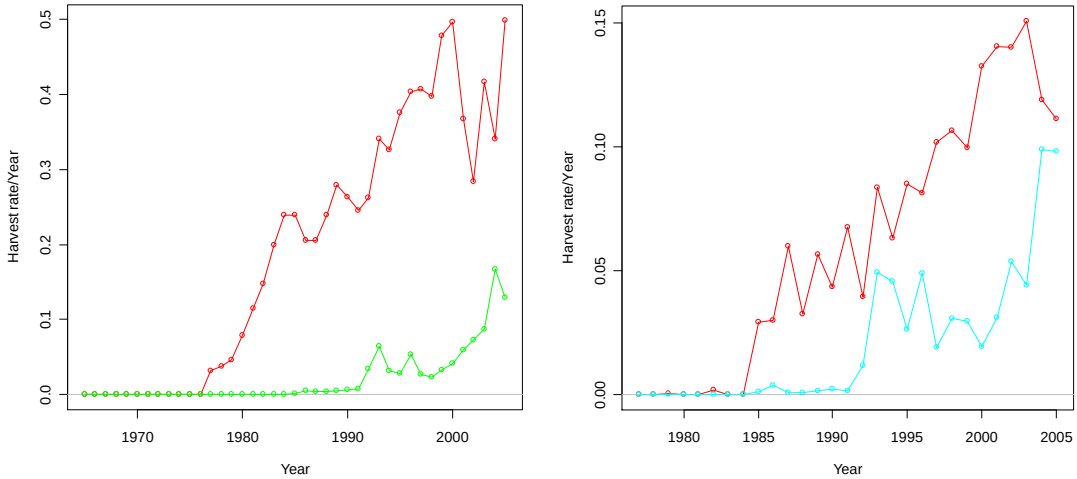


Figure 14.11. Harvest rate by gear type for the Eastern Zone (left) and the Western Zone (right). The harvest rate for trawl is red (upper) and for non-trawl is green/blue (lower).

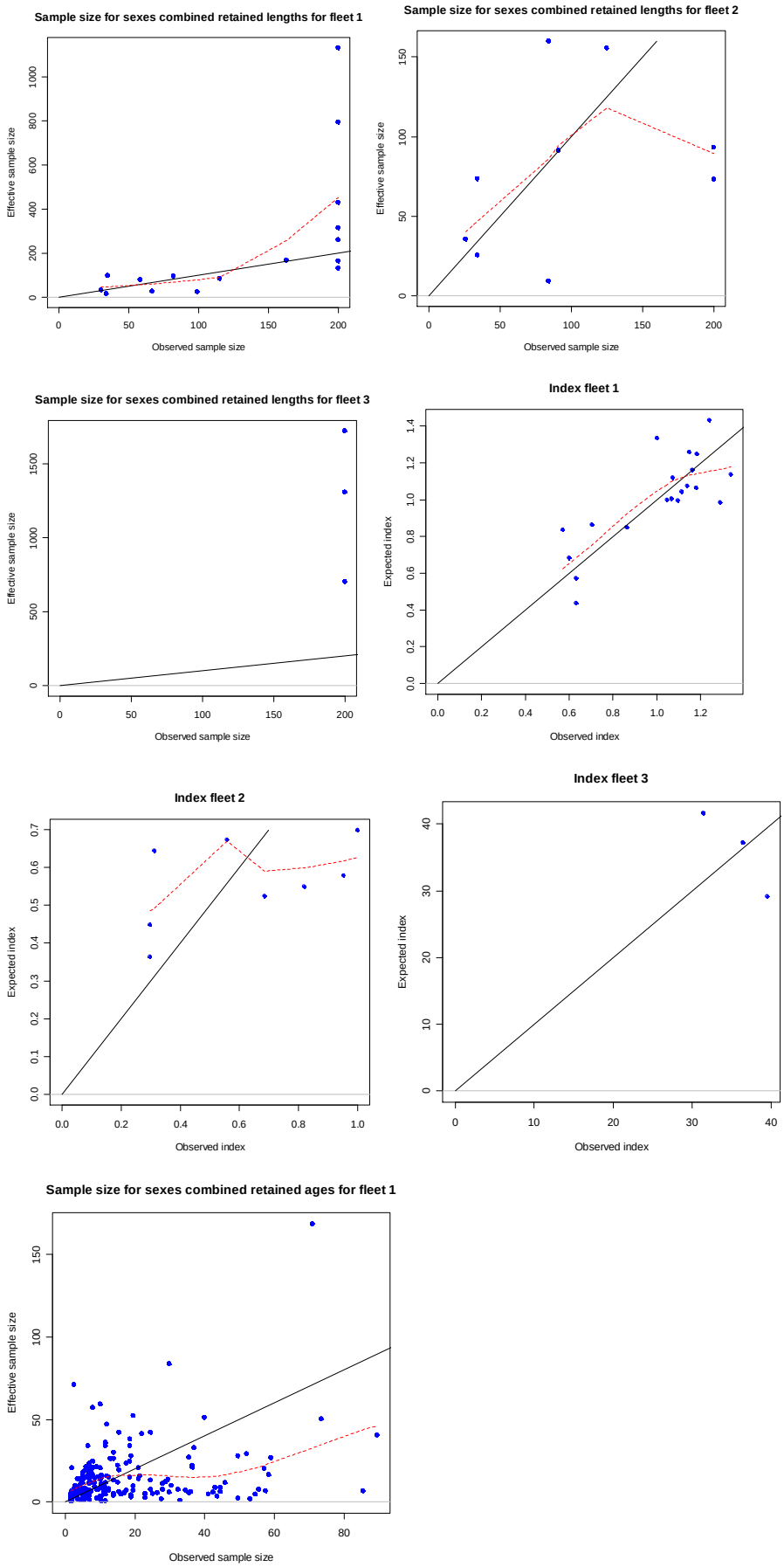


Figure 14.12. Diagnostics from the East (fleet 3 is the Kapala survey).

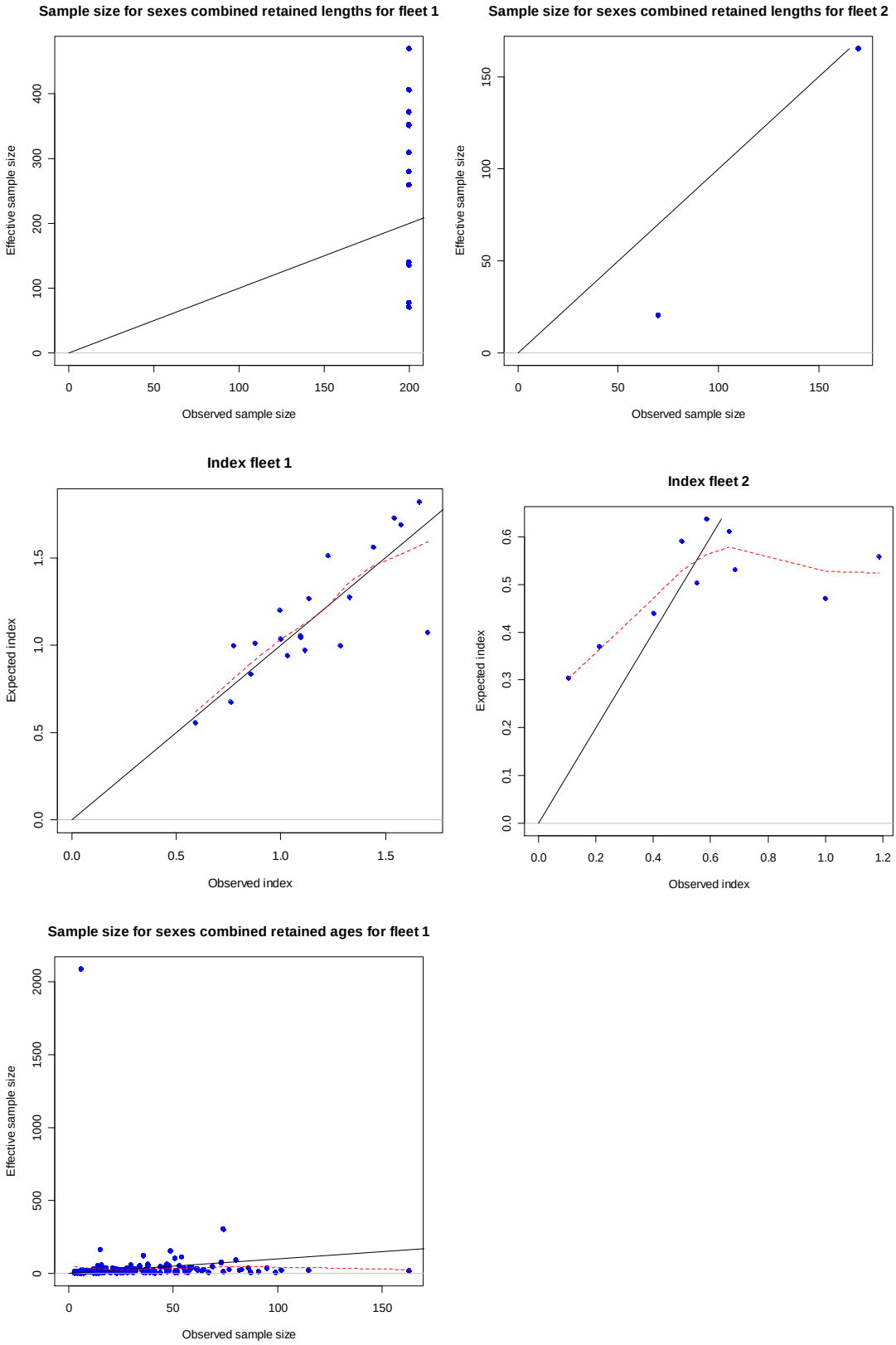
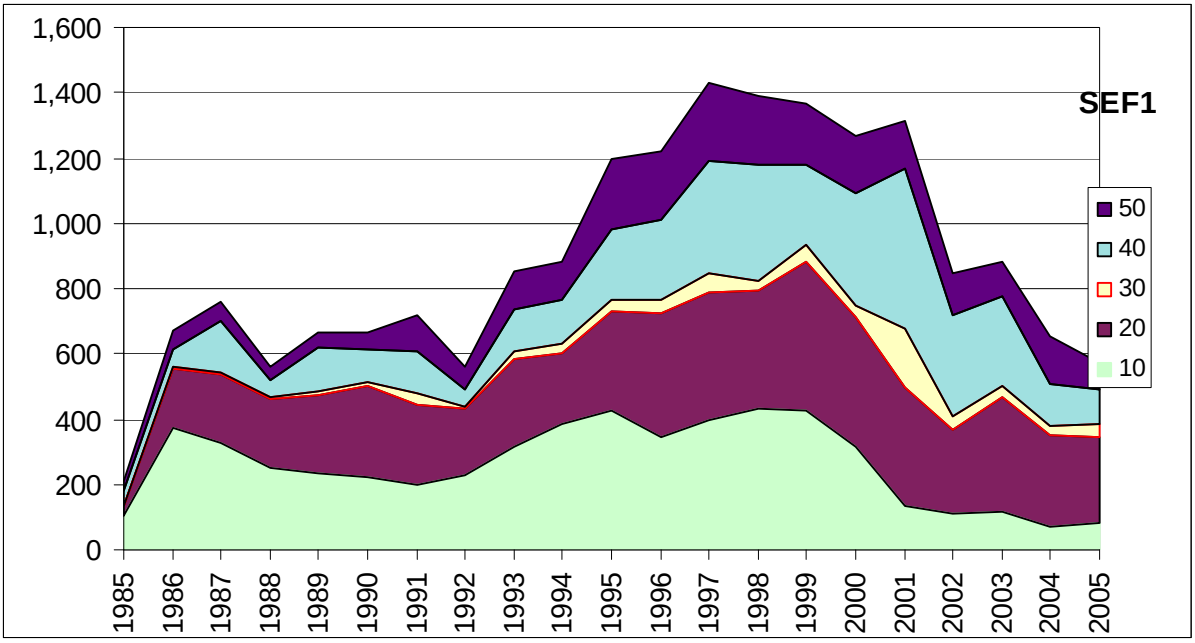


Figure 14.13. Diagnostics from the West.



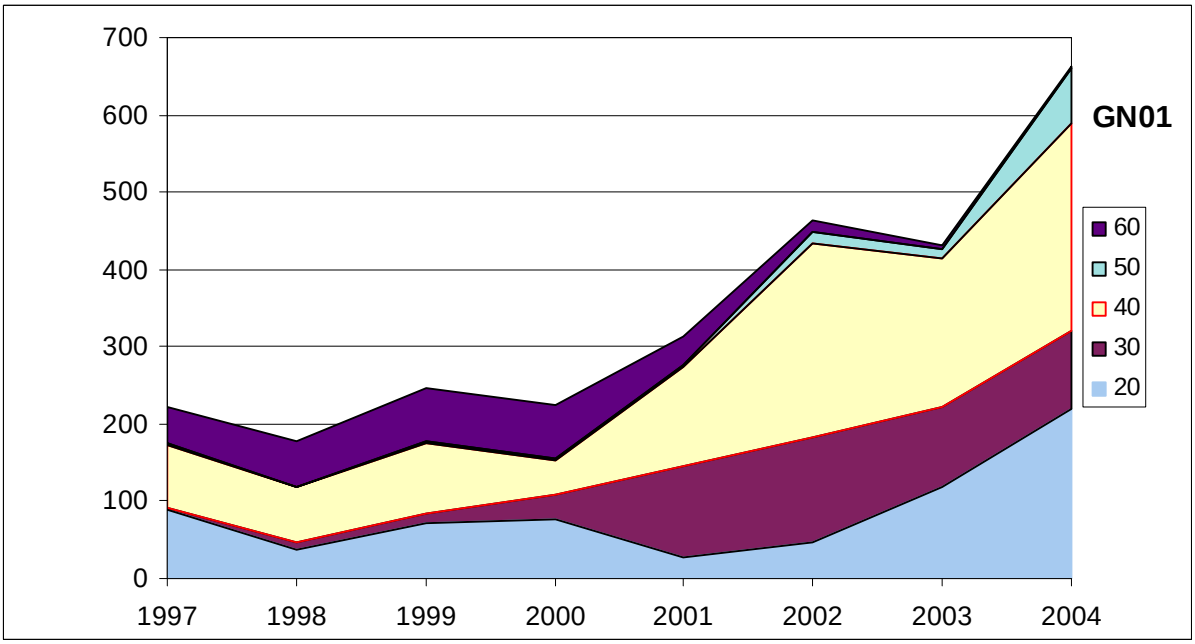


Figure 14.14. Catches (tonnes) from SEF1 (upper) and GN01 (lower) by calendar year, fishing method and zone (5 most fished zones, full data set is in Table 2.

Table 1. Reported catches and estimated discards (1998-2002) for each zone and gear by origin (State or Commonwealth) .

Year	Victoria				Tasmania				NSW		Commonwealth				Total catch (modelled)					Total catch			
	East		West		East		West		East		East		West		East		West			Gear			
	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Trawl	NT	Total	Trawl	NT	East	West
1977									95						95	0			95	95	0	95	0
1978									114						114	0			114	114	0	114	0
1979	1	0	3	0					136						138	0	3	0	140	140	0	138	3
1980	0	0	0	0					215						215	0	0	0	215	215	0	215	0
1981	0	0	0	0					299						299	0	0	0	299	299	0	299	0
1982	8	0	9	0					340						348	0	9	0	357	356	0	348	9
1983	8	0	0	0					419						427	0	0	0	427	427	0	427	0
1984	4	1	0	0					507						511	1	0	0	513	512	1	512	1
1985															564	8	116	8	695	680	15	571	124
1986	1	9	0	4		18		18	3		561	0	116	0	565	27	116	23	730	681	50	592	139
1987	10	18	0	0		4		4	2		597	0	241	0	609	22	241	4	876	850	26	631	245
1988	28	15	0	0		5		5	7		590	0	127	0	625	20	127	5	777	752	25	645	132
1989	33	22	0	2		7		7	2		548	0	212	0	583	29	212	8	832	795	37	611	221
1990	17	20	0	2		10		10	3		515	0	153	0	535	30	153	12	729	688	42	565	164
1991	20	26	0	1		7		7	4		488	0	247	0	512	33	247	9	801	759	42	545	256
1992	36	114	3	0		27		58	2		510	0	145	1	548	141	148	59	896	696	200	689	208
1993	67	177	8	1		76		249	2		707	1	329	1	776	254	337	251	1618	1113	505	1030	588
1994	42	33	0	0		83		228	3		740	1	307	1	785	116	307	229	1437	1092	345	901	536
1995	39	81	0	0		20		143	2		901	0	509	0	942	101	509	144	1697	1452	245	1044	653
1996	36	102	0	2		94		300	6		906	1	543	2	948	197	543	304	1992	1491	501	1145	847
1997		Discards				119		107	5		1040	94	716	132	1045	94	716	132	1987	1761	226	1139	848
1998		25		73		3		3	4		1000	52	692	150	1098	80	696	226	2100	1794	306	1178	922
1999		16		30		11		11	3		1158	92	543	178	1169	118	581	219	2087	1750	337	1287	800
2000		7		8					10		938	121	651	130	949	141	652	138	1880	1601	279	1090	790
2001		2		3					6		688	174	657	202	695	180	659	205	1738	1353	385	874	864
2002		3		4							514	206	557	316	514	208	557	321	1600	1071	529	723	877
2003											636	246	493	231	636	246	493	231	1607	1130	477	883	725
2004											438	410	320	441	438	410	320	441	1608	758	851	848	760
2005											508	260	245	360	508	260	245	360	1372	753	619	768	604
2006	(assumed)														444	227	214	315	1200	658	542	671	529

Notes: Zero catches are those with less than 0.5 tonne, all catches are rounded to the nearest tonne.
Catches with unknown gear are reported as non-trawl (for NSW, it is included in trawl catches)
SEF1 was inroduced in 1985.
Estimated discards are only listed underneath Victoria for convenience.
The 2006 catch is assumed to total to the quota, and follow the 2005 proportions for gear type and east/west split.

Sources Pearce (1995), Wayte & Smith(2003), PIRVic data set (July 2006), Klaer (2003b) data

Table 2. Catch summary from SEF1 and GN01 by calendar year, fishing method and zone

Year	Records	Catch(t) Zone 10	20	30	40	50	60	80	East	West	Total
SEF1											
1985	1,992	105	30	1	47	29	0		135	76	213
1986	7,868	371	185	3	52	63	1		559	115	679
1987	7,041	325	214	3	160	56	3		542	219	765
1988	6,242	251	209	5	54	43	3		465	100	567
1989	6,943	236	237	9	139	46	2		482	187	672
1990	5,942	222	281	12	101	49	2		514	153	668
1991	7,157	201	242	33	133	107	1		477	242	735
1992	6,489	230	203	7	48	71	6		441	125	567
1993	8,455	314	272	21	130	118	35		607	283	892
1994	9,728	386	213	31	134	116	11		630	261	895
1995	11,722	427	303	37	215	216	2		767	433	1,209
1996	11,829	345	378	43	243	215	1		765	458	1,231
1997	13,420	398	392	60	343	240	1		850	584	1,444
1998	12,907	434	359	28	356	210	2		821	569	1,394
1999	14,087	428	456	50	248	188	2		933	438	1,372
2000	14,379	317	393	38	345	171	3		748	520	1,269
2001	14,877	133	367	179	492	143	36		678	671	1,389
2002	12,906	114	255	39	311	130	1		408	442	851
2003	12,863	118	350	34	275	107	3		502	385	887
2004	11,217	69	282	30	126	150	2		381	278	659
2005	10,443	83	260	44	104	83	1		387	188	575
GN01											
1997		1	90	1	83	2	45	0	92	130	223
1998		0	38	8	72	1	59	0	46	132	178
1999		0	72	12	91	3	68	0	84	162	246
2000		0	76	32	46	3	67	0	108	116	223
2001		1	27	117	130	1	39	0	145	169	315
2002		0	48	135	250	15	16	0	183	281	464
2003		0	119	104	193	12	4	0	222	208	431
2004		0	218	101	270	72	1	50	320	393	713

Note: These catches are from SEF1 and GN01, hence they differ from the catches in table 1 which are based on SEF2 and SAN2. These catches are scaled to the SEF2 and SAN2 totals for modelling.

Table 3. Set parameters and values used in the reference case

Parameter or value		East	West
Biological parameters			
Age classes		Ages 0-20+	
Length classes		Lengths 20-140 cm	
Natural mortality		0.2 for all ages	
Length weight coefficients		a=0.00293, b=3.1	
Maturity logistic curve		inflection=72 cm, slope=-3.0	
SR steepness		0.75	
σ_R		0.6	
Data used			
Catch-rates (CV)	Trawl	0.2	0.16
	Nontrawl	0.4	0.5
	Survey	0.25	
Length-frequency sample size		Nsamp / 3	Nsamp / 2
Age at Length sample size		Nsamp / 2	Nsamp / 1.3
Ageing error		yes	yes
Catch		1977-2005	1979-2005
Catch-rates (CV)	Trawl	1986-2005	1986-2005
	Nontrawl	1996-2005	1995-2005
	Survey	1977,1980,1997	
Number of records (years)			
Length-frequency	Trawl	16	12
	Nontrawl	9	2
	Survey	3	
Age at Length		16	14

Note: Max effective sample size set to 200

Table 4a. Current and projected depletion and RBC under the 20:48:48 rule

Year	East		West		Total
	B/B0	RBC (t)	B/B0	RBC (t)	RBC (t)
2003	0.25		0.70		
2004	0.23		0.60		
2005	0.19		0.49		
2006	0.15		0.40		
2007	0.11	0	0.33	215	215
2008	0.11	0	0.33	224	224
2009	0.14	0	0.34	262	262
2010	0.19	0	0.37	311	311
2011	0.25	94	0.40	353	447
2012	0.29	178	0.42	381	559
2013	0.33	235	0.44	400	635
2014	0.35	279	0.44	414	693
2015	0.37	315	0.45	425	740
2016	0.39	346	0.46	433	780
2017	0.41	373	0.46	441	813
2018	0.42	395	0.47	446	841
2019	0.44	412	0.47	451	863
2020	0.45	425	0.47	454	880
2021	0.45	436	0.47	457	893
2022	0.46	444	0.47	459	903
2023	0.46	450	0.48	461	911
2024	0.47	455	0.48	462	917
2025	0.47	459	0.48	463	922

Note: B/B0 at end of year

Table 4b. Current and projected depletion and RBC under the 20:40:48 rule.

Year	East		West		Total
	B/B0	RBC (t)	B/B0	RBC (t)	RBC (t)
2003	0.25		0.70		
2004	0.23		0.60		
2005	0.19		0.49		
2006	0.15		0.40		
2007	0.11	0	0.33	251	251
2008	0.11	0	0.32	255	255
2009	0.14	0	0.33	292	292
2010	0.19	0	0.35	344	344
2011	0.25	110	0.37	387	497
2012	0.29	204	0.39	410	615
2013	0.32	267	0.40	417	684
2014	0.34	312	0.40	424	736
2015	0.36	349	0.41	430	778
2016	0.38	380	0.41	435	815
2017	0.39	406	0.41	440	845
2018	0.41	421	0.42	444	864
2019	0.42	427	0.42	447	874
2020	0.42	433	0.42	450	883
2021	0.43	439	0.46	452	891
2022	0.44	443	0.46	455	898
2023	0.44	447	0.47	456	903
2024	0.45	450	0.47	458	908
2025	0.45	453	0.47	459	913

Table 4c. Current and projected depletion and RBC under the 20:40:40 rule

Year	East		West		Total
	B/B0	RBC (t)	B/B0	RBC (t)	RBC (t)
2003	0.25		0.70		
2004	0.23		0.60		
2005	0.19		0.49		
2006	0.15		0.40		
2007	0.11	0	0.33	315	315
2008	0.11	0	0.32	304	304
2009	0.14	0	0.32	338	338
2010	0.19	0	0.34	392	392
2011	0.25	136	0.37	437	573
2012	0.29	248	0.38	463	711
2013	0.32	316	0.39	476	792
2014	0.33	361	0.39	484	845
2015	0.35	396	0.39	489	885
2016	0.36	425	0.39	494	919
2017	0.37	449	0.39	498	947
2018	0.38	467	0.40	501	968
2019	0.38	480	0.40	504	984
2020	0.39	490	0.40	506	995
2021	0.39	497	0.40	507	1003
2022	0.39	501	0.40	508	1009
2023	0.40	505	0.40	508	1013
2024	0.40	507	0.40	509	1016
2025	0.40	509	0.40	509	1018

Table 5. Biomass estimates, depletion and RBC for the reference case and a range of sensitivity scenarios.

	spB0	B2006	B2006/B0	B2007/B0	RBC2007	B2008/B0	RBC2008	likelihood	
East									
Reference case (20:48:48)	9727	1468	0.15	0.11	0	0.11	0	2071.1	
Reference (20:40:40 rule)	9727	1468	0.15	0.11	0	0.11	0	2071.1	
Reference (20:40:48 rule)	9727	1468	0.15	0.11	0	0.11	0	2071.1	
No trawl cpue	9082	765	0.08	0.04	0	0.04	0	2071.6	#
No nontrawl cpue	10582	1516	0.14	0.10	0	0.11	0	2073.9	#
Lambda(Age) = 0.5	9690	1470	0.15	0.11	0	0.12	0	1512.5	#
Lambda(Length) = 0.5	10625	1728	0.16	0.13	0	0.13	0	1595.5	#
No Kapala data	10189	1703	0.17	0.12	0	0.13	0	2022.5	#
steepness=0.9	9154	1458	0.16	0.12	0	0.12	0	2074.1	
steepness=0.65	10137	1427	0.14	0.10	0	0.10	0	2082.8	
West									
Reference case (20:48:48)	7999	3230	0.40	0.33	215	0.33	224	1968.0	
Reference (20:40:40 rule)	7999	3230	0.40	0.33	315	0.32	304	1968.0	
Reference (20:40:48 rule)	7999	3230	0.40	0.33	251	0.32	255	1968.0	
No trawl cpue	18806	16265	0.86	0.78	1333	0.69	1251	1951.3	#
No nontrawl cpue	8678	3945	0.45	0.38	305	0.36	300	1972.4	#
Lambda(Age) = 0.5	8224	3363	0.41	0.34	208	0.32	205	1241.7	#
Lambda(Length) = 0.5	6585	2045	0.31	0.25	72	0.26	94	1733.9	#

The negative log likelihood is not comparable to that in the reference case.

15. 2006 Assessment Report for Spotted Warehou

Bruce Taylor[1]

[1]Primary Industries Research Victoria, Queenscliff, Victoria, 3225, Australia

The model was not updated in 2006.

The results from the 2004 assessment were used to calculate RBCs for 2007. This involved projecting the maximum likelihood estimates of the numbers-at-age at the start of 2004 from the 2004 assessment forward to 2007 to estimate the numbers-at-age at the start of the biological year for spotted warehou (1 May). Fecundity-at-age and selectivity-at-age were set to the values estimated during the 2004 assessment. Mean weight-at-age at mid-year (needed to calculate the RBC) was set to the average of the mean weights-at-age at the start and end of the year.

The assumed catches for 2004 - 2006 were 3,500t, and the discard rate was set to the average historic discard rate (9.6%).

Application of the Tier 1 rules to calculate the 2007 RBC differs from how these rules were applied last year because account is taken this year of the steepness of the stock-recruitment relationship (0.75). B_0 was set to the reference biomass (the average biomass estimated for the 3 years 1986/87 to 1988/89). The 2007 depletion is $0.484B_0$.

A target of 48% and either the 20:48 or the 20:40 rule leads to an RBC for 2007 of 2,841 tonnes. With a target of 40%, the RBC for 2007 is 3,662 tonnes. The RBC for the range of tier 1 and tier 2 rules are summarised below.

Tier 1 rule	**RBC (t)**
20:48:48	2841
20:40:48	2841
20:40:40	3662

Tier 2 rule	**RBC (t)**
20:60:60	1346
20:50:60	1795
20:50:50	2523

16. Stock Assessment of Jackass Morwong (*Nemadactylus macropterus*) and RBC Calculations for 2007 Using Data up to 2005

Gavin Fay[1]

[1]School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195, USA

16.1 Summary

This document updates the 2004 assessment of jackass morwong (*Nemadactylus macropterus*) in the eastern areas of the SESSF to provide estimates of stock status in 2006. The age-structured stock assessment model is re-fit using the same software package (Coleraine) to take advantage of data that have become available since the last assessment. Changes to the 2004 assessment model include the addition of age and length composition data for 2003-2005, the updating of standardised CPUE indices for the otter trawl fleets for 1986-2005. As with the 2004 assessment, no consideration is made for discarding, or for catches from areas west of Tasmania. The assessment results are sensitive to the data included when calculating the standardised CPUE indices. Base-case estimates of 2006 spawning depletion when the model is fit to the updated CPUE indicate that the stock is at low levels, around 15% of the unfished equilibrium state. This leads to 2007 recommended biological catches (RBCs) of zero under all tier 1 and tier 2 harvest control rules (HCRs). If the model is fit to the new age and length data but uses the CPUE indices in the previous assessment, estimates of current stock status are more optimistic, with 2006 spawning depletion estimated to be 35% of the unfished state. As with the 2004 assessment, model results are sensitive to the values for h and M. For the base-case, the stock is therefore assessed to be below the tier 1 and tier 2 target biomass values. 2007 RBCs using the 2004 CPUE range from 787–1,540 mt under tier 1, and from 337–677 mt under tier 2.

Estimates of stock status and RBCs are lower than those calculated in 2005. Retrospective analyses show the differences are largely due to additional age data for the years 1991-2002 that have become available since the previous assessment, but are also a result of the assessment update estimating negative recruitment residuals for 2002 and 2003. Sensitivity analyses that fit to a new CPUE index from the ISMP data are slightly more optimistic regarding stock status than the base-case assessment update, suggesting that the stock is slightly above 40% of the unfished spawning biomass. Due to the sensitivity of the results to the standardised CPUE indices, it is of extreme importance to determine what CPUE data are representative of changes in relative abundance. Recommendations for future assessments include moving to the Stock Synthesis 2 (SS2) assessment software, in order to accommodate many of the technical shortcomings of the current modelling

approach highlighted by Fay (2004), and accounting for the western areas of the SESSF. Inclusion of discard data available from the ISMP (onboard length frequencies) would improve the ability to estimate the recruitment levels in recent years, which impact the calculation of the RBC.

16.2 Background

16.2.1 History of the fishery

Jackass morwong have been landed in southern Australia since the inception of the steam trawl fishery off New South Wales in the early twentieth century (Fay 2004). Catches of jackass morwong rose to a peak of 1,600 t in 1989. They have since dropped, but have remained relatively stable at between 700 and 1,000 t. Landings of jackass morwong in the eastern zones (New South Wales, eastern Victoria, eastern Bass Strait, and east Tasmania) in 2005 were 528 mt, while 2005 landings from the western areas were 205 mt. Trawl catches of morwong in these latter areas has increased substantially since 2001 (Fay 2004).

16.2.2 Previous assessment

The 2004 assessment for jackass morwong (*Nemadactylus macropterus*) by Fay used a generalised age-structured modelling approach to assess the status and trends of the jackass morwong trawl fishery in the eastern zones, using data from the period 1915-2002. Although data were provided for the western areas of the SESSF, these data were not included in the assessment, as it is not clear these landings are from the same stock as that from which the landings in the east are taken. Results indicated that morwong in the eastern areas appeared to be somewhere around 25-45% of 1915 spawning biomass in 2003. The projection results presented indicated that, given the assumptions in the base-case scenario, the recent removals from the eastern areas are perhaps sustainable. Sensitivity analyses that provided a more pessimistic prediction of 2003 stock status unsurprisingly suggested that a lower TAC than that suggested by the base-case analysis may be appropriate.

Following the adoption of a harvest strategy framework (HSF) for the SESSF in 2005, the 2004 assessment was used to calculate recommended biological catch (RBC) for jackass morwong in eastern areas under both tier 1 and tier 2 harvest control rules (HCRs) using a simple projection under mean recruitment (Fay 2005). 2006 spawning biomass was estimated to be 44% of virgin spawning biomass, with tier 1 and tier 2 RBCs calculated as 2,082 mt and 1,436 mt respectively (Fay 2005). The calculated Tier 2 RBC corresponded well with the results of projections conducted in the 2004 assessment.

16.3 Description of assessment update

This stock assessment for jackass morwong in eastern areas updates the 2004 assessment by including data from 2003 to 2005. The updates uses the same modelling approach as the 2004 assessment (Coleraine, Hilborn et al. 2003) to fit to these and the 1915-2002 data. The majority of the framework, fleet definitions, parameterisation, and technical properties remain the same as the previous assessment and are described in full in Fay (2004). These details are not repeated here, instead this document focuses on providing details of changes made.

16.3.1 Data

The data used for model fitting purposes are updated by including catch, effort, age, and length data for eastern areas for the years 2003-2005 that has become available since the last assessment. The updated assessment model then includes landed catches by fleet (1915–2005), and is fitted to catch-rate data (numerous indices covering years from 1918–2005), length-frequency data (1947-66, 1991–2005), and age-composition data (1991–94, 1996-97, 1999-2004).

The landed catches for 2003-2005 (Table 16.1) were calculated by multiplying the fleet-specific values from the SEF1 logbook database by 1.128, obtained in the 2004 assessment by finding the average annual difference among these numbers and SEF2 landings data for 1995-2002. Recalculation of the 1986-2002 landings due to the addition of recent catch data caused minimal changes to the time series of catches used, and so the previous (2004) catch time series was used.

Age compositions for 2003 and 2004 are included for the NSW/EVic/BS, and East Tasmania otter trawl fleets (fleets 3 and 5), and 2004 for the Danish seine fleet (fleet 5, Table 16.2a). Length compositions from port data are included for 2005 for all three fleets (Table 16.2b), with the 2003 and 2004 port length data being used to construct the catch-at-age for these years. The age data from 1991-2002 were updated from the 2004 assessment, to take account of age samples from these years that had become available since the previous assessment. This translated to an additional 358 ages over the period.

The 2004 assessment fitted the population dynamics model to standardised CPUE indices for both otter trawl fleets (fleets 3 and 5) from 1986-2002. These CPUE indices were updated (Haddon 2006) to extend the time series to 2005 based on the additional catch and effort data from the SEF1 logbook database. A standardised CPUE series for the Danish Seine fleet (fleet 4) was also available (Haddon 2006). The resulting indices are shown in Table 16.3. The updated indices are more pessimistic than those used in the 2004 assessment (Figure A.1, Section 16.7), with the general trend being sensitive to the data included in the standardisation : the 2006 analyses included all tows with catch rates > 0 whereas those in the previous assessment excluded tows that caught < 30kg of morwong (Appendix A, Section 16.7). The increasing discrepancy between the two methods with time results from

an increase in the proportion of morwong records with a catch < 30kg from 15% in 1990 to over 50% in recent years (Malcolm Haddon, pers. commn.). A 30kg tow appears now to be somewhat typical for catches of morwong. Two standardised CPUE indices based on ISMP data were also made available for the eastern areas for 1994-2005, resulting from data using a) just targeted shots, and b) all shots catching morwong. Both these indices were highly variable. The former of these had very low sample size for those years in which targeted shots were available for analysis. The CPUE index for all shots using these data is shown in Table 16.4.

16.3.2 Biological parameters

16.3.2.1 Growth

Age and length measurement pairs for jackass morwong for the years 2003-2005 were used to re-estimate the von Bertalanffy growth curve for the species (both sexes combined). This resulted in estimates of L_∞, K, and t_o of 37.15 cm, 0.166 yr^{-1}, and -4.168 yr respectively. Fixing the value of t_o at zero (as per Fay 2004) led to estimates of L_∞ and K of 34.2 cm and 0.411 yr^{-1}, which are almost identical to the 2004 estimates (34.2 cm and 0.42 yr^{-1}). The 2004 growth curve parameters were therefore used in the assessment update.

16.4 Analytical Approach

16.4.1 Population dynamics model

As with the 2004 assessment, a single-sex population dynamics model for jackass morwong was fitted to the available data using the software package Coleraine (version 3.2; Hilborn *et al*, 2003). Additional estimated parameters to those described in Fay (2004) included recruitment residuals for 2003-2005.

16.4.2 Base-case and sensitivity analyses

The base-case analyses reflect a 'most' likely' set of assumptions. Sensitivity tests then examine the sensitivity of the model outputs to changes to these assumptions. The scenario representing the base-case from the previous assessment (h=0.7, M=0.15, σ_R=0.3) was used to fit the population dynamics model to the updated data set. Two versions of the base-case model are presented, which fit to either the updated CPUE indices for fleets 3 and 4 (1986-2005), or the indices for these fleets from the previous assessment (1986-2002).

Given the update nature of the assessment, a limited number of sensitivity tests were run, which addressed some of the key areas of uncertainty highlighted in the 2004 assessment. Standardized CPUE to 2005 for the "≥ 30kg" cut-off rule was not available, so an additional sensitivity analysis was conducted that fit the model to the geometric mean CPUE for fleet 3 given this cut-off for 1986-2005. The standardised CPUE for morwong differs only slightly from the geometric mean of

the data set used, despite accounting for a large proportion of the variance (Haddon 2006, Fay 2004, Malcolm Haddon, pers. comm.) and so it is likely that fitting to the geometric mean of the alternative data set would provide essentially the same estimates as a standardized index.

16.4.3 Parameter and variance estimation

Maximum likelihood estimates (MLEs) of the model parameters were obtained for the base case and various sensitivity analyses. The variances for the estimates of the model parameters and derived variables of interest for the base case scenario were not calculated for this update, but could be determined using Bayesian methods, using Markov Chain Monte Carlo (MCMC) techniques to obtain a sample from the posterior distribution following adoption of a preferred base-case scenario. Estimation methodology was the same as described by Fay (2004) in the previous assessment.

2007 RBC was calculated for both tier 1 and tier 2 HCRs using the average fleet-specific landings from 2003-2005 as an estimate of landings for 2006, needed to determine estimated numbers-at-age for the start of 2007. Selectivity of age 1 fish is effectively zero, so there was no need to make an assumption about 2007 recruitment in order to calculate the RBC for that year.

16.5 Results and discussion

The results of the base-case and sensitivity analyses are summarised in Table 16.5, while 2007 RBCs are given in Table 16.6. There are considerable differences among the base-case results when fitting to the two different CPUE indices. Fitting to the updated CPUE indices results in a base-case estimate of 2006 spawning depletion (SB_{2006}/SB_{1915}) of 0.15, or 15% of virgin unfished spawning biomass, which is below the minimum stock size threshold (MSST) of $SB_{20\%}$. Under both the tier 1 and tier 2 HCRs, this results in a 2007 RBC of zero for the eastern areas (Table 16.6). Unsurprisingly, the results of fitting the base-case to the CPUE indices from the previous assessment are more optimistic regarding stock status, with 2006 spawning depletion estimated to be at 35% of virgin (1915) conditions, with resulting RBCs ranging from 787–1,540 mt under tier 1 HCRs, and from 337–677 mt under tier 2. The model fits to the CPUE indices are good (Figure 16.1), with these indices driving the population trend for both analyses. As with the 2004 assessment, fits to length and age frequency data are generally adequate, but poor for some years. Time series for base-case estimates of spawning biomass are shown in Figure 16.2. Although base-case estimates with the 2004 CPUE result in RBCs lower than that of previous (2005) calculations, the tier 2 RBC of 813 mt for the eastern areas is still in excess of recent landed catches from these zones, which have been < 550 mt (Table 16.1).

Figure 16.3 compares estimates of recruitment among the two different base-case updates, and those from the 2004 assessment. As in the previous assessment, these

estimates show a period of generally poor recruitment during the 1980s and 1990s. The base-case updates estimate negative residuals (weak year-class strengths) for 2002 and 2003. The update fitted to the 2004 CPUE shows less negative estimates for recruitment residuals in 1999 and 2000 than in the previous assessment (Figure 16.3). These year-classes were only just appearing in the data from the fishery at the time of the last assessment, and thus the updated estimates are consistent with the notion that information regarding the relative size of these recruitments has improved as the cohorts have moved through the fishery. The absence of small fish from the 2005 port length data for fleets 3 and 5 likely influences the estimates of negative recruitment residuals for 2002 and 2003; fish < 25 cm (1-3 yrs) in length are not retained by the trawl fishery.

The results of the sensitivity tests (Table 16.5) are generally consistent with the equivalent analyses from the 2004 assessment. When the 2004 assessment CPUE indices are used, a less productive stock than the base case (h=0.6, M=0.1) results in a 2006 spawning depletion below the MSST. 2007 RBC for models fit to the 2004 CPUE data are otherwise greater than zero (because the stock is estimated to be above the MSST), but less than equivalent calculations from 2004/2005 (Fay 2005, Fay 2004) as expected from the base-case results. There was some concern that the value for the standard deviation of the recruitment residuals used in the 2004 assessment (0.3) was low – as with sensitivity tests from 2004, models with a higher value for this parameter result in estimates of current spawning depletion lower than that in the base-case (Table 16.5). The sensitivity analysis which used the geometric mean of shots with ≥ 30kg morwong from 1986-2005 for fleet 3 instead of the 2004 CPUE produced very similar results to the base-case fitted to the 2004 CPUE indices (Table 16.5). This is unsurprising, as the standardisation for morwong does not differ much from the geometric mean (Haddon 2006), and this series is very similar to the 2004 CPUE for this fleet (Figure 16.4). The results of this analysis then probably provide the closest approximation to a model fitted to an updated standardised CPUE that only used shots catching ≥ 30 kg morwong in the standardisation. 2006 spawning biomass under this scenario is estimated to be 34% of the unfished equilibrium, with 2007 RBCs for eastern areas of 635–1,234 mt under tier 1 and 274–547 mt under tier 2. Models fit to the ISMP CPUE index (either solely or through some combination of this and the other CPUE indices) were more optimistic regarding stock status, providing results comparable to the 2004 assessment in that the spawning biomass is predicted to be at or just above 40% of the unfished state (Table 16.5). These data do not show as sharp a decline in CPUE as the updated indices, although the estimates for 2003 and 2004 are low (Table 16.4). However, the models did not mimic these two data points well at all, even when the high 2005 data point was removed from the analysis.

The results of the assessment update are clearly sensitive to the catch and effort data used to describe a CPUE index that is representative of changes in biomass. As the estimated population trend is primarily driven by these CPUE indices, the choice of data included is key to estimates of stock status for this population. For the 2004

assessment, it was considered that a ≥ 30 kg cut-off for catch and effort data was reasonable for morwong. However, the increasing trend in the number of shots catching small amounts of morwong from those vessels targeting the species (Section 16.7, Appendix A, Day 2006) suggest that this might not be the case, even when attempting to account for changes in reporting rates of smaller shots.

The updates that used the 2004 CPUE give more pessimistic estimates of 2006 stock status and lower RBCs than the 2004 assessment and 2005 calculations of 2006 RBC (Table 16.5). Figure 16.5 and Figure 16.6 show the results of retrospective analyses conducted to explore the reason for these differences. In addition to the 2003-2005 data, the main differences between the update and the 2005 projected estimates are a) the 2003-2005 catch history, and b) changes in the age composition data from 1991-2002 as a result of 358 newly aged samples from these years becoming available since the last assessment. Figure 16.5 and Figure 16.6 show that the difference in population trajectory can be attributed to the changes in the 1991-2002 age data between the 2004 and 2006 extractions. The sequential removal of the 2003-2005 age and length data from the updated base-case has little impact on the population trajectory when these older age data are included (Figure 16.6).

The results of the assessment update presented here, along with trends in CPUE indicate large uncertainty in the current stock status of morwong relative to target reference points. A full stock assessment for this species should be given priority in the very near future (ie 2007), however the main issues with the assessment relate to which CPUE data are considered to be relative indicators of stock abundance, with an absence of evidence for not choosing the more pessimistic updated (Haddon 2006) CPUE indices (Day 2006). Recommendations for the future assessment would include moving to the Stock Synthesis 2 (SS2) assessment software, in order to accommodate many of the technical shortcomings of the current modelling approach highlighted by Fay (2004). Such a move would facilitate inclusion of discard data available from the ISMP (onboard length frequencies). Although the inclusion of these data would not be expected to effect the general results (discarding of morwong is low), Fay (2004) noted that discarding for morwong was primarily size-based, and accounting for these data should improve estimation of recent year-class strengths, which may provide more rapid responsive updates of RBC calculations. Bravington (pers. commn) also noted some disparities in the length at age data for jackass morwong among years prior to and post-2002, which may represent changes in sampling that would affect assumptions made when generating age length keys to obtain age composition data. Given the trends in CPUE in the eastern areas, attention should also be paid to trends in the western areas of the SESSF. Landings from the western zones now account for about 30% of total landings for jackass morwong, and so some accounting for the population in these areas (either as a separate or mixed stock) should be made in order to determine an RBC for the entire SESSF.

16.6 References

Day, J. 2006. Small shots and related CPUE series for jackass morwong (*Nemadactylus macropterus*) 2006. prepared for Shelf Assessment Group, August 14-15, 2006.

Fay, G. 2005. 2006 Recommended biological catch calculations for jackass morwong (*Nemadactylus* macropterus). In: Tuck, G.N. (Ed.) 2006. Stock assessment for the southern and eastern scalefish and shark fishery 2005-2006. AFMA and CSIRO Marine and Atmospheric Research, Hobart, p213-217.

Fay, G. 2004. Stock assessment for jackass morwong (*Nemadactylus macropterus*) based on data up to 2002. In: Tuck, G.N. and Smith, A.D.M. (Eds.) Stock assessment for south east and southern shark fishery species. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart 412 p.

Haddon, M. 2006. Standardized Commercial Catch-Effort data for selected Shelf and Slope Assessment Group Species for 1986 - 2005. Draft document. 55pp.

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and P. Starr. 2003. Coleraine: A generalized age-structured stock assessment model (May 2003). SAFS-UW-0116.

Table 16.1. Landings by fleet (mt) for 2003-2005, and estimated landings for 2006 (average of 2003-2005) for calculation of 2007 RBC.

	fleet		
	3	4	5
Year	NSW/Evic OT	NSW/ET DS	ETAS OT
2003	290	19	221
2004	262	13	228
2005	339	19	170
2006	297	17	206

Table 16.2. a) Age composition and b) port length frequency data for 2003-2005.

a)

		Age																			
	# Ages	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20+
fleet 3																					
2003	259	0.0000	0.0006	0.0065	0.0166	0.0634	0.3387	0.1117	0.0571	0.0635	0.0891	0.0597	0.0907	0.0428	0.0074	0.0069	0.0043	0.0214	0.0000	0.0047	0.0149
2004	869	0.0000	0.0144	0.0364	0.0875	0.1615	0.1716	0.0549	0.0743	0.0868	0.0622	0.0809	0.0571	0.0412	0.0168	0.0101	0.0168	0.0121	0.0042	0.0055	0.0057
fleet 4																					
2004	869	0.0000	0.0086	0.0596	0.1216	0.1619	0.2585	0.0699	0.0857	0.0643	0.0413	0.0557	0.0336	0.0183	0.0051	0.0021	0.0075	0.0030	0.0009	0.0003	0.0022
fleet 5																					
2003	259	0.0000	0.0000	0.0038	0.0112	0.0549	0.3726	0.1361	0.0593	0.0495	0.0801	0.0609	0.0961	0.0336	0.0087	0.0041	0.0034	0.0154	0.0000	0.0058	0.0045
2004	869	0.0000	0.0049	0.0321	0.0612	0.1416	0.1220	0.0437	0.0597	0.0885	0.0684	0.1084	0.0645	0.0510	0.0399	0.0138	0.0305	0.0253	0.0121	0.0238	0.0086

b)

			mean	length (cm)																								
	#tows	#fish	length (cm)	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40+
fleet 3																													
2003	53	4,127	30.0	0.0000	0.0000	0.0000	0.0000	0.0011	0.0000	0.0003	0.0015	0.0133	0.0325	0.0428	0.0675	0.0696	0.0722	0.0833	0.1007	0.1109	0.1088	0.0943	0.0600	0.0446	0.0340	0.0226	0.0142	0.0115	0.0143
2004	41	3,544	29.4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0024	0.0086	0.0100	0.0191	0.0439	0.0671	0.1034	0.0837	0.0956	0.1036	0.0953	0.0797	0.0670	0.0486	0.0522	0.0270	0.0246	0.0194	0.0205	0.0280
2005	56	5,440	30.3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0018	0.0045	0.0096	0.0192	0.0504	0.0668	0.1009	0.1188	0.1143	0.1254	0.0956	0.0665	0.0608	0.0462	0.0377	0.0240	0.0224	0.0174	0.0177
fleet 4																													
2004	2	108	28.5	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0093	0.0648	0.1388	0.1388	0.2593	0.0834	0.0927	0.1112	0.0370	0.0371	0.0000	0.0093	0.0093	0.0093	0.0000	0.0000	0.0000
2005	3	385	30.2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0077	0.0256	0.0974	0.1165	0.1026	0.1057	0.1021	0.0904	0.0749	0.0587	0.0469	0.0325	0.0260	0.0293	0.0484	0.0352
fleet 5																													
2003	4	376	30.1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0074	0.0111	0.0370	0.0617	0.0818	0.1117	0.1249	0.1240	0.1102	0.0641	0.1122	0.0744	0.0318	0.0267	0.0070	0.0070	0.0028	0.0042
2004	11	1,274	28.2	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0009	0.0007	0.0092	0.0307	0.0601	0.0692	0.0859	0.0879	0.0739	0.0689	0.0524	0.0360	0.0300	0.0447	0.0654	0.0837	0.0695	0.1310
2005	7	1,391	30.9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0014	0.0007	0.0202	0.0586	0.1422	0.0365	0.1951	0.1745	0.1103	0.0617	0.0478	0.0443	0.0470	0.0226	0.0185	0.0111	0.0074

Table 16.3. Updated standardized CPUE indices for 1986-2005 (Haddon 2006). Annual CPUE standardized to 1986 value for each fleet.

	Standardised CPUE		
Year	fleet 3	fleet 4	fleet 5
1986	1.0000	1.0000	1.0000
1987	1.1733	1.2471	0.8972
1988	1.1017	1.3335	1.2021
1989	1.0663	1.4230	1.7107
1990	0.8659	3.2252	1.2466
1991	0.7724	1.0117	0.9383
1992	0.6237	0.8601	0.9784
1993	0.6352	0.4086	0.7612
1994	0.5566	0.2927	0.5245
1995	0.5582	0.2194	0.4988
1996	0.4820	0.4350	0.4998
1997	0.5225	0.4629	0.6014
1998	0.4214	0.4570	0.5703
1999	0.4206	0.3303	0.6598
2000	0.3446	0.5933	0.5145
2001	0.2364	0.9183	0.2992
2002	0.2674	0.6889	0.2490
2003	0.2019	0.6192	0.3527
2004	0.2044	0.4252	0.2366
2005	0.2510	0.4359	0.1753

Table 16.4. Standardized CPUE from ISMP data for eastern areas (all shots).

Year	Standardised CPUE
1994	4.36
1995	5.01
1996	6.03
1997	3.28
1998	5.47
1999	3.93
2000	3.44
2001	3.79
2002	3.85
2003	2.17
2004	1.78
2005	4.35

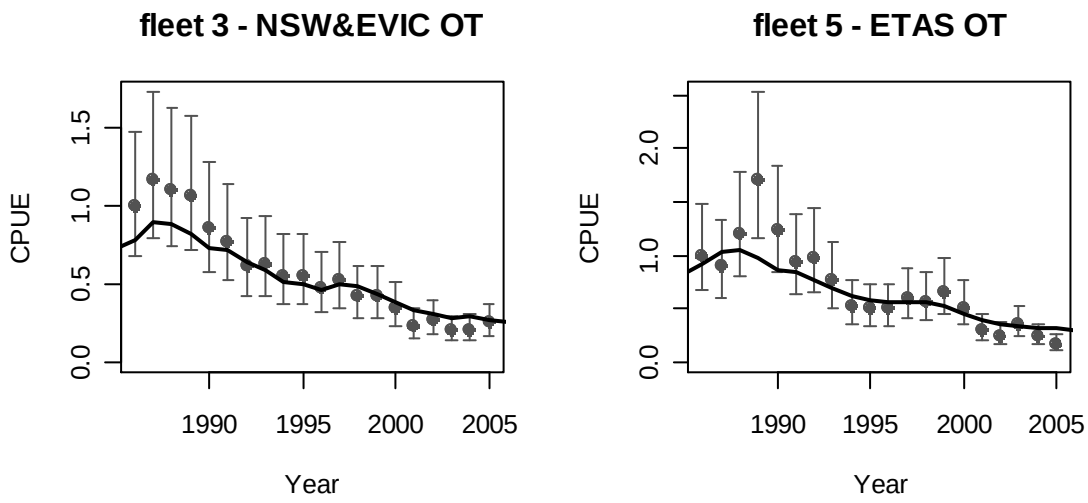
Table 16.5. Summary of the results for the base-case and sensitivity analyses. *For the base-case results from the 2004 assessment, 2006 values correspond to projected estimates under mean recruitment used by Fay (2005) for 2006 RBC calculations.

Model	SB_0	SB_{2006}	SB_{2006} / SB_0	B_0	B_{2006}	B_{2006} / B_0
Fay 2004 base-case (h =0.7, M =0.15)*	26,413	11,622	0.44	27,686	12,798	0.46
Update using Fay 2004 CPUE (1986-2002)						
Base-case	24,821	8,798	0.35	26,018	9,743	0.37
h =0.6, M =0.1	32,281	5,881	0.18	33,194	6,382	0.19
h =0.8, M =0.2	23,052	12,680	0.55	24,684	14,179	0.57
CPUE CV = 30%	26,191	12,360	0.47	27,444	13,439	0.49
std dev. recr = 0.6	27,914	5,567	0.20	29,231	6,380	0.22
>30 kg geometric mean CPUE 1986-2005	23,968	8,103	0.34	25,116	9,016	0.36
Haddon 2006 CPUE						
Base-case	22,541	3,307	0.15	23,623	3,931	0.17
Include fleet 4 CPUE (Haddon 2006)	22,228	3,792	0.17	23,293	4,455	0.19
ISMP CPUE						
1994-2005 ISMP CPUE only	25,615	11,070	0.43	26,849	12,104	0.45
1986-1993 >30kg, 1994-2005 ISMP	25,096	9,809	0.39	26,306	10,795	0.41
1986-1993 all shots, 1994-2005 ISMP	25,411	10,413	0.41	26,636	11,431	0.43

Table 16.6. Recommended Biological Catch (RBC) for 2007 under both tier 1 and tier 2 Harvest Control Rules (HCRs).

					Tier 1 RBC			**Tier 2 RBC**		
Model	**F_{40}**	**F_{48}**	**F_{50}**	**F_{60}**	**HCRa**	**HCRb**	**HCRc**	**HCRa**	**HCRb**	**HCRc**
Base-case update using Fay 2004 CPUE	0.236	0.169	0.155	0.103	1,540	787	1,101	677	337	449
base-case update using Haddon 2006 CPUE	0.233	0.167	0.154	0.102	0	0	0	0	0	0
>30 kg geometric mean CPUE 1986-2005	0.225	0.162	0.150	0.100	1,234	635	889	547	274	365
1994-2005 ISMP CPUE only	0.229	0.164	0.152	0.101	2,131	1,391	1,532	1,198	599	799
Fay 2004 base-case (h =0.7, M =0.15)*	0.221	0.160	0.147	0.099	2,248	1,582	1,625	1,363	685	913

a) base-case, updated CPUE



b) base-case, 2004 CPUE

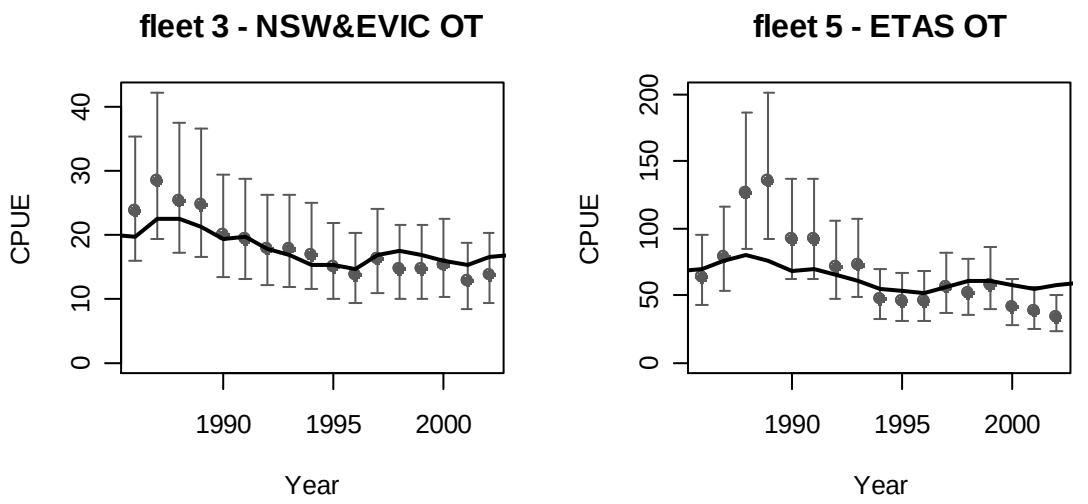


Figure 16.1. Base-case fits to CPUE data for fleets 3 and 5, given a) the updated (Haddon 2006) CPUE time series, and b) CPUE from 2004 assessment.

a) base-case, updated CPUE b) base-case. 2004 CPUE

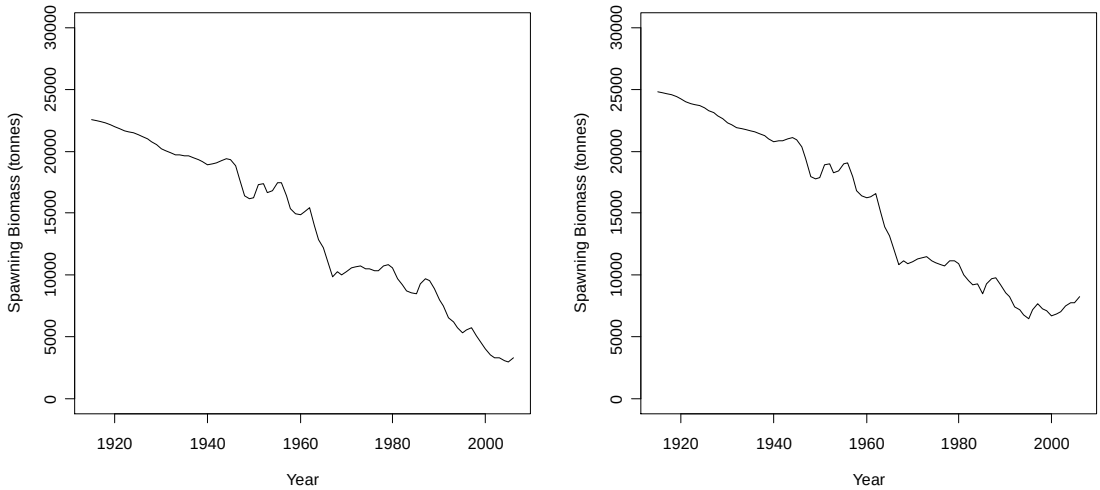


Figure 16.2. Estimated time series of spawning biomass for versions of the base-case fitted to a) the updated standardized CPUE indices, and b) the CPUE indices from the previous assessment.

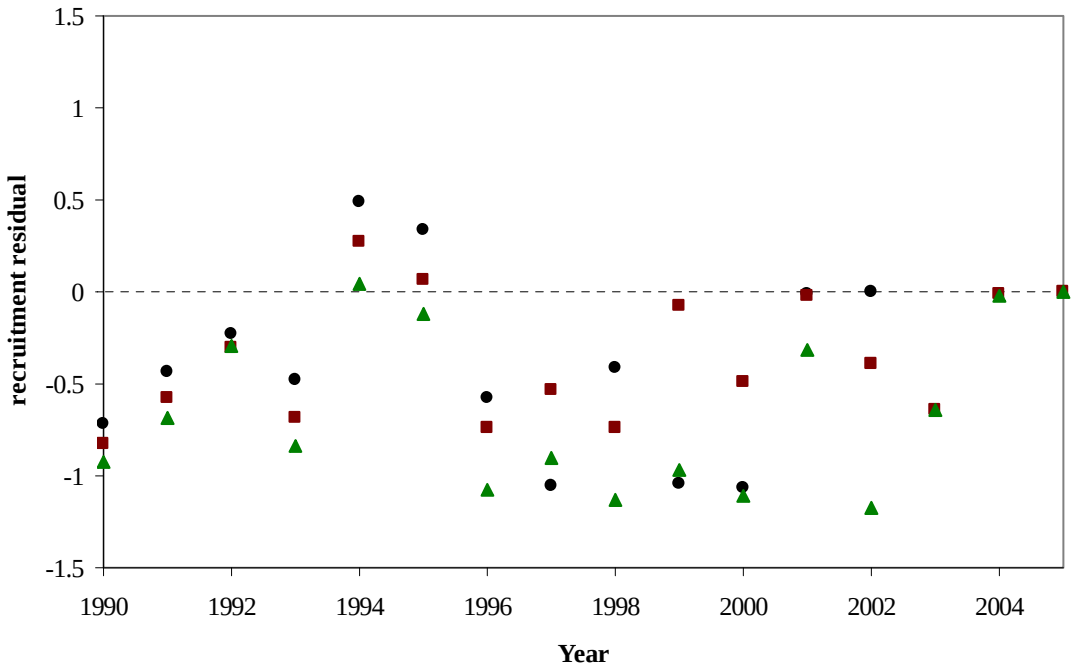
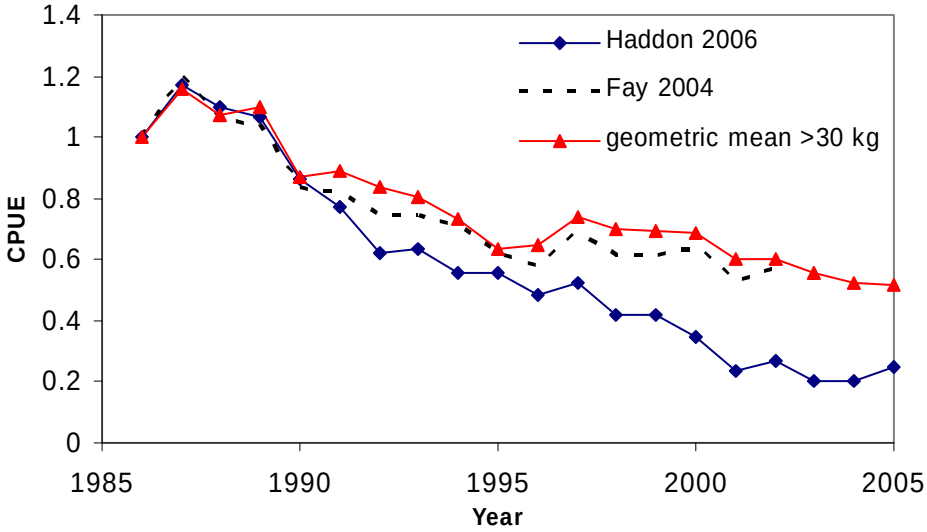


Figure 16.3. Comparing base-case estimates of 1990 – 2005 recruitment residuals (circles: Fay 2004, triangles: update with new CPUE, squares: update with 2004 CPUE



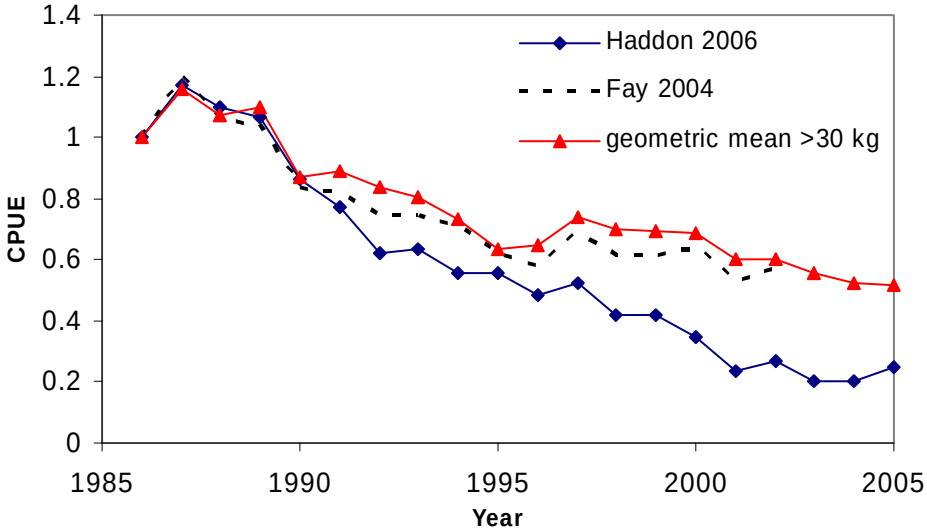


Figure 16.4. Comparison of standardized CPUE indices for fleet 3 with the geometric mean CPUE of shots catching ≥ 30kg jackass morwong.

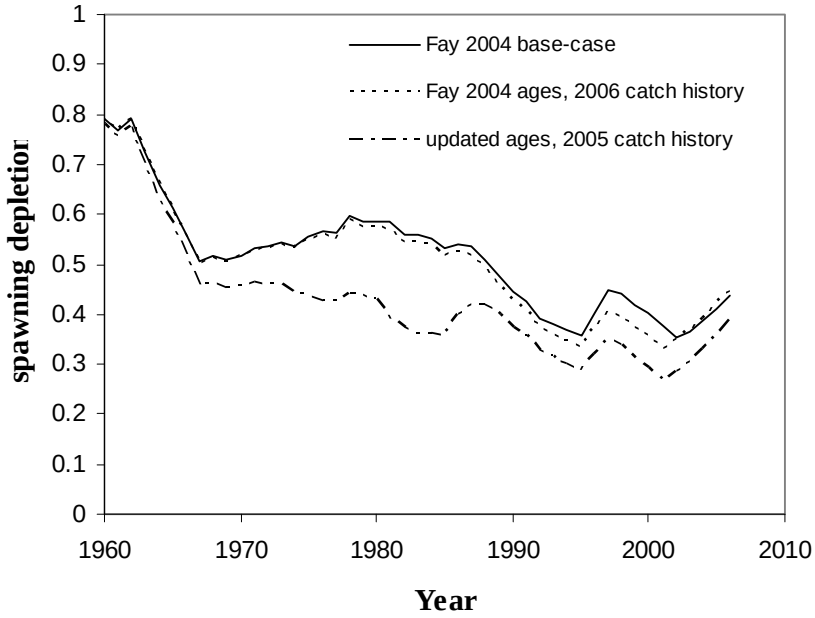


Figure 16.5. Time-series of spawning depletion for analyses using data to 2002 only (as per 2004 assessment). Series differ in catch history used (Fay 2005 projection or updated catches presented in this update) and whether the age data to 1992 is based on the extraction for the previous (2004) assessment, or that for the assessment update.

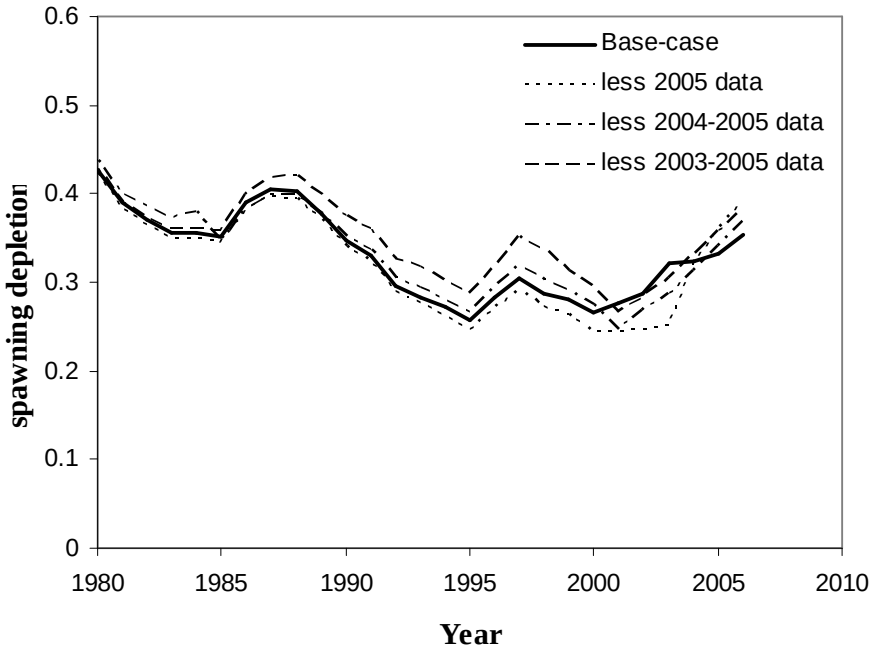


Figure 16.6. Time series of estimated spawning depletion for the retrospective analysis of the updated base-case that used the Fay 2004 CPUE indices for fleets 3 and 5 (ie only age and length data for the years 2003-2005).

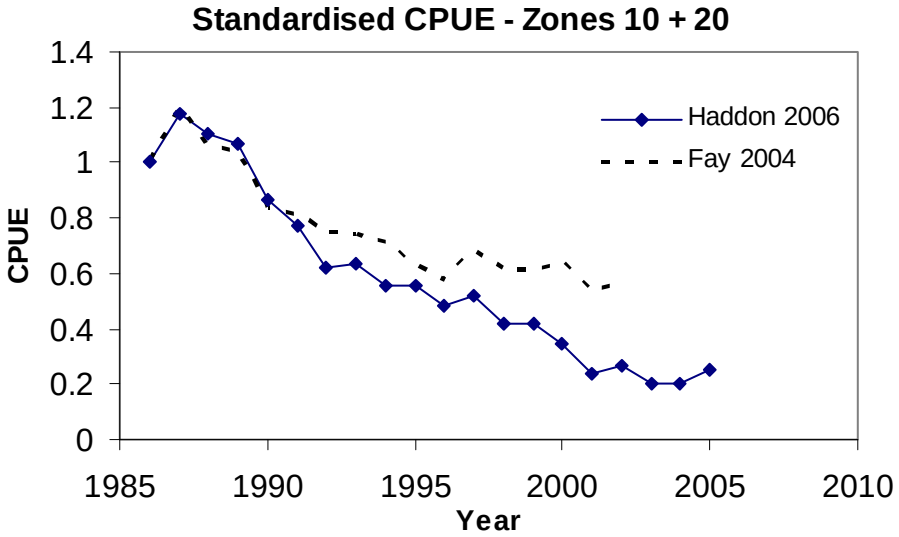
16.7 Appendix A: Comparison of CPUE standardisation methods for jackass morwong

The updated standardized CPUE indices for jackass morwong that utilize data to 2005 (Haddon 2006) show a more negative trend than those included in the 2004 stock assessment for the species (Figure A.1, Fay 2004). These indices are used in the stock assessment as indices of relative abundance of the population, and fitting population dynamics models to the updated indices unsurprisingly results in more pessimistic estimates of stock status than analyses that fit to the 2004 data. Table A.1 compares the specifications of the two standardizations (Fay 2004, and Haddon 2006) for the Zone 10 & 20 Otter trawl fleet, in terms of the data included in the analysis, and the various factors included in the model. The approaches differ on both accounts, with the Haddon model making use of more data, and using a simpler model. Re-runs of the Fay analysis to 2002 that varied the specifications of the model and data restriction to those employed by Haddon demonstrate that the difference among the indices is a result of the data included in the analysis (Figure A.2). The more pessimistic result is obtained when all tows that caught morwong are included in the analysis, rather than just those tows where more than 30kg were caught. Tows with < 30kg morwong were removed from the analysis by Fay in 2004 as it was thought these tows likely did not represent targeted fishing for the species and may therefore not be representative of abundance. The increasing magnitude of the difference between the Fay and Haddon series over time would indicate that the relative proportion of tows catching < 30kg of morwong has increased in recent years.

Table A1. Comparisons of data restrictions and factors included in the CPUE standardizations for the Zone 10 & 20 Otter Trawl fleet.

	Fay 2004	Haddon 2006
Data restrictions		
participation	≥ 5 yrs	≥ 3 yrs
median annual catch	≥ 5 mt	≥ 2 mt
tows	catch ≥ 30 kg	catch rate > 0
depth	no restriction	< 400 m
Factors		
Year	X	X
Vessel ID	X	X
DepthCat	X	X
Month	X	X
Zone	X	X
Flathead	-	- / X
DepthCat : Month	-	X
DepthCat : Vessel	X	-
Month : Vessel	X	-
DepthCat : Flathead	X	-

a)



b)

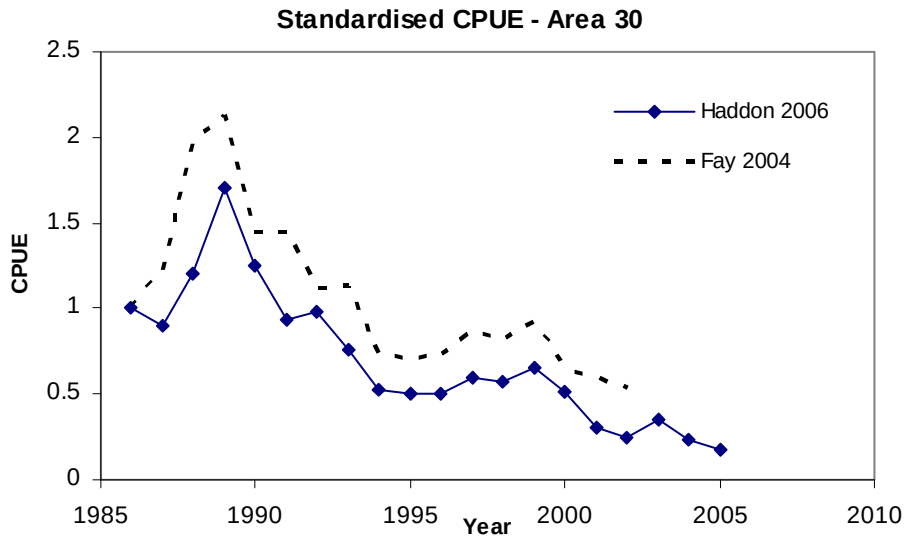


Figure A1. Comparing standardized CPUE of jackass morwong for the two OT fleets.

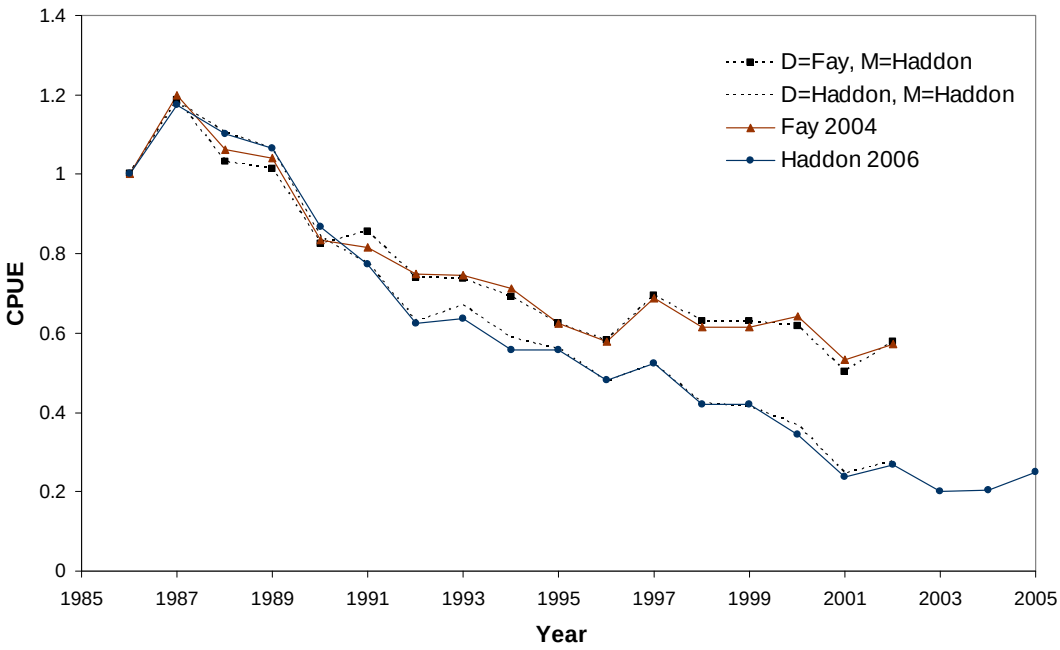


Figure A2. Comparing among CPUE indices for OT Areas 10 and 20 that vary in the data restrictions and fitted model. The restrictions on the data included in the analysis are indicated by "D", whereas "M" refers to the specifications of the model used for the GLM.

17. Small Shots and Related CPUE Series for Jackass Morwong (*Nemadactylus macropterus*)[6]

Jemery Day[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

This paper presents a collection of information relating to shot sizes and CPUE data for jackass morwong (*Nemadactylus macropterus*) in the eastern areas of the SESSF. In the initial 2006 stock assessment for jackass morwong (Fay, 2006), two standardised CPUE series were presented. One series excluded any tows with < 30kg morwong (Fay series) and, in contrast, the second included all tows that caught morwong, with some restrictions on vessels such as operating for 3 years or more, median catch of 2 tonnes across all years of reporting, (Haddon series). The previous stock assessment for morwong (Fay, 2004) only used a single standardised CPUE series, a series which excluded any tows with < 30kg morwong. This contrasts with standard criteria used for other CPUE standardisations for other Slope and Shelf species (Haddon, 2006). Further the number and the proportion of tows with small catches of morwong appears to have increased in recent years and the two CPUE series produce quite different results. This paper attempts to provide background data on both of the CPUE series and on the issue of an increase in the number of tows with small catches of morwong. This may be used to inform a decision on which CPUE series to use.

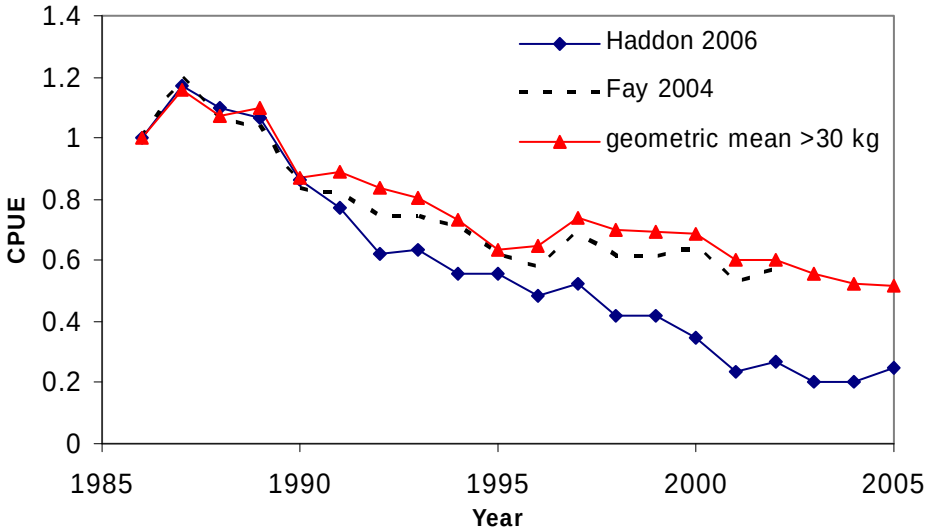


Figure 17.1. Three different standardised CPUE series where the series all equal 1 in the year to which they are standardised: the Fay series (tows with > 30kg morwong only), data to 2005 the Haddon series (all tows catching morwong, with vessel restrictions as noted above) data to 2005; and the geometric mean (not standardised) of catches >30kg, data to 2005. This graph is from Fay (2006).

[6] Paper presented to the Shelf Resource Assessment Group 14-15 August, 2006

In earlier assessments, tows with < 30kg morwong were removed from the analysis as it was thought these tows likely did not represent targeted fishing for the species and may therefore not be representative of abundance. When the first assessments were done, there was little difference between the standardised CPUE series obtained with different thresholds of catch of morwong per tow. This issue was discussed at a past Shelf Assessment Group meeting and agreement was reached to use this criterion for selecting targeted shots of morwong, although the exact details and timing of this discussion have not yet been determined. The increasing magnitude of the difference between the Fay and Haddon series over time would indicate that the relative proportion of tows catching < 30kg of morwong has increased in recent years. Data were obtained from a number of sources to investigate this issue.

Figure 17.1 shows the two standardised CPUE series, as presented in Fay (2006) and the differences which they demonstrate. Note that the Fay series contains data only up to 2002 but shows a very similar trend to the geometric mean of the same series, which is extended to 2005.

Figure 17.2 shows similar data (from Malcolm Haddon's analysis), although with both series standardised to 1986 in this case and with the major variation on the criteria used for selecting all catch records (those from vessels in the fishery for greater than two years and a median catch > 2 tonnes versus only those data with catches > 30 kgs). The disparity between the two series is clear in both Figure 17.1 and Figure 17.2.

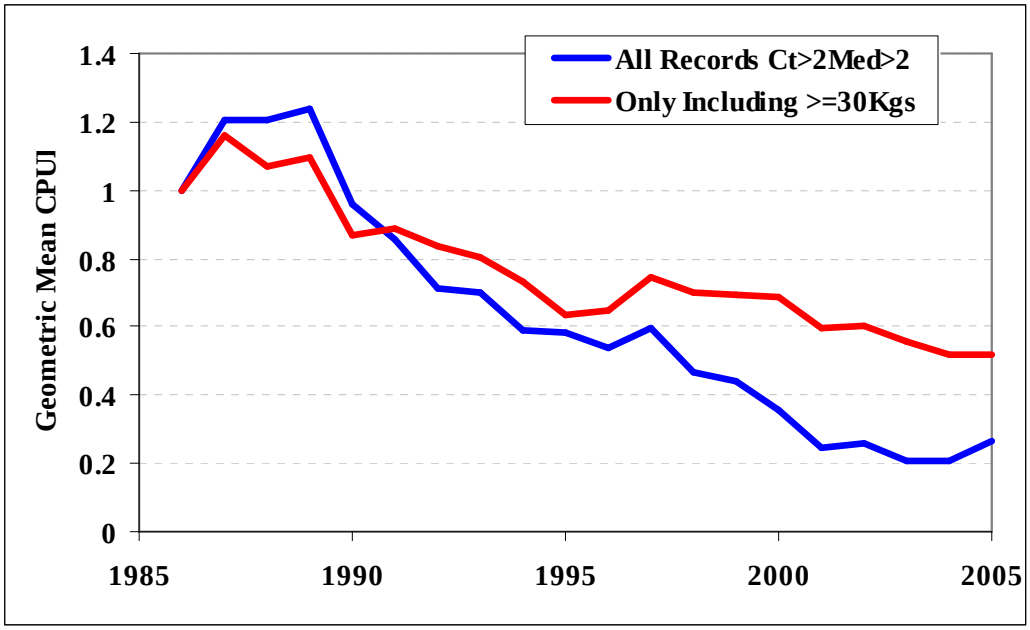


Figure 17.2. Standardised catch rates (source: Malcolm Haddon) for morwong with and without tows with catches < 30kg, and using the restrictions on vessels in the fishery for greater than two years and a median catch > 2 tonnes.

Figure 17.3 shows the number of records of tows with catches of less than 30kg of morwong over time and the percentage of available records that this data represents, which gives an indication of the number of records and the total proportion of records that are discarded if a filter is applied which ignores the data from any tows with catches of less than 30kg of morwong. The data presented in both Figure 17.2 and Figure 17.3 is

based on SESSF logbook records. These figures show a clear increase in both the number of tows catching < 30kg and the proportion of tows catching < 30kg over time, with the percentage increasing from less than 20%, in the late 1980s to around 50% in recent years.

One possible explanation for this increase in number of small shots of morwong is due to a change in reporting practice, where it is postulated that there may have been an increase in reporting of small shots over time, in line with a possible tightening of regulations and a possible increase in compliance with these regulations over time. To explore this possibility, a database query was undertaken by Mike Fuller from CSIRO to match ISMP and logbook records. This enabled records to be classified into three categories: records where an observer was on board; an observer was not onboard; and some doubt as to whether an observer was on board or not. Of these three categories, the records where it is clear that an observer was present or absent were most useful.

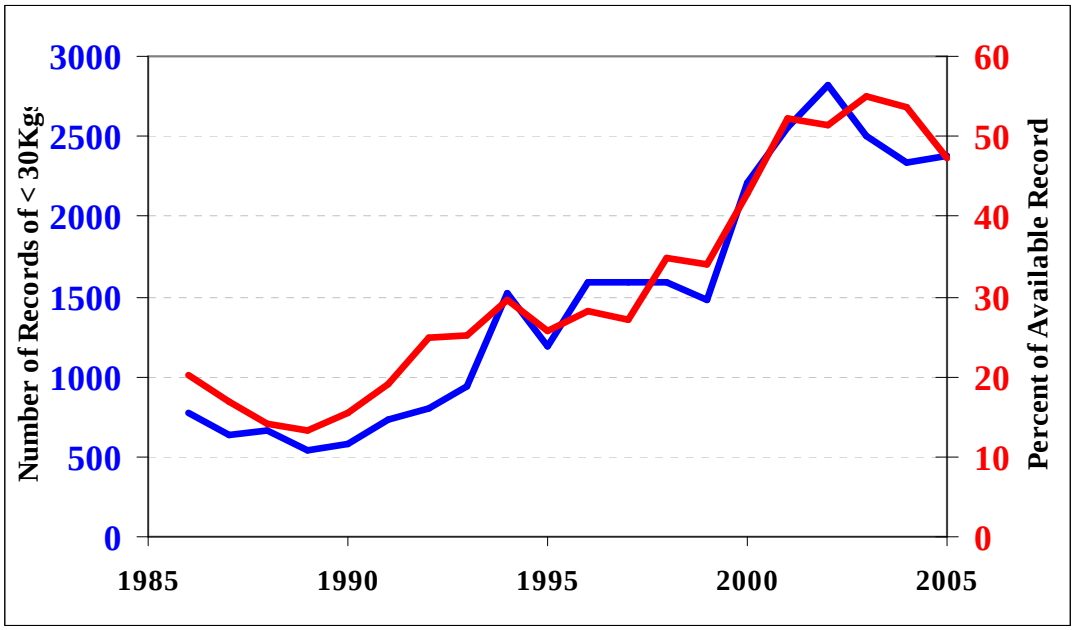


Figure 17.3. Numbers of records and percent of available records (source: Malcolm Haddon) for tows with shots of < 30kg of morwong, using the restrictions on vessels in the fishery for greater than two years and a median catch > 2 tonnes.

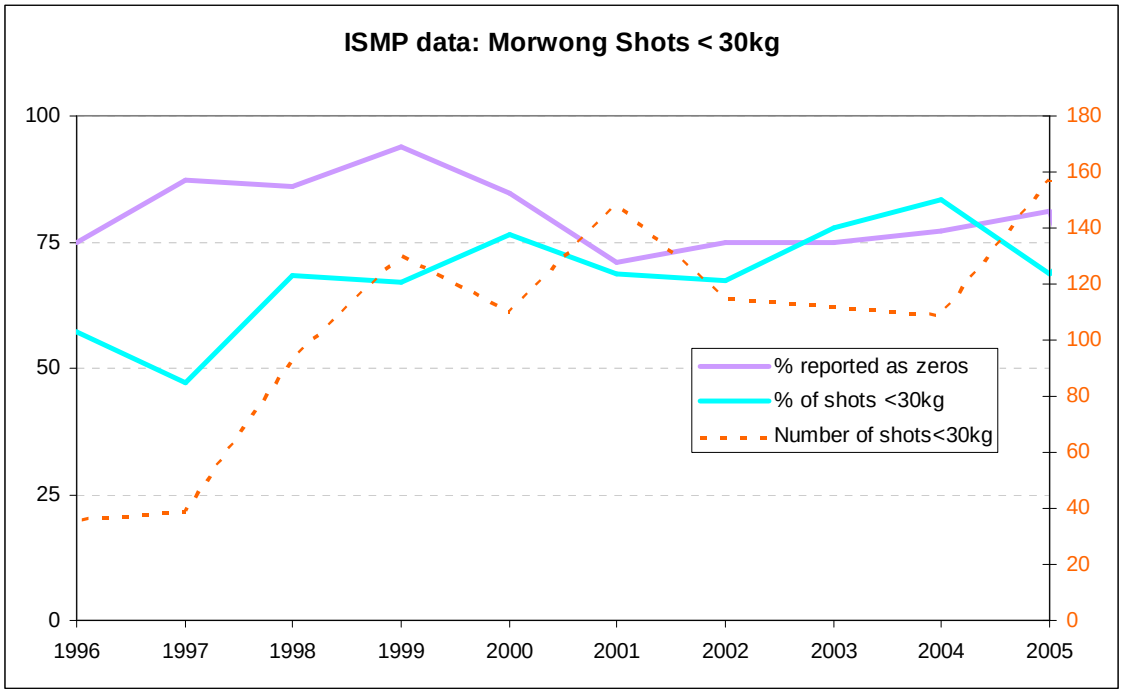


Figure 17.4. Matched data from ISMP and logbook records where an observer was on board, showing the absolute number of records where the observer lists a catch of less than 30kg, the proportion of tows (with an observer present) where the catch of morwong was <30kg and the proportion of these same tows where the logbook record shows a zero catch.

Figure 17.4 shows records of tows in which morwong were caught and an observer was present. The absolute number of tows where the catch of morwong was less than 30kg (as reported by the observer) is listed over time and this also shows a clear increase, with the percentage of tows with small catches (<30kg) increasing in this dataset from around 20% to well over 50% from the late 1990s onwards. The number of zero shots reported in the logbook, when the observer has recorded a non-zero catch of morwong of <30 kg is consistently high (around 75%), with little trend apparent over time. This suggests that there has not been a significant change in logbook recording practices of small catches of morwong when an observer is on board, and this reporting rate of small catches has been low over this period.

This same data (logbook data when observers are known to be either present or absent) can be analysed to show the proportions of logbook recorded catches < 30kg in the presence and absence of observers. These series are shown in Figure 17.5, along with a repeat of the data extracted by Malcolm Haddon from Figure 17.3 and a repeat of the ISMP only series (from the matched records) from Figure 17.4. In additions to these two series from previous figures, there is an additional analysis of SESSF logbook records obtained by Mike Fuller (using all non-zero catches) and the two series from the matched logbook and ISMP data with and without observers present. All of these series show an increasing trend in the number of small shots of morwong over time.

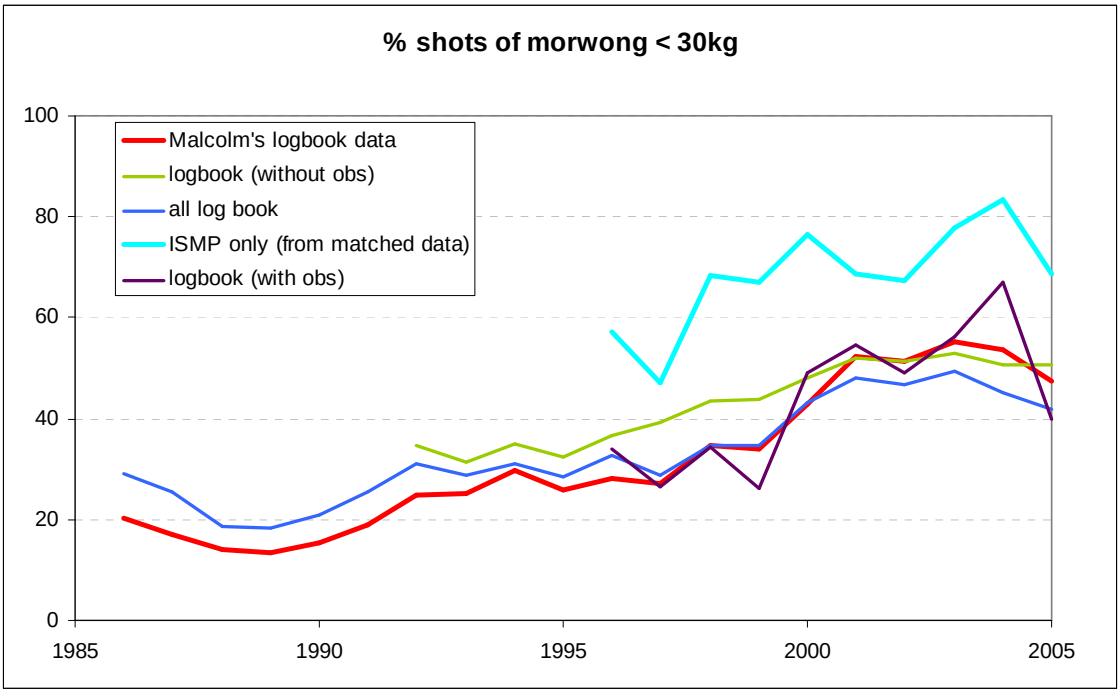


Figure 17.5. Proportion of morwong tows with catches less than 30kg from a variety of sources.

The data presented in Figure 17.5 are repeated in Figure 17.6, for the period 1996-2005, with the natural logarithm of the percentage of small catches for all of the series and regression lines plotted for each of these series.

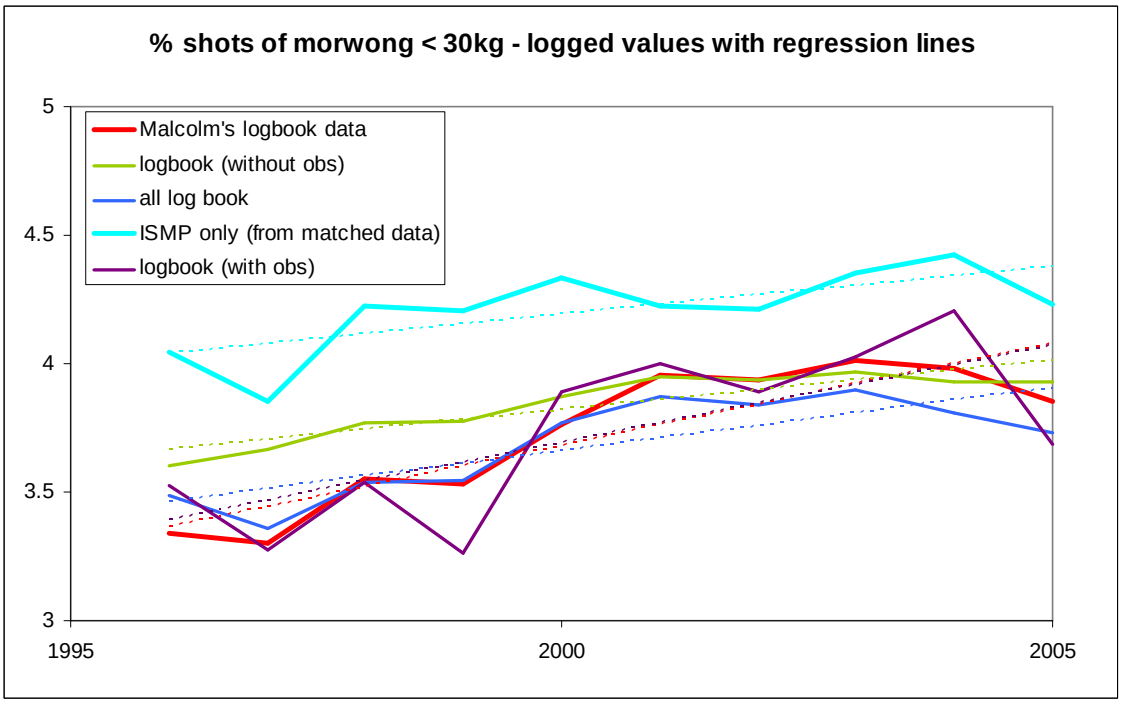


Figure 17.6. Proportion of morwong tows plotted as natural logarithms with catches less than 30kg from a variety of sources.

A final analysis was done to examine whether this increase in proportion of small shots was occurring with other species in the SESSF, where logbook records were examined for blue grenadier, blue warehou, tiger flathead and jackass morwong to examine the proportion of tows with catches less than 30kg over time for each of these species. These results are presented in Figure 17.7 where raw proportions are presented and in Figure 17.8 where these results are scaled by taking natural logarithms of the percentages, and a regression line fitted to these log series, for comparison with Figure 17.6. Figure 17.8 shows an increase trend for tows with small catches for morwong, flathead and blue warehou – but a stable series for blue grenadier over this time period 1986-2005.

An alternative comparison to Figure 17.6 is also provided in Figure 17.9 where the series for the same 4 species are plotted and regression lines fitted over the period 1996-2005, the same period as used in Figure 17.6. Over this time frame the only species with an increasing trend of smaller catches is morwong.

Table 17.1 gives the slope of the regression lines plotted in Figure 17.6 with upper and lower 95% confidence intervals on these slopes, showing a positive slope for all of these series – but some variation in the slope for different data series. Table 17.2 gives the slope of the regression lines plotted in Figure 17.8 with upper and lower 95% confidence intervals for the 4 different species with morwong, blue grenadier and blue warehou all having a positive slope over the time period 1986-2005. Table 17.3gives the slope of the regression lines plotted in Figure 17.9 with upper and lower 95% confidence intervals for the 4 different species over the time period 1986-2005. In contrast to Figure 17.8 and Table 17.2 morwong is the only species with a positive slope over the time period 1996-2005. While there is an increase in the proportion of small shots for some of these other species over time, this increase is stronger for morwong in recent years.

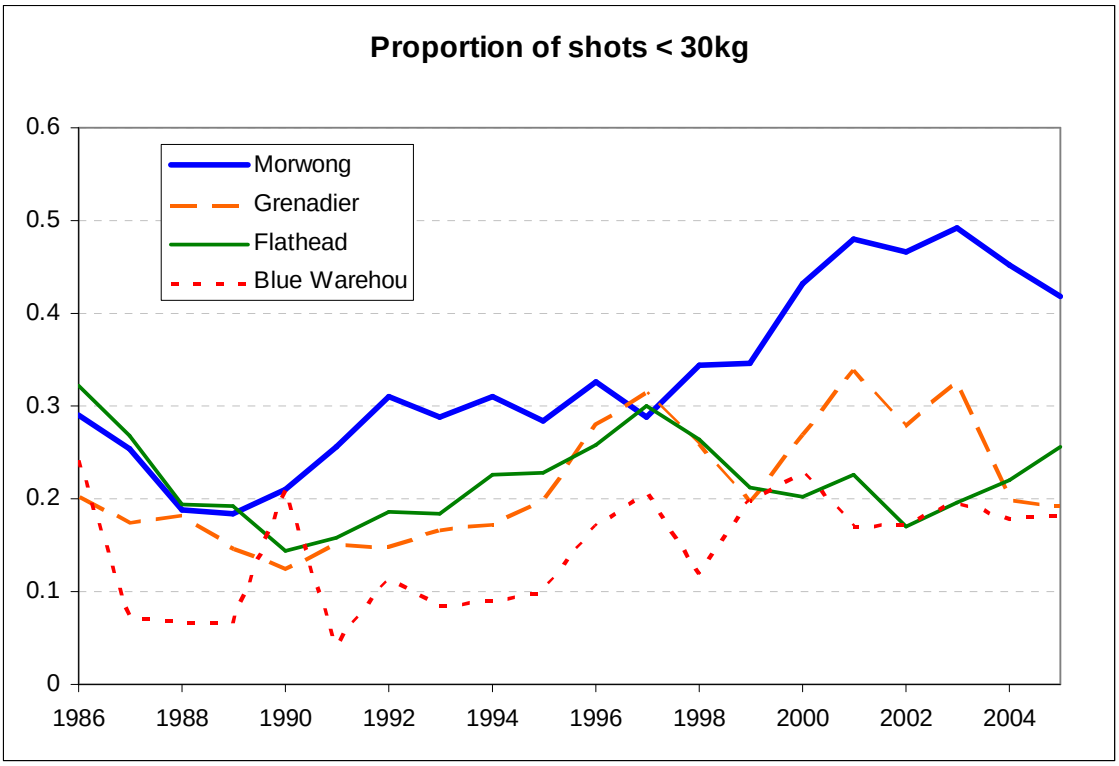


Figure 17.7. Proportion of tows with catches < 30kg for jackass morwong, blue grenadier, tiger flathead and blue warehou over time.

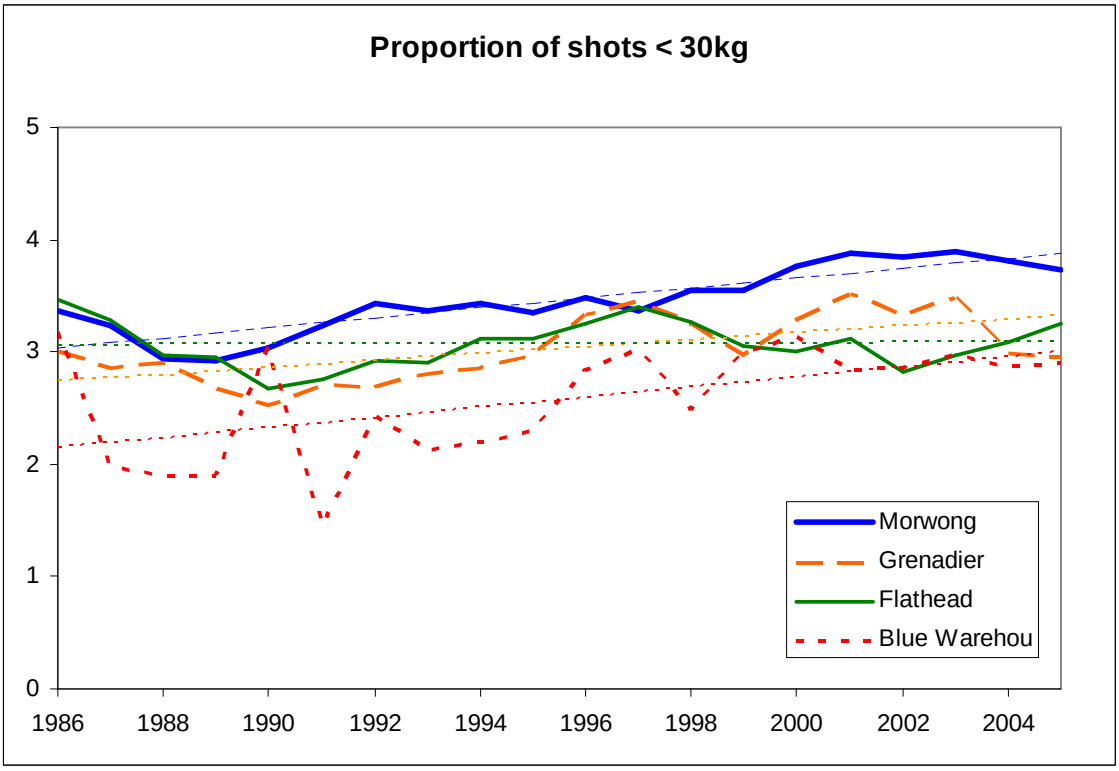


Figure 17.8. Proportion of tows with catches < 30kg for jackass morwong, blue grenadier, tiger flathead and blue warehou over time, scaled by taking the natural logarithm of the percentages of shots <30kg and fitting a regression line.

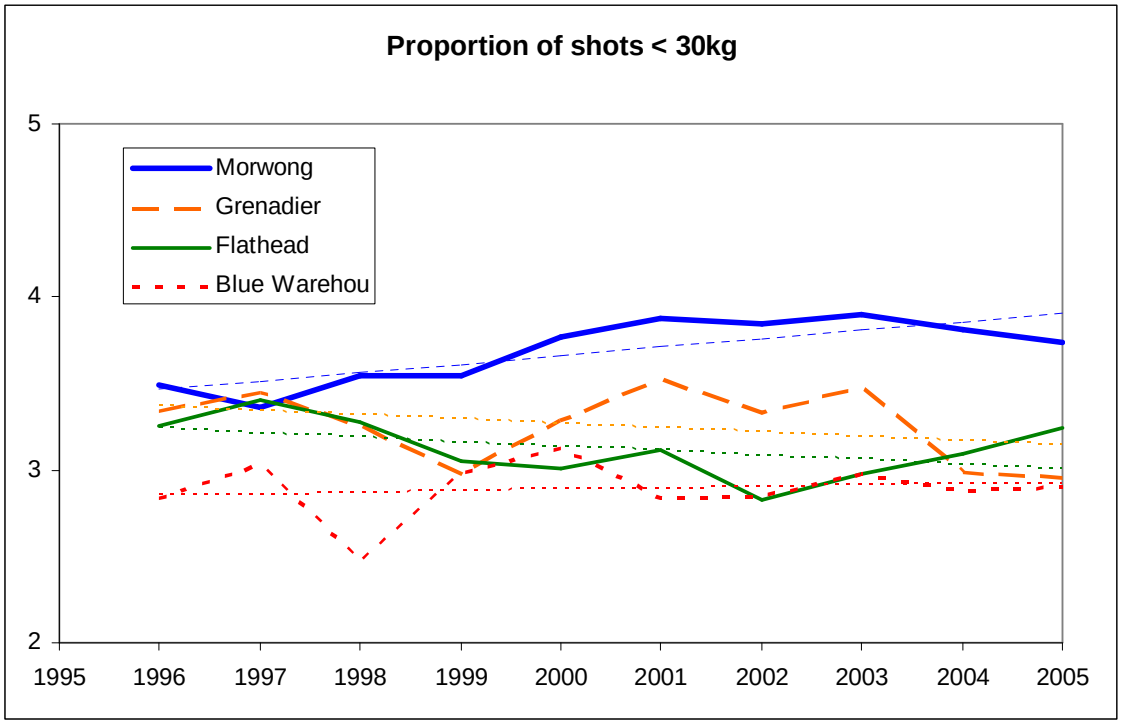


Figure 17.9. Proportion of tows with catches < 30kg for jackass morwong, blue grenadier, tiger flathead and blue warehou over time, scaled by taking the natural logarithm of the percentages of shots <30kg and fitting a regression line. This is a subset of the data presented in Figure 17.8, with the regressions only fitted over the period 1996-2005.

Table 17.1. Slope of regression line of the natural logarithm of percentage of shots < 30kg for the 5 different morwong data series used in Figure 17.6 with 95% upper and lower confidence intervals.

	Malcolm's logbook data	logbook (with observers)	all logbook data	ISMP only (from matched data)	logbook (without observers)
Slope of log % regression line	0.0797	0.0752	0.0382	0.0493	0.0375
Lower 95%	0.0463	0.0132	0.0230	0.0192	0.0060
Upper 95%	0.1130	0.1372	0.0534	0.0795	0.0689

Table 17.2. Slope of regression line of the natural logarithm of percentage of shots < 30kg for the 4 different species used in Figure 17.8 with data from 1986-2005.

	Morwong	Grenadier	Flathead	Blue Warehou
Slope of log % regression line	0.0441	0.0308	0.0012	0.0450
Lower 95%	0.0318	0.0113	-0.0163	0.0092
Upper 95%	0.0564	0.0503	0.0187	0.0808

Table 17.3. Slope of regression line of the natural logarithm of percentage of shots < 30kg for the 4 different species used in Figure 17.9 with data from 1996-2005.

	Morwong	Grenadier	Flathead	Blue Warehou
Slope of log % regression line	0.0493	-0.0252	-0.0262	0.0083
Lower 95%	0.0192	-0.0790	-0.0667	-0.0381
Upper 95%	0.0795	0.0286	0.0144	0.0546

17.1 References

Fay, G. 2004. Stock assessment for jackass morwong (*Nemadactylus macropterus*) based on data up to 2002. In: Tuck, G.N. and Smith, A.D.M. (Eds.) Stock assessment for south east and southern shark fishery species. Fisheries Research and Development Corporation and CSIRO Marine Research, Hobart 412 p.

Fay, G., 2006. Stock Assessment of jackass morwong (*Nemadactylus macropterus*) and RBC calculations for 2007 using data up to 2005. prepared for Shelf Assessment Group, July 5-6, 2006.

Haddon, M. 2006. Standardized Commercial Catch-Effort data for selected Shelf and Slope Assessment Group Species for 1986 - 2005. Draft document. 55pp.

18. Updated Stock Assessment for Silver Trevally (*Pseudocaranx dentex)* in the South East Fishery: August 2006

Jemery Day[1], Kevin Rowling[2] and André E. Punt[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia
[2]NSW DPI Fishing and Aquaculture, PO Box 21, Cronulla, NSW 2230, Australia

18.1 Summary

The 2006 silver trevally (*Pseudocaranx dentex*) assessment is an update to the preliminary 2005 assessment (Day *et al.*, 2005) including a transfer from the package Coleraine (Hilborn *et al.*, 2000) to a new package Stock Synthesis 2, or SS2, (Methot, 2006). Coleraine is an age based model and hence selectivity can only be expressed in terms of the age of fish, not the size. Selectivity for trevally is thought to be dome-shaped at least for the trawl sector, with, larger (and presumably older) fish thought to be able to out swim trawl nets. Getting adequate fits to length frequency data, age data and CPUE series was difficult using Coleraine, with the fits to the CPUE series being relatively poor. The 2005 assessment used a one fleet model as the base case, with catch data beginning in 1985. Using catch data starting from 1970 was also investigated as a sensitivity to this base case. In addition a two fleet model, using trawl and non-trawl fleets, was investigated in 2005, but the mix of length frequencies from a range of gear types in the non-trawl fleet gave poor fits to the length frequencies for this fleet. There were difficulties in estimating the selectivity curve in both the one and two fleet scenarios.

The 2006 update uses all catch data, starting from 1945, and uses length based selectivity and a separate one fleet and a 4 fleet model. SS2 also allows the age data to be entered as conditional age-at-length data, which (in theory) enables simultaneous fitting of the growth curve, as well as fits to CPUE, length frequencies and age-at-length data. In contrast the 2005 Coleraine assessment assumed a fixed growth curve, rather than estimating this directly from the data.

Analyses of the 1 fleet model have shown that the model is quite sensitive to a number of key parameters and assumptions. In some scenarios, selectivity is narrow and biomasses are large, and with small changes in parameters, selectivity can be broad and biomasses can be small. This sensitivity has been seen in growth parameters (assumptions about the maximum size of fish), inclusion or exclusion of length frequency data (some length frequency data is noisier and potentially less reliable than other length frequency data) and the year for the start of recruitment estimates.

The 2005 silver trevally stock assessment (Day et al., 2005) has been updated with new data and transferred from Coleraine to Stock Synthesis 2, or SS2, (Methot, 2006) and an integrated analysis model. In contrast to the 2005 assessment, in this assessment catch data are included from 1945 onwards (compared to 1986 in the base case, and 1972 in a sensitivity in the 2005 assesment), and additional catch and length frequency data from 2005 are incorporated. In addition to these changes an updated standardised CPUE series (Haddon 2006) is used. As in the 2005 assessment, only a single year (1998) of ageing data was available. A base case assessment was constructed with length based selectivity assuming a single fleet, with some sensitivity analyses performed on key parameters. A four fleet model was constructed with different selectivity estimated for the estuary haul fleet, commonwealth (SEF) trawl fleet, state trawl fleet and the trap and line fleet.

Difficulties were encountered in getting stable results with both the one fleet and the four fleet version of this model, with some runs giving quite pessimistic results and others giving unrealistic very large single recruitments, resulting in a very large biomass being fished down. While the results are very uncertain, the runs with very large biomasses appear to be less plausible than those with very small biomasses.

18.2 Introduction

18.2.1 The fishery

Silver trevally occur in estuarine and near-shore ocean waters to a depth of about 100 m from southern Queensland to Western Australia, and form a significant component of both commercial and recreational fisheries in many areas. Silver trevally is a relatively long lived and slow growing species with a maximum age in excess of 25 years, with full recruitment to the fishery occurring at around 3-4 years. Recruitment to the overall fishery generally coincides with maturation, with 50% maturity at around 19cm and full maturation at 26-28cm. Most of the Australian commercial catch is taken from waters off NSW and north-eastern Victoria. One year old fish range from 13 to 25cm (Rowling and Raines, 2000).

Silver trevally in NSW have an extended spawning period from September to March. Spawning is thought to occur throughout the range of the population, although little is known about spawning behaviour in the species (Rowling and Raines, 2000). Silver trevally are reported to be partial spawners, releasing several batches of eggs over a spawning season (Annala et al., 1999).

In Australia there has been only limited study of silver trevally stock structure, and annual TACs for the South East Fishery (SEF) are determined under the assumption of a common stock in the SEF area, from South Australia to NSW (Tilzey, 1995). There is no evidence to support the existence of more than one distinct breeding population in NSW, Victorian and Tasmanian waters, so they are considered to be a single breeding population in this assessment.

Determining catches by gear types is somewhat speculative, given the range of reporting methods and some confusion of reporting between state and Commonwealth waters and

different mixes of gear types in different locations. Rowling and Raines (2000) state that in NSW, demersal fish trawling is thought to account for just over half the catch reported, with fish trapping and line fishing in ocean waters accounting for another 25 - 30 % of the catch. Commercial catches from estuarine waters (predominantly taken with hauling nets) accounts for around 21% of the total in 1997/98, but declined to 11% of the total catch in 1998/99. Silver trevally catches using other methods (including recreational fishing) are difficult to obtain, although a survey in the late 1990's suggests that the recreational catch may be as high as 100-200t. In this assessment, recreational fishing catches were ignored, but if suitable data can be obtained, this could be included in a future assessment. Data from Commonwealth waters suggest that demersal trawling is responsible for around 90% of the catch reported, with the remainder from the trap fishery. In NSW, catches from the non-trawl sector have declined recently and trawl now comprises around 70% of the NSW catch. Victorian and Tasmanian catches largely come from the non-trawl sector. Annual catches from Victorian state records averaged over 100t in the period 1980-1991, then declined to around 50t from 1992-1996 and have averaged around 25t annually since then. Tasmanian state catches have averaged around 5t per year in the last decade.

The agreed global agreed TAC was 500t in 2000 and 2001, but was reduced in 2002 to 400t and then reduced further from 2003-2005 to 320t. However a considerable proportion of the silver trevally catch is taken under state jurisdiction, so these global agreed TAC's do not seem to limit the overall catch of silver trevally. Following the initial preliminary stock assessment of silver trevally, the 2006 TAC was set at 270 t and the projected TAC for 2007 was suggested to be 0t.

18.2.2 Previous assessments

An early South East Fishery stock assessment report (Tilzey, 1995) described the status of the silver trevally stock as "uncertain", and acknowledged that the lack of appropriate data meant that the effects of fishing on the resource could not be assessed, and management strategies could not be evaluated. In a preliminary assessment, Rowling and Raines (2000) suggested the optimum size at first capture for silver trevally to be well above 30 cm LCF, whereas the size at first capture for the fishery then was in the range 20 to 25 cm. Rowling and Raines argue that the silver trevally stock can be described as 'growth overfished', with the fish being caught, on average, well below the size at which the optimum biological yield would result. In another preliminary assessment of silver trevally, Hall (2002) reported that the silver trevally stock is overfished and that overfishing is continuing and suggests that catch per unit of effort is likely to be a poor index of stock abundance.

The 2005 assessment (Day *et al.*, 2005) used a 1 fleet model as the base case, with catch data beginning in 1985, using the package Coleraine (Hilborn *et al.* 2000). Using catch data starting from 1972 was also investigated as a sensitivity to this base case. In addition a two fleet model, using trawl and non-trawl fleets, was investigated in 2005, but the mix of length frequencies from a range of gear types in the non-trawl fleet gave poor fits to the length frequencies for this fleet. There were difficulties in estimating selectivity for both the one and two fleet scenarios. The selectivity estimated for both fleets in the two fleet model predicted a zero selectivity for fish aged 16 years and above

for both gear types – which suggested that old fish could not be caught by any gear type. In both the one and two fleet cases the fits to the standardised CPUE series were relatively poor and both failed to fit the hump in this CPUE series. It was suggested that a length-based selectivity was more appropriate than an age-based selectivity for silver trevally, but this option was not available in Coleraine, which only allows for an aged based model.

18.3 Methods

18.3.1 The data and model inputs

Catch data were obtained from both commonwealth and state records. Commonwealth data used includes annual landings from the SEF1 log-book data (1986-1991) and from the SEF2 log-book data (1992-2005). State data includes records from NSW, including catches north of the Barrenjoey line (1945-2005), Victoria (1978-2005) and Tasmania (1995-2005). Due to problems associated with possible double reporting of catches in state and commonwealth waters in NSW resulting from dual endorsed trawlers in the period 1985-1995, the NSW landings for all methods were added to the catches declared for Commonwealth waters by dual-endorsed trawlers. Total catches for the period 1945-2005 were obtained and allocated to four separate fleets: estuary haul fleet; commonwealth trawl fleet (SEF trawl); state trawl fleet and state trap and line fleet (Figure 18.1 and Table 18.1). An agreed total catch series and agreed allocation of state data between fleets was reached in consultation with Kevin Rowling and Matt Koopman. Some of these records were based on decisions made about which ‘fleet’ the fisher most likely belonged to and in the early years catches were allocated to fleet by fixed proportions, with these proportions varying over time and based on the best available knowledge. In addition to the added catch history from 1945 to 1969, and the new catch data from 2005, additional catches were added to the catch history used in the 2005 assessment (Day et al., 2005), in the period 1970-2004, correcting omissions in the previous catch history.

Recreational catches were not included, as there are only two point estimates of recreational catch history. These point estimates include an estimated 250t caught in the period 1993-1995 and an estimated 88 t caught in NSW alone in 2000-2001. These figures suggest that recreational catches of the order of 100t per year may not be unusual, but there is no information about any trend in these catches over time, apart from these two periods of time.

In addition to annual landings, data collated included: catch-per-unit effort information(CPUE) standardised by GLM analysis (Haddon, 2006); mean length- and weight-at-age; catch length frequency distributions collected in port and on board for a range of years; and catch-at-age by length data for a single year only, 1998.

Discarding for silver trevally was negligible, so for the purposes of this assessment was assumed to be zero. Data were formulated by calendar year (i.e. 1 Jan to 31 Dec).

Standardised CPUE data from Haddon (2006) are shown in Figure 18.2. This standardised CPUE series only includes data from the Commonwealth SEF trawl records.

18.3.2 The assessment model

The 2006 assessment of silver trevally is based on the age-length model Stock Synthesis 2 (Methot, 2006). Stock Synthesis 2 (SS2) is a generalised size and age structured stock assessment package. It allows several fisheries to be modelled at once and can be simultaneously fitted to many different sources of information, like catch-at-age and/or size data from the fishing fleet, and several indices of abundance (commercial fishery and survey). The estimation is performed using maximum likelihood theory in a first step and a Bayesian approach in a second. Prior information on the parameters that can be estimated may be readily incorporated, given the Bayesian framework of this statistical approach. Uncertainty around the estimates of the derived parameters of interest can be assessed directly from the Bayesian posteriors.

Recruitment is governed by a stochastic Beverton-Holt stock-recruitment relationship, parameterised in terms of the steepness of the stock-recruitment (*h*), the average recruitment in an unfished state (R_0), and the extent of variability in recruitment (σ_R). SS2 allows the user to choose among a large number of age- and length-specific selectivity patterns. The values for the parameters of SS2 are estimated by fitting it to data on catches, catch-rates, catch length-frequencies, survey length-frequencies, mean lengths-at-age, and conditional age-at-length data.

In principle, it is possible to estimate the values for all of the parameters of the model, but in practice limited data restricts the ability to estimate all parameters. The rate of natural mortality, *M*, is pre-specified rather than being estimated, with the base-case value for *M* set at 0.1yr^{-1}. Similarly, the extent of variation in recruitment, σ_r, is taken to be 0.6 and the steepness of the stock-recruitment relationship is set to 0.75, for consistency with assumptions made during the 2005 assessment.

The multinomial sample sizes for the age- and length-frequency data are tuned so that these match (on average) the effective sample sizes. Within each data series, years are weighted in proportion to the number of fish actually measured.

Prior information on the parameters that can be estimated may be readily incorporated, given the Bayesian framework of this statistical approach. Uncertainty around the estimates of the derived parameters of interest can be assessed directly from the Bayesian posteriors (Hilborn et al., 2000).

The primary data component are conditional length-at-age and catch-at-length from state trawl and non-trawl sectors and standardised CPUE from SEF trawl. A number of parameters were fixed, including natural mortality and steepness. Parameters which were able to be fitted by the model included recruitment, catchability, growth curves, initial biomass and selectivity.

Initially data from the trawl and non-trawl fleets were combined to make a one fleet model. A four fleet model was also constructed, separating catches and length frequency data into SEF trawl and three state-based fleets, estuary haul, state trawl and line and trap fleets.

18.4 Results

18.4.1 Integrated analysis – 1 fleet model

There were a number of issues of concern with the integrated analysis model for 1 fleet. Combining both the catches from different fleets with the length frequencies and assuming that there is only one selectivity curve for the whole fishery results in some conflict between different components of the input data. With the one fleet model, selectivity of this fleet is assumed to be dome shaped.

A key issue with this model is how broad or how narrow is the shape of the dome shaped selectivity curve. A narrow dome leads to a large section of the population which can not be accessed by the fishing fleet, which in turn leads to a large spawning biomass but a small vulnerable biomass. If this selectivity is to be believed, there must be many large fish in the population. If the dome for selectivity is broad enough, this approximates logistic selectivity, where effectively all fish above a certain size are available to the fishery. This can lead to very small estimates of the vulnerable biomass and the spawning biomass. If this selectivity is to be believed, this suggests there are very few large fish in the population.

In addition to these issues, the reduction in number of large fish caught from 1997 onwards as evidenced in the length frequencies (Figure 18.3) means that there are difficulties in adequately estimating selectivity. If a broad selectivity is fitted (Figure 18.4), this suggests that there are very few large fish in the population from the late 1990s onwards. In contrast, if a narrow dome shaped selectivity is assumed, this can produce estimates of a very high single recruitment event which is then fished down. This results in good fits to the length frequency data but poor fits to the CPUE data.

In the base case, the single year of age data (1998) is entered as conditional age at length data, allowing estimates of the growth curve, as well as estimates for selectivity, recruitment and initial spawning biomass. The resulting selectivity is shown in Figure 18.4, and this is effectively logistic selectivity. While the fits to the length frequency data look reasonable (Figure 18.5), the recruitment deviations show recruitment pulses just prior to periods where length frequency data is available (Figure 18.6) and the fit to the CPUE data (Figure 18.7) is poor, with a particularly poor fit to the hump in standardised CPUE in 1990. The spawning biomass shows a dramatic decline in the 1980s and then a surprising reversal in recent years with a final spawning biomass at around 20% of the 1945 spawning biomass. Figure 18.9 shows a summary of the key output for the base case, including plots of spawning biomass, CPUE, selectivity, length frequency fits, numbers at age, showing recruitment pulses, and growth curves.

Some sensitivities were examined to this base case. In the first sensitivity examined, selectivity was fixed to a much narrower dome-shaped selectivity. These selectivity

parameters were obtained independently by fitting only the SEF trawl length frequency data, data which has very few large fish, and then fixing these selectivity parameters with all the length frequency data added back in. The selectivity pattern with a similar range of output plots are shown in Figure 18.10– with the main differences being a much larger spawning biomass, poorer fits to the CPUE and length frequencies and the growth curve and a very large recruitment in 1980, with the final spawning biomass at around 80% of the 1945 spawning biomass.

A second sensitivity followed naturally from this result, investigating the large recruitment in 1980. In the base case and the first sensitivity, 1980 was the first year in which recruitment deviations were allowed. Typically these deviations should be allowed to vary around the maximum age before the first CPUE or length frequency data appears. For silver trevally, with a maximum age around 25 or 30 years, this parameter should be set around 1955 or 1960, rather than 1980. When this year of first recruitment deviations was set prior to 1976, the resulting model output gives a single very large recruitment in 1977 and a final spawning biomass higher than the initial spawning biomass.

A third sensitivity was explored where only the length frequencies since 1997 were incorporated. This gives good fits to both the length frequencies and the CPUE series with narrow fitted dome-shaped selectivity, but poor fits to growth, with 30 year old fish still growing and very large numbers of fish in the plus group and a very high spawning biomass.

At this stage it is unclear as to whether there is sufficient information in the data in this assessment to fit selectivity and growth well. If a range of selectivity curves can give similar maximum likelihood estimates, then there may be insufficient data to choose between a narrow and broad selectivity curve or between very low and very high biomasses

Additional sensitivities of the 1 fleet model have shown that the model is quite sensitive to a number of key parameters and assumptions and in some scenarios, selectivity is narrow and biomasses are large, and with small changes in parameters, selectivity can be broad and biomasses can be small. This sensitivity has been seen in growth parameters (assumptions about the maximum size of fish), inclusion or exclusion of length frequency data (some length frequency data is noisier and potentially less reliable than other length frequency data) and a number of other parameters. Exploring the sensitivity of the output to these parameters, and making sure that a number of outputs make sense (growth curves, fits to CPUE, fits to length frequencies) is very important if the model is to be considered stable. The instability in results could be due to the problems with estimating a single selectivity curve to data that clearly comes from fleets with different selectivity. This leads to exploration of the four fleet model.

18.4.2 Integrated analysis – 4 fleet model

While the 4 fleet model has the potential to resolve some issues of poor fits to length frequencies, it also requires either a number of assumptions about selectivity and or estimation of a larger number of parameters. While there are some length frequency data from 1967 and 1973/4, inclusion of these length frequencies simply resulted in large recruitments to fit these length frequency data. The presence of length frequency data alone, seems unlikely to cause a big recruitment, but rather the big recruitments are being estimated in association with this data to try to cope with anomalies in this length frequency data. Hence length frequency data prior to 1987 were not used.

The base case include 9 years of length frequencies for both estuary haul and state trawl fleets and 5 years for the combined trap and line fleet, with the state data starting from 1987 and 8 years of length frequencies for the SEF trawl fleet from 1998. The trap and line fleet is known to catch large fish so selectivity was assumed to be logistic for this fleet, and dome shaped for the other 3 fleets, with the expectation that the estuary haul fleet would catch smaller fish than any of the other fleets.

The only CPUE data available is from the SEF trawl fleet, and the length frequencies from this fleet are much less noisy than from the state trawl fleet. Selectivity is expected to be the same for both trawl fleets and due to the quality of the data, the SEF trawl data was expected to be able to give more reliable estimates for the dome shaped selectivity of the trawl fleet. However, the state trawl fleet is responsible for the majority of the catch. Options were explored where the state trawl fleet selectivity could either be estimated separately from the SEF trawl fleet – or it could mirror the fitted selectivity from the SEF trawl fleet.

The base case for the 4 fleet model allowed recruitment deviations from 1956, and estimated selectivity for all 4 fleets, with results showing the spawning biomass and CPUE and selectivity fits by fleet shown in Figure 18.11 and length frequency fits by fleet and numbers at age and the fit to growth shown in Figure 18.12. The numbers at age plot shows another very large recruitment in 1977. The fit to growth indicates that fish are still growing at age 30 and the fits to the length frequencies for the trap and line fleet are particularly poor. The best fits to length frequencies come from the SEF trawl fleet, partly because this data spans a smaller period of time than the other length frequency data, but also due to the narrower range of sizes caught by this fleet.

The first sensitivity considered set the first year of recruitment deviations to 1980, to prevent the implausible large recruitment occurring in 1977. This scenario results in an even higher initial spawning biomass (3.5 million tonnes) and clear problems with the fit to the growth curve and a final spawning biomass at 86% of the initial spawning biomass. Similar problems with the growth curve occur when recruitment deviations start in 1986.

A further sensitivity was conducted where the maximum growth was fixed, rather than estimated, in an attempt to produce a more reasonable growth curve for the four fleet

model. In contrast to the previous 4 fleet results, this produces a final spawning biomass of 6% of the initial spawning biomass (Figure 18.13 and Figure 18.14).

18.5 Discussion

The results of both the 1 fleet and the 4 fleet model are very sensitive to some key parameters with some scenarios predicting very high spawning biomasses and others predicting very low spawning biomasses. There are problems with the fits to various quantities ranging from growth curves to length frequencies to recruitment parameters, and attempts to force more reasonable behaviour on any one of these can result in a bifurcation between these two states with very high and very low biomasses.

While the fits to the very high biomasses seem implausible, the sensitivity of the model to key parameters suggest that there may not be sufficient signal in the input data to give a reliable estimate of spawning biomass. Given the changes in distributions of length frequencies over time, the interactions of multiple fleets with differing selectivity between gear types and the single year of ageing data, stable results could not be obtained from this assessment at this stage. Some of the more important issues include growth, selectivity and fits to the CPUE data.

18.6 Acknowledgements

Many thanks to Geoff Tuck, Neil Klaer, Gavin Fay, Sally Wayte, Tony Smith and Richard Methot who provided assistance with the modelling and the transition to SS2. Commonwealth SEF data was provided by Mike Fuller and Neil Klaer (CSIRO) and Matt Koopman (MAFRI) provided state based data. Malcolm Haddon (TAFI) provided standardised CPUE data.

18.7 References

Annala, J.H., Sullivan, K.J. and O'Brien, C.J. (compilers) 1999. Report from the Fishery Assessment Plenary, April 1999: stock assessments and yield estimates. 430 pp Unpublished report held in NIWA Library, Wellington. MAF, New Zealand.

Day, J., Klaer, N. and Rowling K., 2005. Stock assessment for silver trevally *Pseudocaranx dentex* in the South East Fishery. Prepared for the Shelf Assessment Group. September, 2005.

Haddon, M. 2006. Standardized commercial catch-effort data for selected shelf and slope assessment group species. Document submitted to the 24-25 July 2006 meeting of SlopeRAG. 55 pp.

Hall, N.G. 2002. Draft Assessments of the mirror dory and silver trevally stocks of the South East Fishery. October 6, 2002.

Hilborn, R., Maunder, M., Parma, A., Ernst, B., Payne, J. and Starr, P. 2000. Coleraine – A generalized age structured stock assessment model. http://www.fish.washington.edu/research/coleraine/

Methot, R., 2006. User Manual for the Integrated Analysis Program Stock Synthesis 2 (SS2). Model Version 1.23a.

Thomson, R, and Haddon, M. 2004. Standardized commercial catch-effort data for selected Shelf Assessment Group Species. Prepared for the Shelf Assessment Group. June 15-16, 2005.

Rowling, K.R and Raines, L.P., 2000. Description of the biology and an assessment of the fishery of Silver Trevally Pseudocaranx dentex off New South Wales. Final Report to Fisheries Research and Development Corporation. Project no. 97/125.

Tilzey, R.D. 1995 Silver Trevally, 1994. Stock Assessment Report, South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

18.8 Tables

Table 18.1. Agreed catch history by fleet for silver trevally in the SESSF.

Year	Total	Estuary	SEF trawl	state trawl	trap & line
1945	90.7	90.7	0	0	0
1946	61.9	61.9	0	0	0
1947	56.7	56.7	0	0	0
1948	56.4	56.4	0	0	0
1949	50.3	50.3	0	0	0
1950	43.8	43.8	0	0	0
1951	25.2	25.2	0	0	0
1952	14.7	14.7	0	0	0
1953	20.1	20.1	0	0	0
1954	34.6	34.6	0	0	0
1955	30.5	7.9	0	11.3	11.3
1956	32.6	12.4	0	10.1	10.1
1957	25.2	7.7	0	8.8	8.8
1958	14.9	3.9	0	5.5	5.5
1959	18.8	5.6	0	6.6	6.6
1960	17.6	9.5	0	4.1	4.1
1961	55.2	11.0	0	22.1	22.1
1962	46.8	19.0	0	13.9	13.9
1963	46.7	36.3	0	5.2	5.2
1964	102.8	65.3	0	18.8	18.8
1965	166.0	90.1	0	57.0	19.0
1966	228.7	156.0	0	54.5	18.2
1967	118.8	39.4	0	59.5	19.8
1968	111.2	33.6	0	58.2	19.4
1969	144.9	32.4	0	84.4	28.1
1970	50.1	11.0	0	29.3	9.8
1971	109.2	21.8	0	65.6	21.9
1972	156.3	27.2	0	103.3	25.8
1973	179.3	34.4	0	115.9	29.0
1974	236.6	31.5	0	184.6	20.5
1975	274.3	25.9	0	223.5	24.8
1976	268.1	33.7	0	211.0	23.4
1977	272.0	39.2	0	209.5	23.3
1978	364.2	80.4	0	257.9	25.9
1979	508.6	107.7	0	305.6	95.3
1980	412.8	117.6	0	274.8	20.4
1981	613.9	124.2	0	472.2	17.5
1982	733.5	159.2	0	549.5	24.7
1983	1040.3	123.9	0	900.0	16.4
1984	1520.7	170.8	0	1324.5	25.4
1985	1263.4	147.9	0	1086.3	29.2
1986	1166.6	147.5	114.5	857.4	47.2
1987	1142.3	191.5	7.8	877.5	65.5
1988	1226.5	131.7	5.2	989.7	99.9
1989	1394.2	296.1	19.8	996.2	82.1
1990	1587.7	222.4	71.9	1175.3	118.2
1991	990.1	196.1	67.3	633.3	93.3
1992	947.2	147.3	206.8	440.7	152.4
1993	1029.9	155.3	159.6	582.4	132.6

Year	Total	Estuary	SEF trawl	state trawl	trap & line
1994	835.8	136.6	138.5	464.2	96.5
1995	995.6	112.6	202.0	473.0	208.1
1996	1018.9	110.4	215.3	409.9	283.2
1997	785.2	107.3	167.1	287.8	223.0
1998	628.5	168.0	99.7	245.6	115.2
1999	486.6	115.4	72.5	169.8	128.8
2000	493.3	117.4	92.3	127.2	156.3
2001	640.4	125.6	153.7	235.2	125.9
2002	516.8	104.2	157.9	171.2	83.5
2003	523.8	83.1	123.8	230.1	86.9
2004	648.4	81.2	138.6	374.3	54.3
2005	402.0	78.6	96.0	189.1	38.3

18.9 Figures

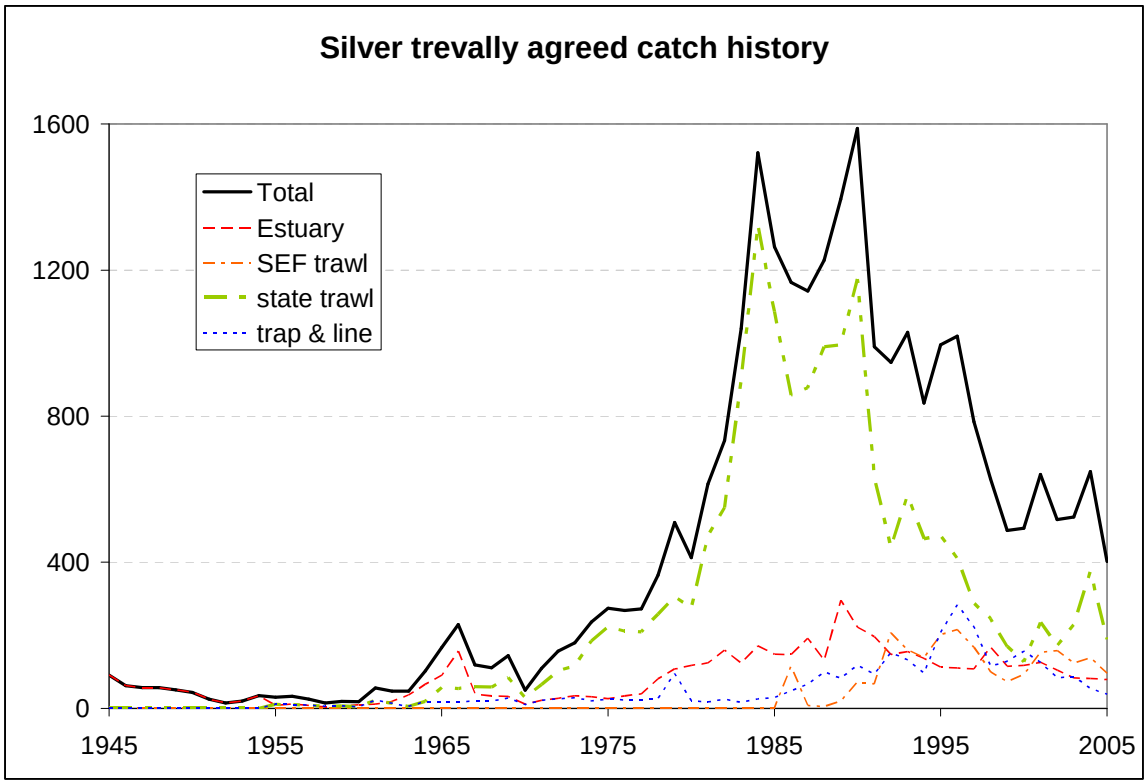


Figure 18.1. Catch history for silver trevally, showing total catch (bold) and catch separated by fleet, estuary haul, Commonwealth (SEF) trawl, state trawl (green, largest separate fleet values with some catches over 1000 t), Commonwealth trawl (yellow, starting in 1986 and with maximum in the 1996) and line and trap (blue with maximum in 1996 slightly higher than commonwealth trawl in that year).

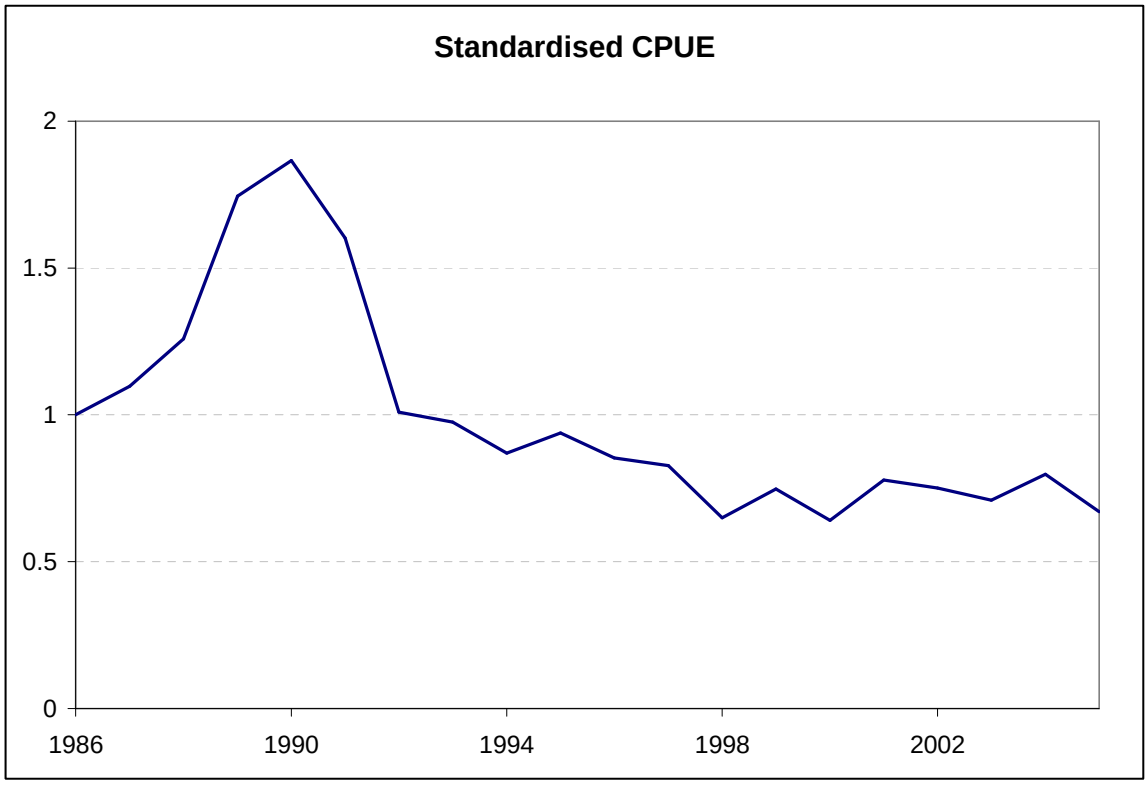


Figure 18.2. Standardised CPUE series for silver trevally.

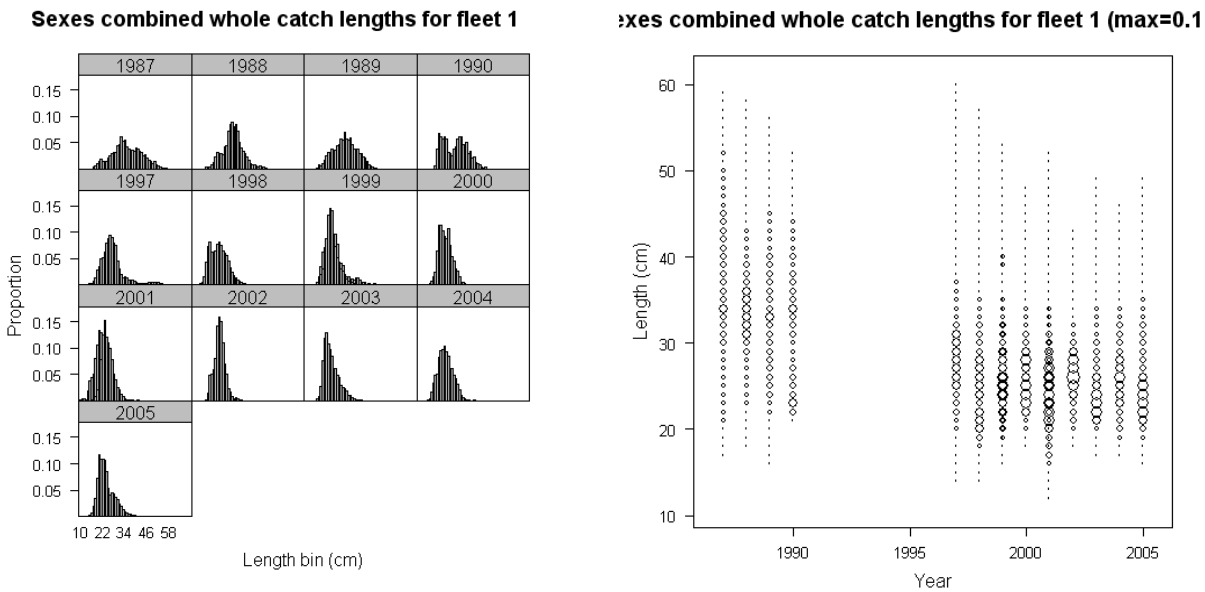


Figure 18.3. Length frequencies for the 1 fleet model. Note the change in mode and number of large fish caught in this series prior to 1991 and post 1996.

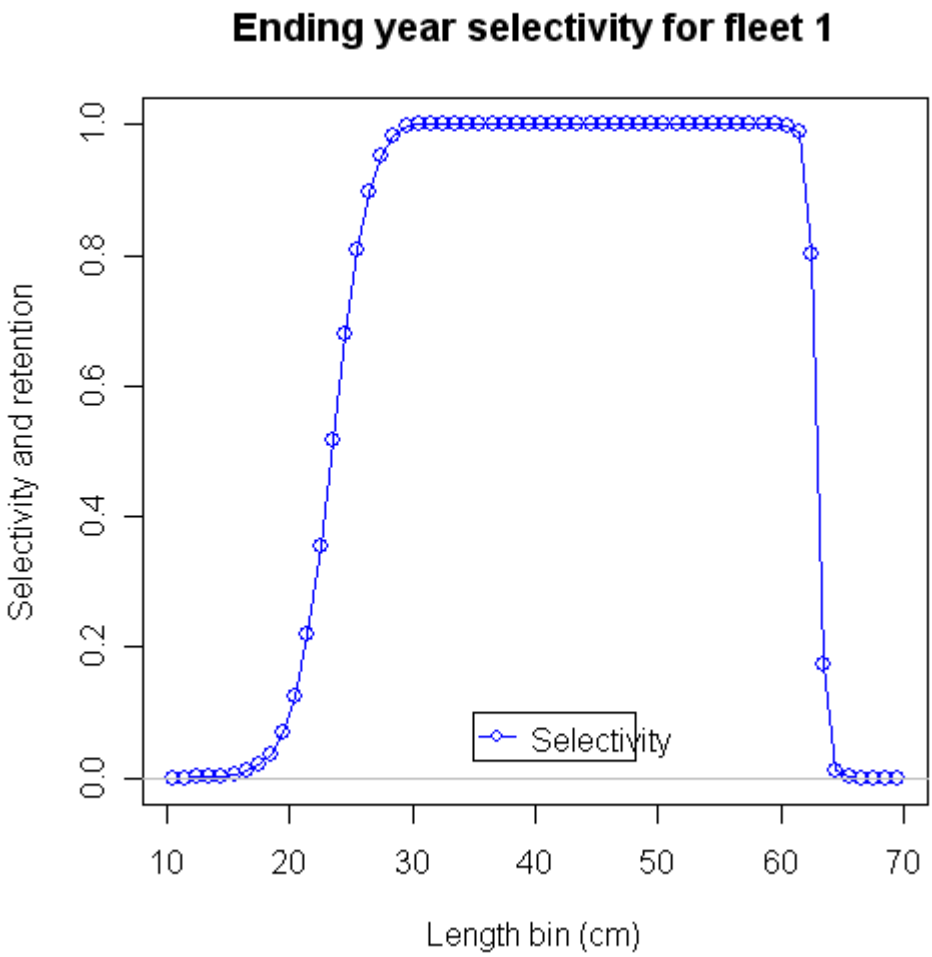


Figure 18.4. Fitted selectivity for the 1 fleet model. While this is theoretically dome shaped selectivity, in practice it is logistic selectivity as there are no fish recorded as caught beyond 60cm in length

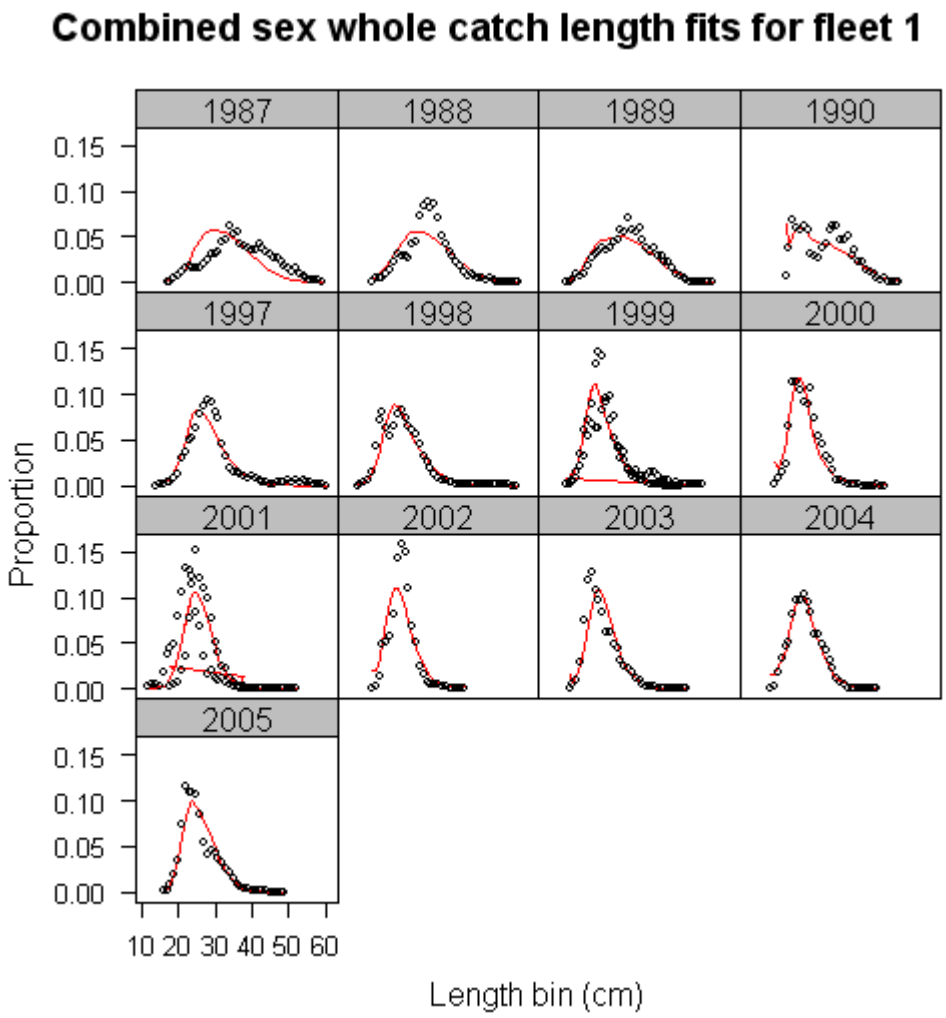


Figure 18.5. Length frequencies fits for the 1 fleet model with broad (fitted) selectivity.

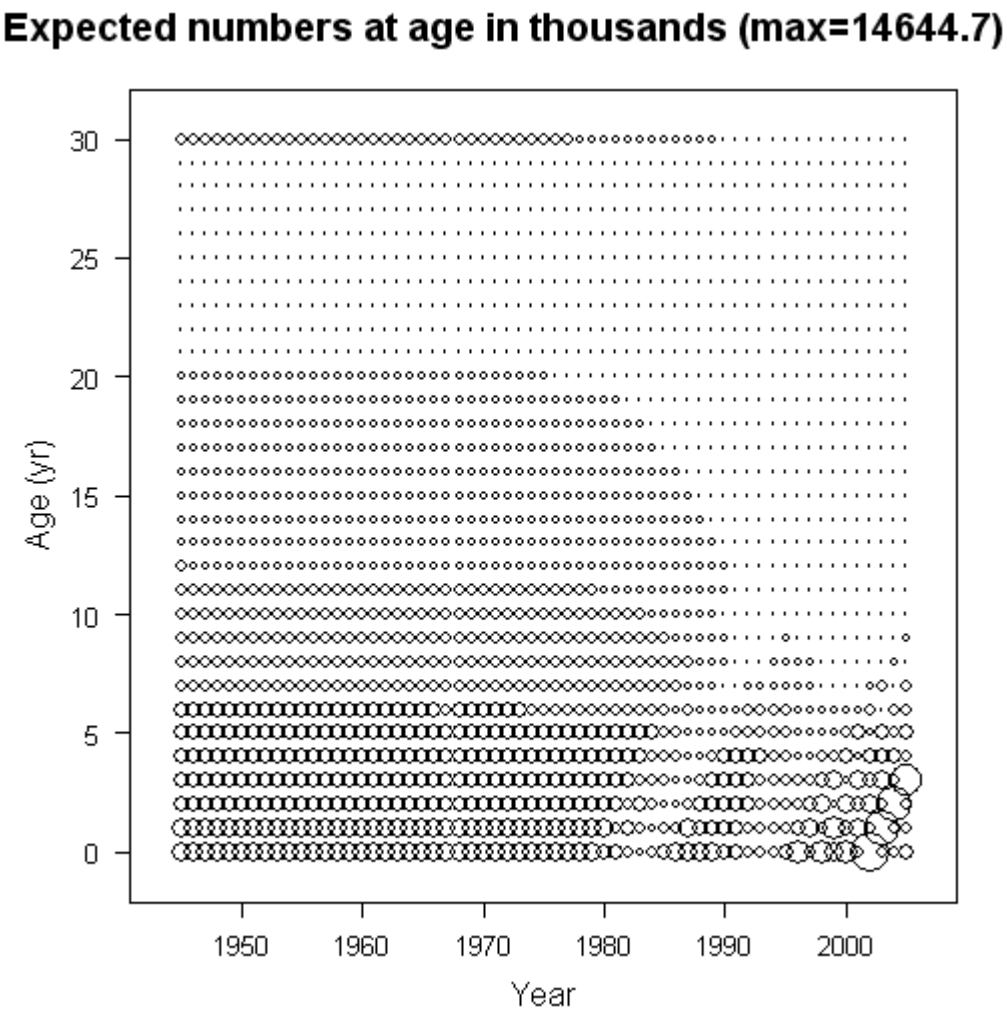


Figure 18.6. Numbers at age for the 1 fleet model. Note the large recruitment in 2002, and recruitment peaks in the late 1980s and late 1990s when length frequency information is available and poor recruitment when no length frequency data is available (in the early 1980s and early 1990s).

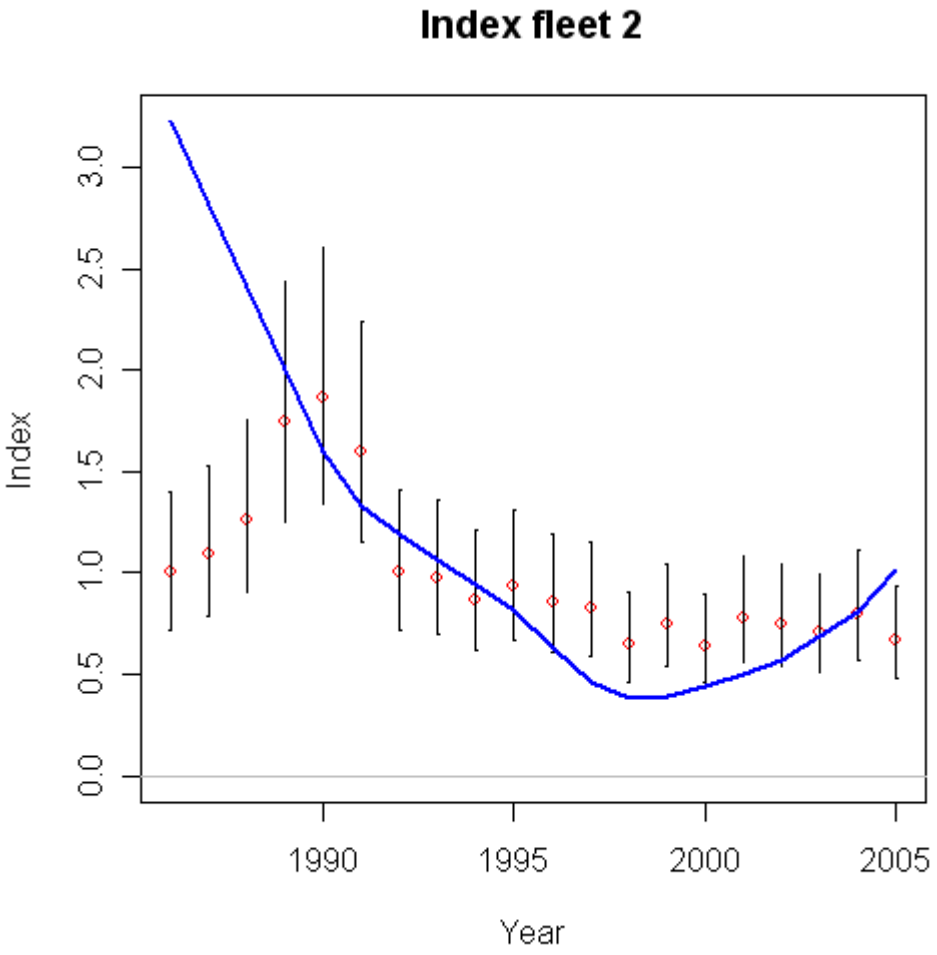


Figure 18.7. Fit to CPUE data for the 1 fleet model with broad (fitted) selectivity. This fit is poor, but is qualitatively similar to the fit from the 2005 assessment.

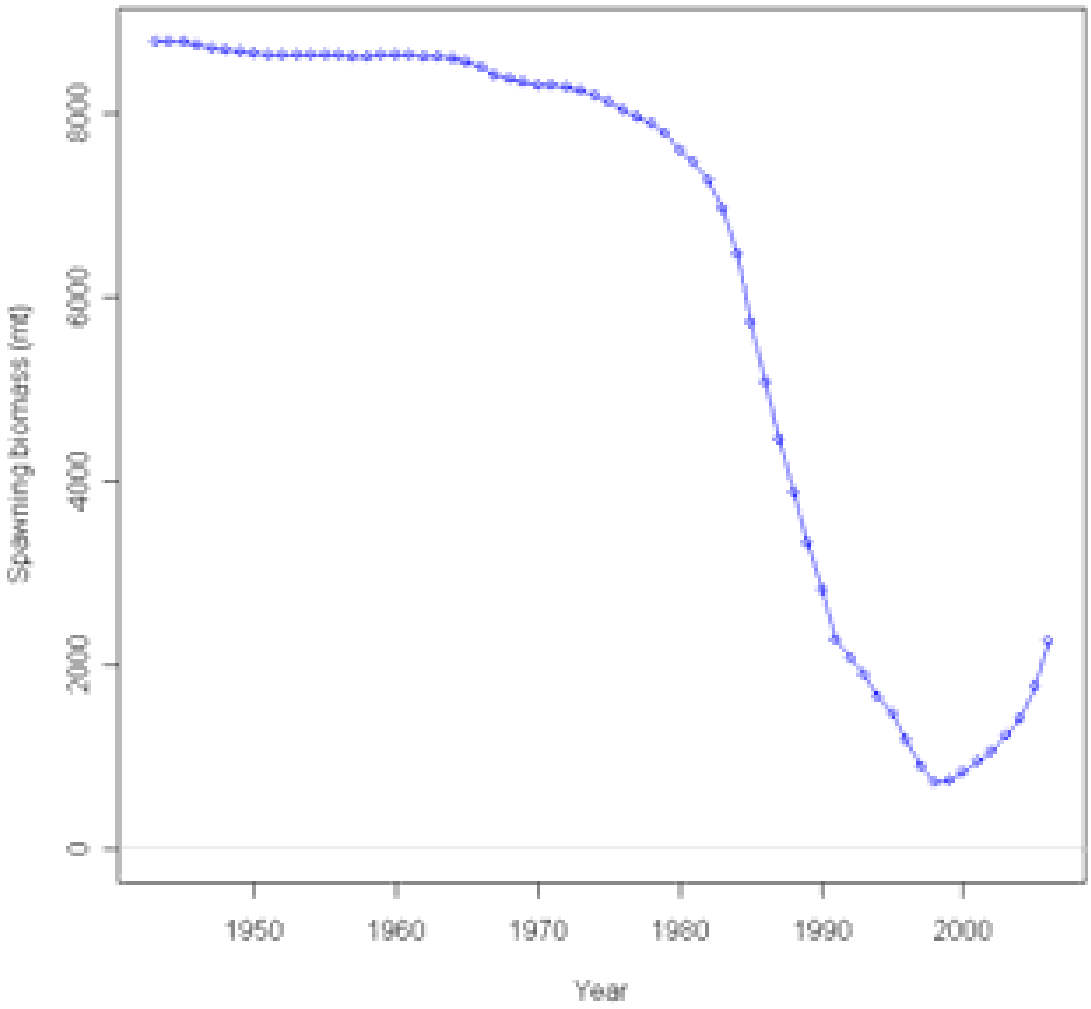


Figure 18.8. Spawning biomass estimate for 1 fleet base case.

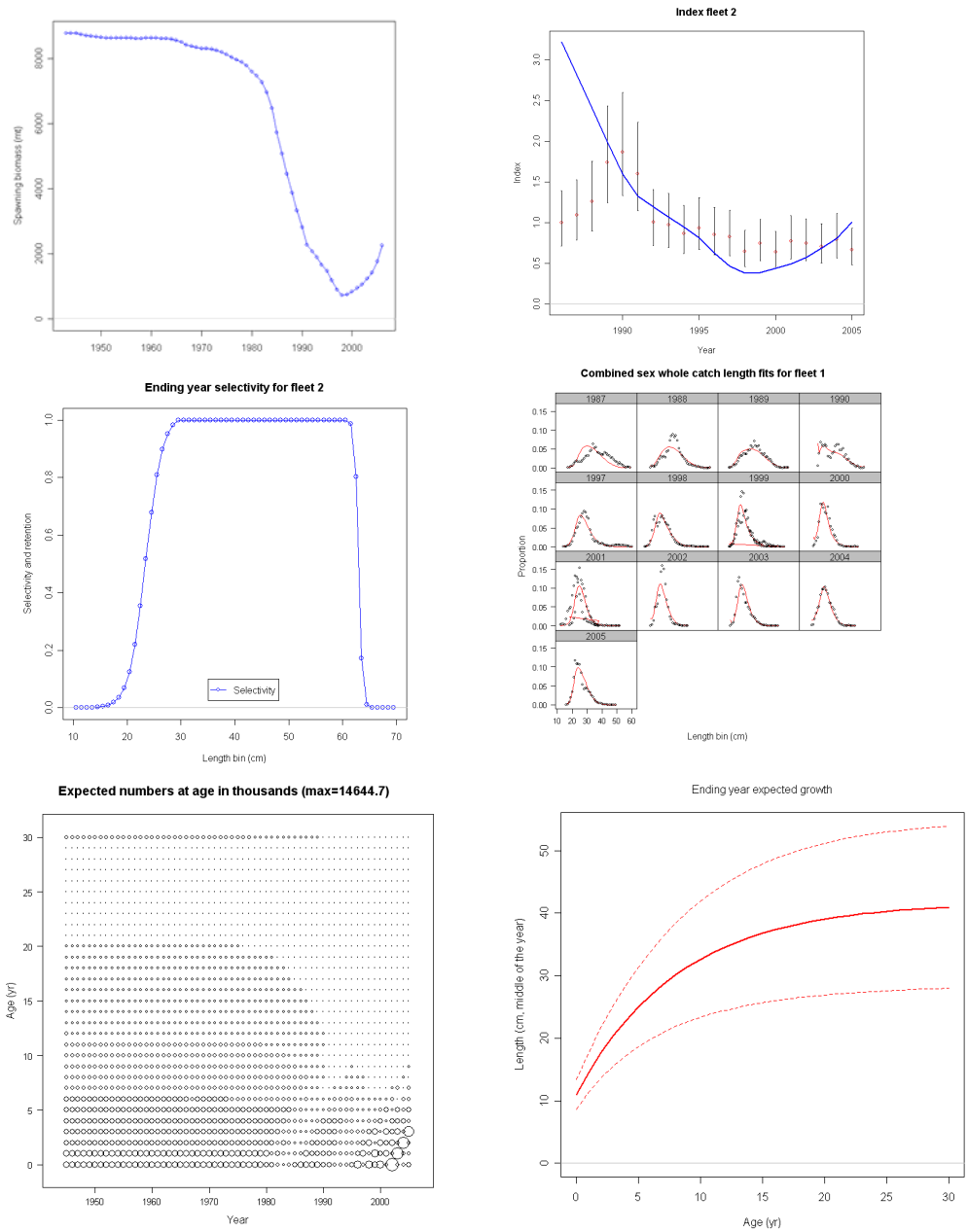


Figure 18.9. Base case for the 1 fleet model with broad (fitted) selectivity, showing spawning biomass, CPUE fit, fitted selectivity, fits to length frequencies, numbers at age and fitted growth curve.

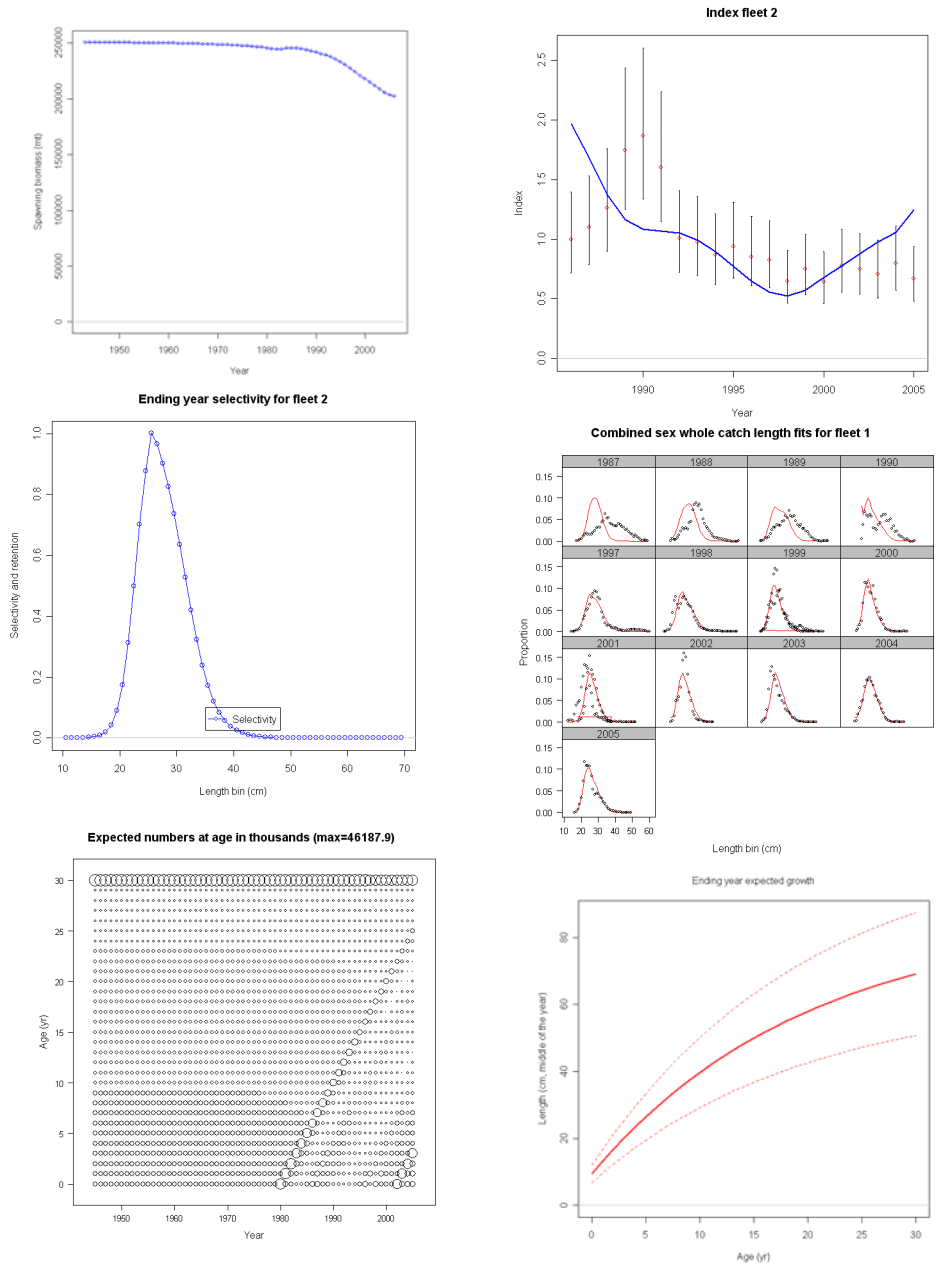


Figure 18.10. Narrow selectivity (forced) for the 1 fleet model, showing spawning biomass, CPUE fit, fitted selectivity, fits to length frequencies, numbers at age and fitted growth curve.

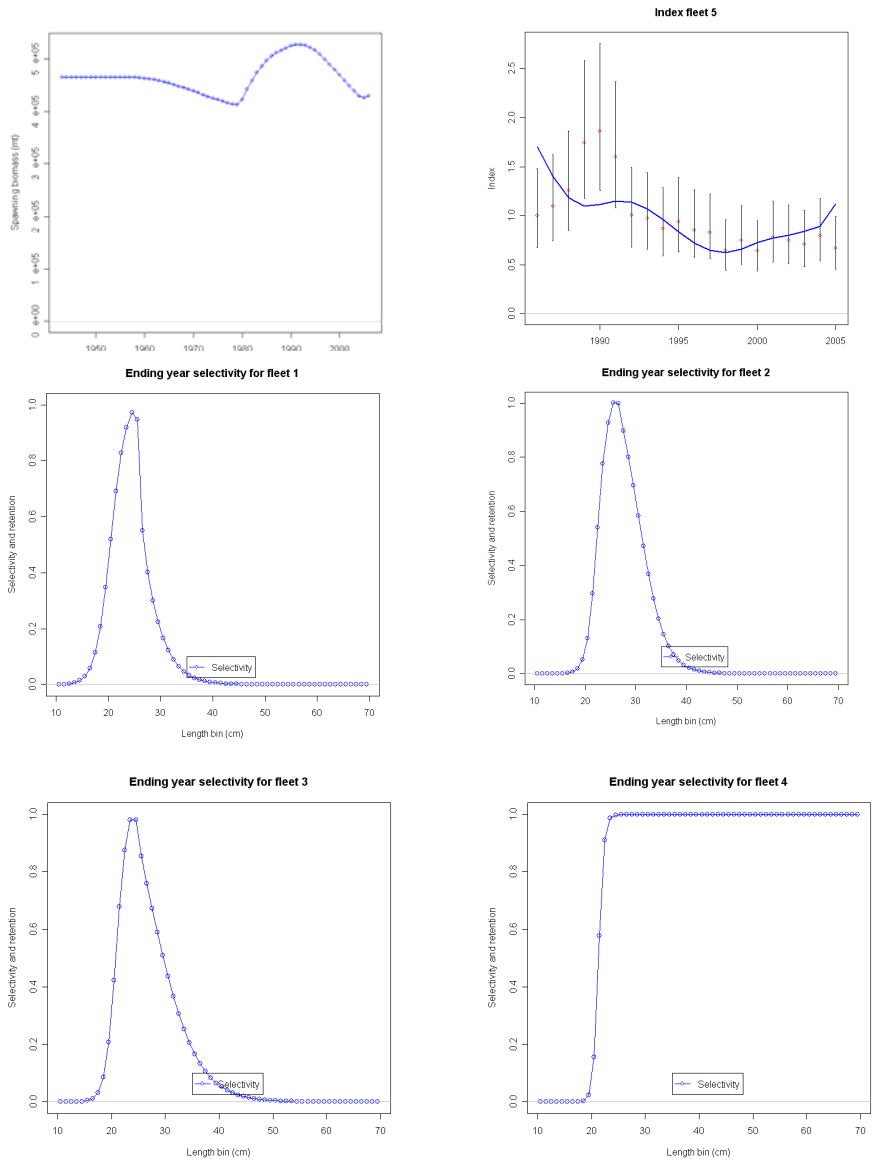


Figure 18.11. Base case for 4 fleet model: spawning biomass, fit to CPUE and fitted selectivity. Fleet 1 is estuary haul, fleet 2 is SEF trawl, fleet 3 is state trawl and fleet 4 is line and trap.

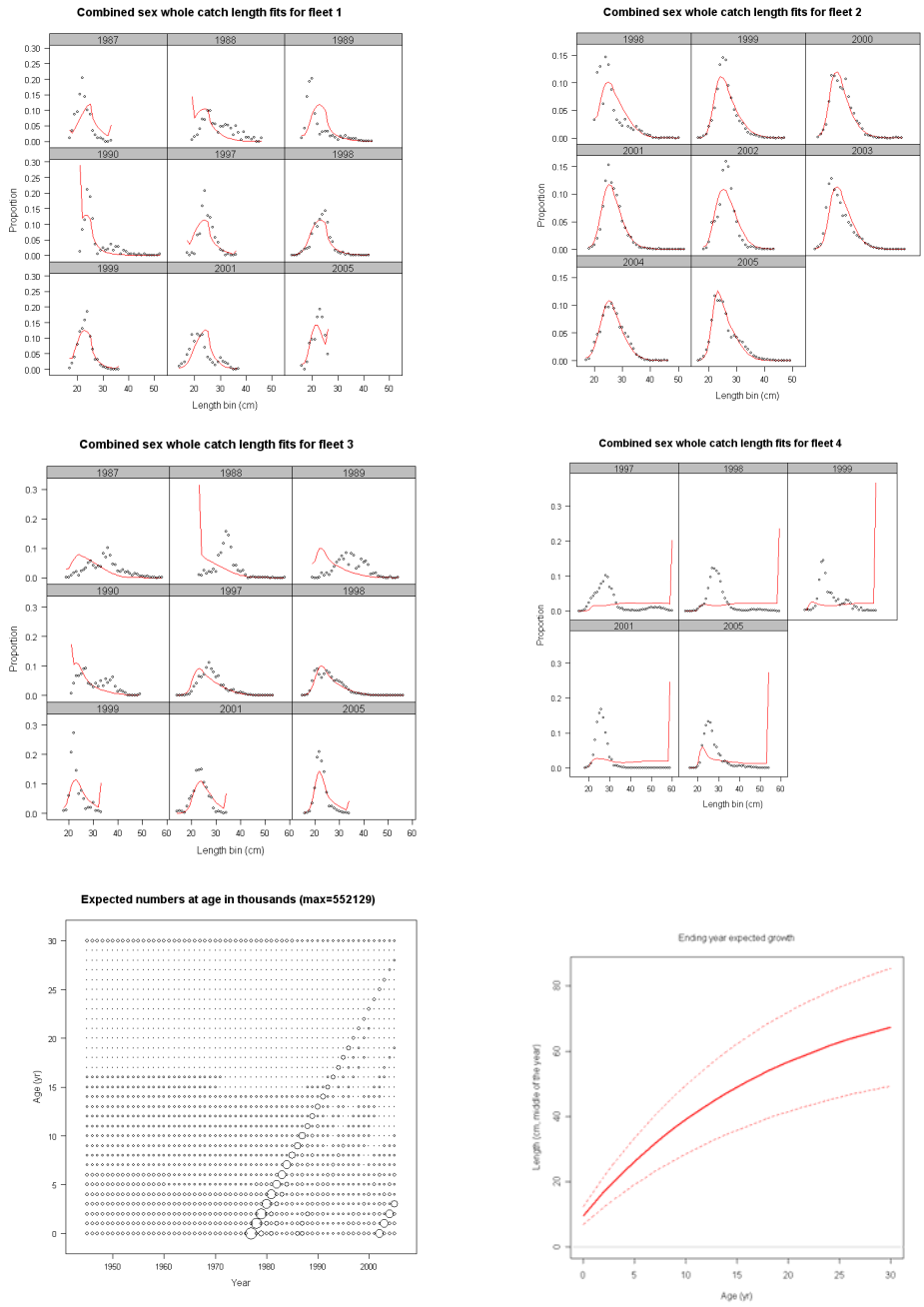


Figure 18.12. Base case for 4 fleet model: Length frequency fits numbers at age and growth fits. Fleet 1 is estuary haul, fleet 2 is SEF trawl, fleet 3 is state trawl and fleet 4 is line and trap.

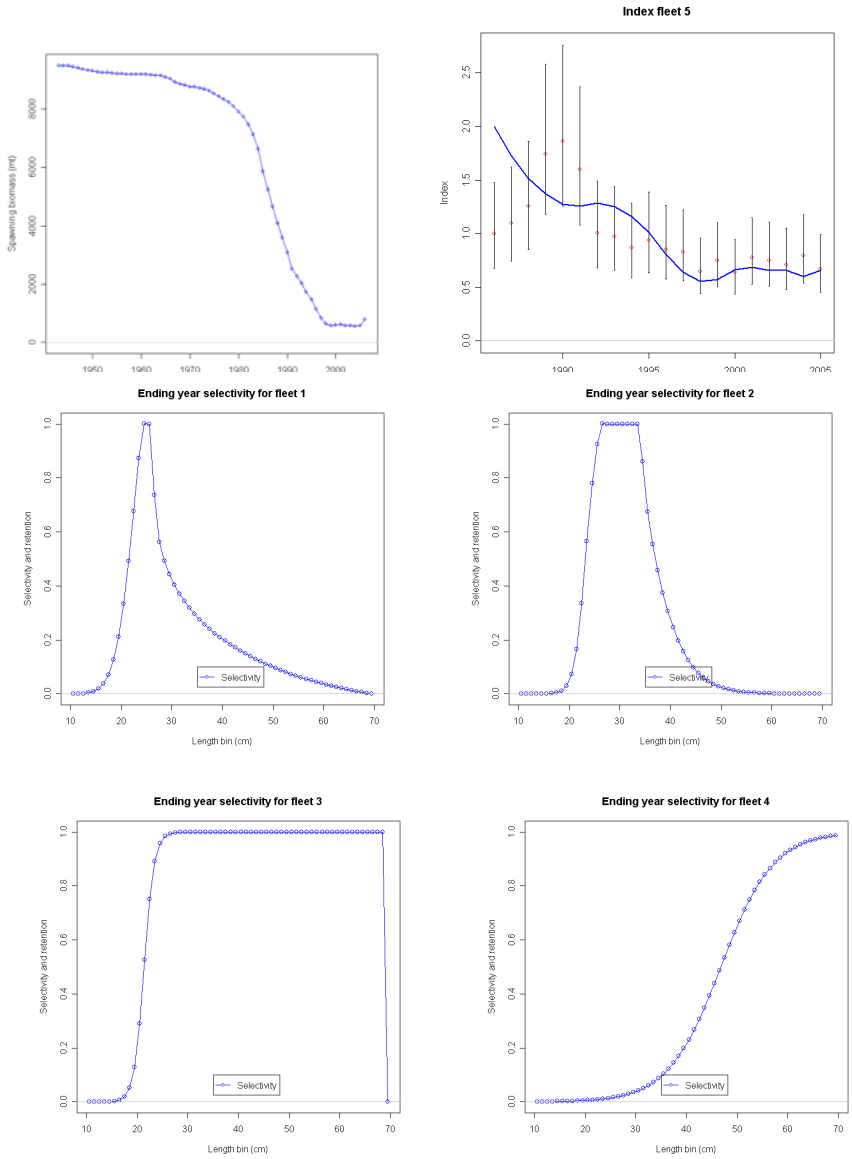


Figure 18.13. Sensitivity for 4 fleet model with fixed maximum size: spawning biomass, fit to CPUE and fitted selectivity. Fleet 1 is estuary haul, fleet 2 is SEF trawl, fleet 3 is state trawl and fleet 4 is line and trap.

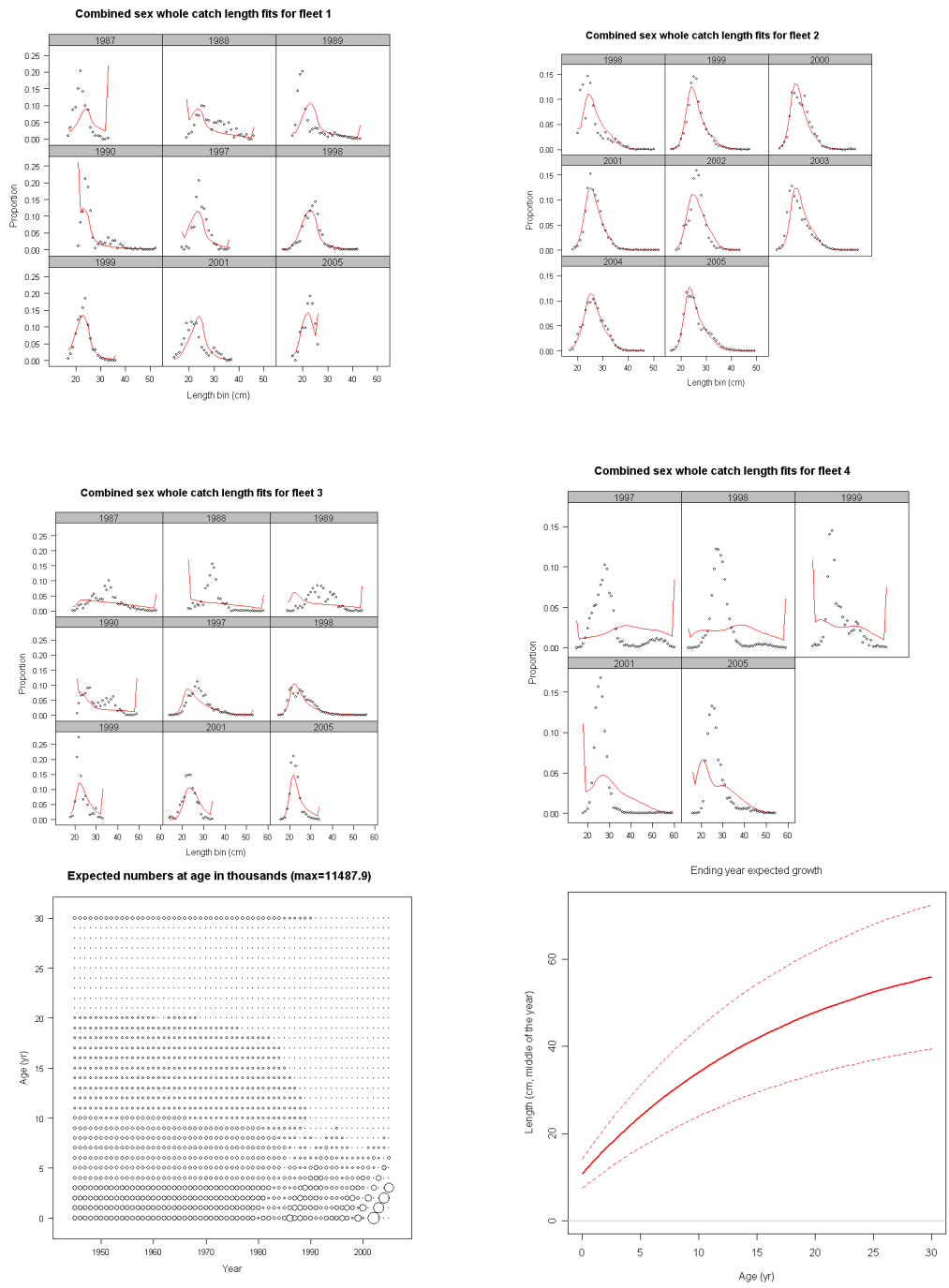


Figure 18.14. Sensitivity for 4 fleet model with fixed maximum size: Length frequency fits numbers at age and growth fits. Fleet 1 is estuary haul, fleet 2 is SEF trawl, fleet 3 is state trawl and fleet 4 is line and trap.

19. Updated Stock Assessment of Tiger Flathead (*Neoplatycephalus richardsoni*) Based on Data up to 2005

Neil L. Klaer[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

19.1 Background

Tiger flathead have been caught commercially in the south eastern region of Australia since the development of the trawl fishery in 1915. They are endemic to Australian waters and are caught mainly on the continental shelf and upper slope waters from northern NSW to Tasmania and through Bass Strait. Historical records (e.g. Fairbridge, 1948; Allen, 1989; Klaer, 2005) show that steam trawlers caught tiger flathead from 1915 to about 1960. A Danish seine trawl fishery developed in the 1930's (Allen, 1989) and continues to the present day. Modern diesel trawling commenced in the 1970's.

19.1.1 Previous assessments

Prior to 2001, the most recent quantitative assessment for tiger flathead was from the late 1980s (Allen, 1989). In that report, the assessment for tiger flathead was conducted based on catch and effort data using a surplus production model. The estimate of Maximum Sustainable Yield, *MSY*, for NSW and eastern Bass Strait was about 2,500 t.

Between 1989 and 2001, assessments of tiger flathead involved examination of trends in catches, catch rates, and age and length data, but no quantitative assessments were undertaken. Assessments from 1993 to 2001 can be found in the annual reports of SEFAG (the South East Fishery Assessment Group). For example, the 1993 assessment noted that tiger flathead catches from south-east Tasmanian waters contained higher proportions of larger, older fish than that those from eastern Bass Strait. This suggested that tiger flathead resources off Tasmania were either more lightly fished than those in the main fishing areas, or that there was a separate stock with different population characteristics off Tasmania.

During 2001–4, data for tiger flathead were collated, summarized and presented at workshops (see Cui *et al*. (2004) for a detailed summary of these workshops and the analyses presented to them). These workshops led to revisions to the data series, the analyses of the data, and to suggestions for revisions to the data

sets and research priorities. The 2004 assessment (Cui et al., 2004) used 89 years (1915–2003) of data to estimate the virgin spawning stock biomass and the 2004 spawning stock biomass relative to that in 1915 and provided, for the first time, a complete picture of the dynamics of the tiger flathead fishery.

A number of changes to both the input data and some model structural changes were made and presented in the assessments developed in 2005 (Punt 2005a, b). These assessments considered tiger flathead caught off eastern Tasmania in SEF zone 30 as either separate to, or part of the same stock in zones 10 (E NSW), 20 (E Bass Strait) and 60 (Bass Strait) combined. In the scenario where E Tasmanian flathead are part of the same stock, a separate fleet was constructed to account for catches made there. Modifications to estimates of historical catches from Klaer (2005) were incorporated into catch series used in the assessments. Length-frequency data for 1945–67 and 1971–84 were obtained, and uncertainty in discard rates was estimated using a bootstrap procedure.

19.1.2 Modifications to the 2006 assessment

The intention for the 2006 assessment was initially to duplicate as far as possible the assessment results from 2005 (Punt, 2005a, b). The same assumptions were made about stock structure, i.e tiger flathead off eastern Tasmania (SESSF Zone 30) may or may not be in the same stock as those off NSW and Victoria (SESSF Zones 10, 20 and 60.

Although it was possible to replicate 2005 results reasonably well, there are a few differences in the model structure implemented in SS2:

- Steepness is treated as an estimable parameter
- Annual age frequencies are added directly into the model as samples independent to length frequencies (not converted to an age-length key and multiplied by length frequencies to generate an age frequency as in 2005)
- Verification and weighting up of length frequencies was carried out using an automated system using procedures documented in Thomson (2002).
- Estimates of discard rates for the steam trawl fleet have been added to the assessment

The population dynamics model implemented in SS2 is documented in Methot (2005).

19.2 Data available for assessment purposes

There are many sources of data for tiger flathead. These include values for biological parameters, landed catches, discard rates (defined here as the ratio of the discard catch (in mass) to the total (i.e. discarded and landed) catch), catch-rates, length-frequencies for the landed and discarded catches, and age-length keys.

The following four 'fleets' are considered in the assessment:

(i) the steam trawlers that operated during 1915–61 (the "steam trawl" fleet);
(ii) the Danish seine fleet (1930 onwards) (the "Danish seine" fleet);
(iii) the otter trawl fleet that started in 1971 (the "diesel trawl" fleet); and
(iv) the fisheries off Tasmania.

These four fleets are distinguished because: a) they differ in terms of their estimated selectivity patterns (reflecting differences in actual gear selectivity but also where the fleets operated), and b) the need to be able to examine the sensitivity of the model outcomes to the inclusion in the assessment of the fisheries off Tasmania.

19.2.1 Catches

Catches for the flathead assessment need to be divided among trawl and Danish seine fleets for SEF zones 10 (E NSW), 20 (E Bass Strait), 60 (Bass Strait) and 30 (Tasmania). State records of flathead catches are also accounted for. Catches described in Punt (2005a) were used for years to 2000, and for 2001 to 2005 the catches were recalculated and scaled to maintain consistency with the most recent estimates of flathead catches provided by PIRVIC (Koopman pers. comm.). Adjustments made to the figures presented last year for the 2001-2004 period were minor. Additionally, an estimate was required for catches in the 2006 calendar year. To make that estimate, it was assumed that the Commonwealth catch will be reduced compared to 2005 in the ratio of the TAC – 3000/3150, and that catches in state waters will be the same as for 2005. Catch estimates for the period 1986 to 2006 are given in
Table 19.2.

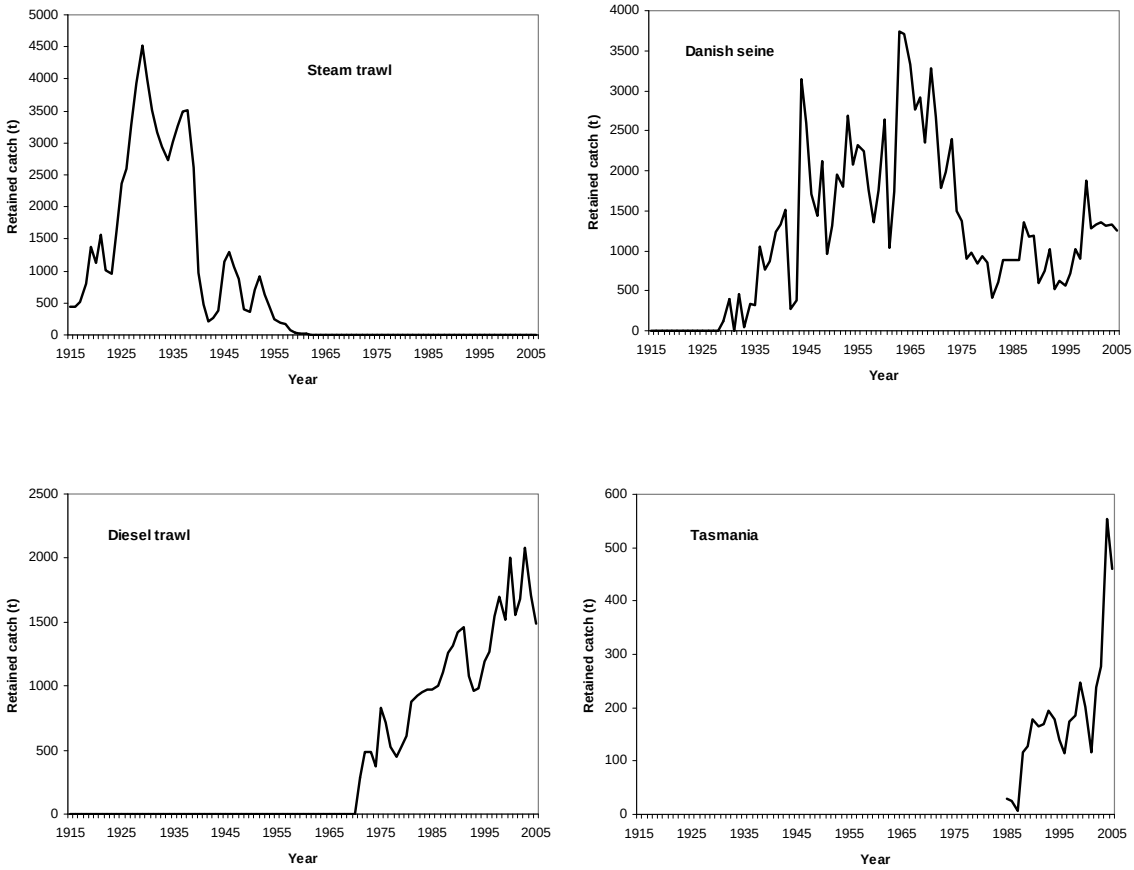


Figure 19.1. The catch time-series used in the analyses of this document. The catches in this figure include state catches and SEF1 catches scaled to SEF2 records.

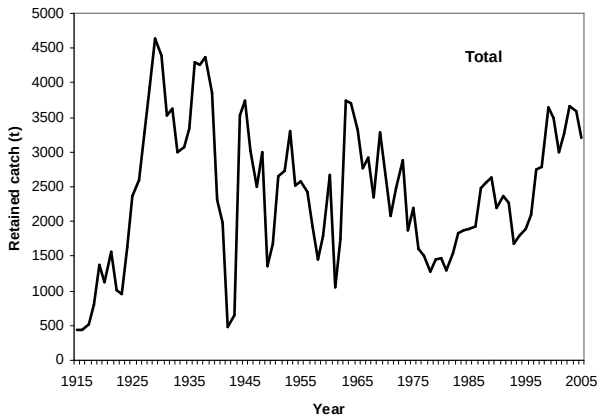


Figure 19.2. The catch time-series (aggregated over fleet) used in the analyses of this document. The solid line includes the catches off Tasmania and the dotted line excludes these catches.

Table 19.1. Reported catches (tonnes) and catch-rates by fleet (1915–83). The catches by steam trawl and Danish seine for 1915–61 have been increased by 20% to account for discarding (Klaer, 2005).

	Catch (t)		Catch-rate			Catch (t)			Catch-rate	
Year	Steam trawl	Danish Seine	Steam trawl	Danish Seine	Year	Steam trawl	Danish Seine	Diesel trawl	Steam trawl	Danish Seine
1915	446	0	-	-	1950	372	1314	0	-	38.7
1916	447	0	-	-	1951	699	1950	0	-	27.6
1917	519	0	-	-	1952	923	1799	0	0.262	31.8
1918	806	0	-	-	1953	620	2682	0	0.208	52.0
1919	1381	0	1.618	-	1954	439	2084	0	0.232	34.4
1920	1117	0	1.732	-	1955	253	2319	0	0.219	47.4
1921	1557	0	1.806	-	1956	188	2242	0	0.208	46.5
1922	1008	0	1.758	-	1957	167	1751	0	0.169	32.1
1923	955	0	1.646	-	1958	82	1365	0	-	22.5
1924	1628	0	-	-	1959	39	1761	0	-	28.7
1925	2363	0	-	-	1960	18	2647	0	-	43.6
1926	2600	0	-	-	1961	11	1036	0	-	-
1927	3282	0	-	-	1962	0	1742	0	-	-
1928	3933	0	-	-	1963	0	3745	0	-	-
1929	4522	122	-	-	1964	0	3707	0	-	-
1930	3994	396	-	-	1965	0	3322	0	-	38.2
1931	3518	5	-	-	1966	0	2769	0	-	41.5
1932	3170	462	-	-	1967	0	2912	0	-	62.5
1933	2947	53	-	-	1968	0	2355	0	-	61.2
1934	2734	332	-	-	1969	0	3289	0	-	77.8
1935	3016	325	-	-	1970	0	2667	0	-	67.1
1936	3255	1046	-	-	1971	0	1793	286	-	69.9
1937	3494	765	0.635	-	1972	0	1981	491	-	114.0
1938	3509	870	0.749	-	1973	0	2397	490	-	88.0
1939	2622	1241	0.723	-	1974	0	1493	369	-	58.1
1940	978	1329	0.611	-	1975	0	1367	827	-	56.6
1941	483	1506	0.618	-	1976	0	900	712	-	41.9
1942	201	270	0.401	-	1977	0	977	522	-	55.5
1943	267	381	-	-	1978	0	836	446	-	51.9
1944	378	3149	-	-	1979	0	928	520	-	-
1945	1144	2602	-	-	1980	0	851	609	-	-
1946	1306	1710	-	-	1981	0	418	877	-	-
1947	1061	1432	-	-	1982	0	615	930	-	-
1948	881	2121	-	-	1983	0	889	950	-	-
1949	396	965	-	-						

Table 19.2. Reported catches (tonnes) by fleet and zone 1986–2005, estimated catch 2006.

	Danish seine					Diesel trawl					Tasmania		
Year	Zone 10	SEF1 Zone 20	Zone 60	State	Total	Zone 10	Zone 20	Zone 60	State	Total	SEF1	State	Total
1986	1.3	246.8	663.3	0.0	911.4	483.6	476.8	29.3	37.0	1026.7	25.9	0.0	25.9
1987	0.0	823.7	478.3	84.0	1385.9	494.4	549.3	24.2	64.0	1131.8	6.0	0.0	6.0
1988	11.3	471.9	589.8	127.0	1200.0	641.0	528.6	48.5	71.0	1289.1	38.7	77.0	115.7
1989	10.6	708.6	375.0	119.0	1213.2	548.9	662.8	67.2	67.0	1345.8	47.3	81.0	128.3
1990	12.9	281.2	201.1	107.0	602.2	665.9	678.8	50.7	60.0	1455.4	25.2	153.0	178.2
1991	10.8	332.5	317.6	99.0	759.9	710.5	639.7	71.0	71.0	1492.2	39.6	126.0	165.6
1992	34.0	621.7	348.4	147.0	1151.1	568.6	529.7	99.2	40.0	1237.5	40.0	130.0	170.0
1993	20.3	206.3	156.9	132.0	515.6	496.5	336.0	74.3	55.0	961.9	72.7	121.0	193.7
1994	9.7	192.6	273.9	150.0	626.2	506.3	330.5	83.7	61.0	981.5	57.0	121.0	178.0
1995	0.1	229.6	232.2	102.0	563.9	504.0	542.9	82.8	59.0	1188.7	68.3	71.0	139.3
1996	0.0	351.4	226.8	133.0	711.3	565.6	520.6	95.7	83.0	1264.9	62.8	51.0	113.8
1997	0.0	592.2	303.1	128.0	1023.3	374.1	914.4	142.3	111.0	1541.8	112.9	62.0	174.9
1998	0.0	679.8	179.1	46.0	904.9	462.5	911.2	145.1	180.8	1699.7	131.6	54.0	185.6
1999	0.0	1241.6	618.0	13.8	1873.4	582.4	698.2	28.5	211.3	1520.4	195.2	53.0	248.2
2000	0.0	1018.2	265.8	2.0	1286.0	1059.7	737.0	25.3	184.2	2006.3	92.5	110.0	202.5
2001	14.0	827.0	459.0	23.5	1323.6	878.3	518.0	31.9	124.2	1552.4	115.9	0.2	116.1
2002	27.9	868.5	440.2	20.5	1357.2	873.1	680.1	16.5	107.9	1677.6	237.1	0.3	237.4
2003	0.1	839.7	469.7	5.8	1315.3	1026.7	863.7	17.7	169.2	2077.3	276.5	0.2	276.8
2004	0.1	903.6	425.2	6.9	1335.7	822.7	669.1	15.2	198.6	1705.6	546.1	8.6	554.7
2005	0.5	716.9	530.1	2.4	1250.0	492.6	806.9	16.8	172.3	1488.5	437.4	23.3	460.7
2006	0.5	682.8	504.9	2.4	1190.6	469.1	768.4	16.0	172.3	1425.8	416.5	23.3	439.9

19.2.2 Catch rates

Catch rate indices are available for the historical period (1915 to 1983, Table 19.1) from Klaer (2004). The catch rates are standardized for the steam trawl fleet, but the catch rates are unstandardized for the Danish seine fleet. Standardized catch rates for the trawl fleet are only available for the periods 1919–23, 1937–42 and 1952–57, but are comparable across these periods. The Danish seine catch rates are available for the periods 1950–60 and 1965–78 (Allen, 1989). Standardized catch rates for the diesel trawl Danish seine, and Tasmanian fleets are available for the period 1986 to 2004 based on the data in SEF1 logbook database (M. Haddon, 2006, Table 19.3).

Table 19.3. The time-series of catch-rates and discard rates (1986–2005).

	Catch rate		Discard rate		
Year	Danish seine	Diesel trawl	Danish seine	Diesel trawl	Tasmania
1986	1.0000	1.0000	-	-	-
1987	1.1465	1.3788	-	-	-
1988	1.2831	1.4324	-	-	-
1989	1.1966	1.3504	-	-	-
1990	0.7814	1.4907	-	-	-
1991	1.0081	1.4101	-	-	-
1992	1.1565	1.24	-	-	-
1993	0.7247	1.2174	-	-	-
1994	0.658	0.8945	-	-	0.090
1995	0.591	0.9215	-	-	-
1996	0.7342	0.8032	-	0.132	-
1997	0.9797	0.8115	-	0.03	0.001
1998	0.7815	0.8244	0.010	0.196	0.0002
1999	1.2882	0.971	0.011	0.214	0.002
2000	0.9149	1.2479	0.164	0.161	-
2001	1.1216	1.1254	0.008	0.073	-
2002	1.2838	1.2415	0.036	0.085	0.009
2003	1.4895	1.2607	0.017	0.064	0.006
2004	1.274	1.071	0.001	0.076	-
2005	1.1341	0.9335	0.067	0.101	0.001

19.2.3 Discard rates

Information on the fraction of the catch (in mass) which is discarded annually is available from onboard observers. Two observer programmes, the SMP (Liggins *et al.*, 1997) and the ISMP (Knuckey *et al.*, 1999) have collected onboard data which can be used to estimate discard rates. The data collected by observers are estimates by shot of the mass retained and the mass discarded. The discard rate used here is simply the ratio of the mass discarded (summed over all shots by a given fleet in a given year) to the total mass (retained and discarded combined). Any records for which the gear code was not bottom trawl or Danish seine and in which the catch did not occur in one of SESSF

zones 10, 20, 30, or 60 were excluded. The discard rates are listed (by year and fleet) in Table 19.3. In the 2005 assessment the coefficients of variation for the discard rates were estimated using a bootstrap procedure. In 2006 the cvs were given a constant value of 0.2 (see future work). Additionally, for the 2006 assessment values of 20% were assigned to the years 1918, 1937 and 1957 for the steam trawl fleet based on discard rates for that period estimated in Klaer (2006).

19.2.4 Age- and length-frequency data

Length frequency data are available from port measurers and from onboard sampling. The former generally involve much larger sample sizes than the latter. In contrast, the onboard sampling programmes provide information on the length-frequencies of the discarded as well as the landed catch.

Table 19.4. Sample sizes for length-frequencies for the landed catches.

Year	Steam trawl	Danish seine	Diesel trawl	Tasmania	Year	Steam trawl	Danish seine	Diesel trawl	Tasmania
1945	5077	21735	0	0	1976	0	0	14442	0
1946	10916	26475	0	0	1977	0	0	18447	0
1947	15488	20287	0	0	1978	0	0	16242	0
1948	11973	20721	0	0	1979	0	0	12189	0
1949	10863	23316	0	0	1980	0	0	8756	0
1950	18057	16640	0	0	1981	0	0	6182	0
1951	25843	21423	0	0	1982	0	0	5893	0
1952	32188	28941	0	0	1983	0	0	5439	0
1953	14561	16264	0	0	1984	0	0	6698	0
1954	12476	26263	0	0	1985	0	0	0	0
1955	1917	9966	0	0	1986	0	0	0	0
1956	0	14878	0	0	1987	0	0	0	0
1957	0	15283	0	0	1988	0	0	0	0
1958	0	17291	0	0	1989	0	0	0	0
1959	0	20354	0	0	1990	0	0	0	0
1960	0	25334	0	0	1991	0	0	684	0
1961	0	18623	0	0	1992	0	1442	761	0
1962	0	20255	0	0	1993	0	0	502	0
1963	0	15988	0	0	1994	0	292	156	0
1964	0	17882	0	0	1995	0	817	617	0
1965	0	17861	0	0	1996	0	2395	1494	0
1966	0	19101	0	0	1997	0	0	638	0
1967	0	7233	0	0	1998	0	0	5649	0
1968	0	0	0	0	1999	0	5079	12747	332
1969	0	0	0	0	2000	0	3566	6698	362
1970	0	0	0	0	2001	0	5690	11065	5201
1971	0	0	610	0	2002	0	3569	6208	574
1972	0	0	1451	0	2003	0	1896	4686	982
1973	0	0	434	0	2004	0	3991	10247	570
1974	0	0	5590	0	2005	0	1834	12621	332
1975	0	0	11681	0					

19.2.4.1 Port length-frequencies

The port length-frequencies for a given fleet are scaled according to the size of the catch the fish were sampled from, as well as the total annual catch reported from that zone as described in Thomson (2002). Table 19.4 lists the number of fish measured by year and fleet. Port length-frequencies were used to provide information on the size structure for retained catch.

19.2.4.2 Discard length-frequencies

The proportion of the catch which is discarded by length-class can be determined from the onboard length-frequency data. The data was scaled in the same way as for port samples.

19.2.4.3 Age-composition data

The analyses of this document are based on the break-and-burn data only, following the reasoning given by Punt (2005a).
Table 19.5 lists the sample sizes for each year.

Table 19.5. Sample sizes for age frequencies.

	Age-frequency (samples)		
Year	Danish seine	Diesel trawl	Tasmania
1998	101	213	0
1999	0	169	50
2000	192	521	60
2001	30	181	0
2002	558	595	149
2003	102	0	0
2004	174	152	0
2005	603	269	19

19.2.4.4 Growth

Von Bertalanffy growth curves were fitted to age and length data by sex in Punt (2005a), (Figure 19.3). Data were derived from SESSF Zones 10 and 20 only. Sample sizes were 1,228 males and 1,379 females. The growth curves for males and females are different (females grow larger). Parameter values are given in Table 19.6.

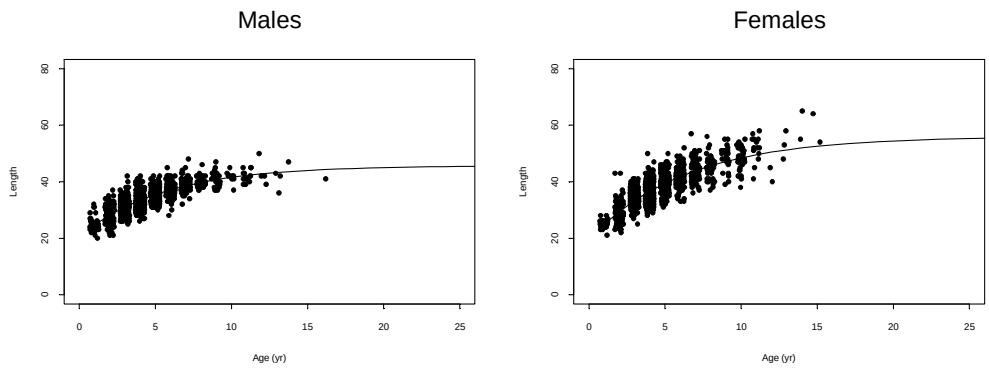


Figure 19.3.Growth curves by sex for tiger flathead.

Table 19.6. Specifications for the parameters of the growth curve.

Quantity	Females	Males
ℓ_∞ (cm)*	56.04	45.70
κ (yr^{-1})*	0.156	0.180
t_0 (yr)*	-2.783	-3.322
Length-weight – a	0.00588	0.00588
Length-weight – b	3.310	3.310

* Note: The standard von Bertalanffy parameters are not directly used in SS2, a conversion is necessary.

19.3 Analytical framework

19.3.1 Model and parameter estimation

Table 19.7. The parameters of the population dynamics model. Parameters indicated by an asterisk are considered in the tests of sensitivity.

Parameter	Value
Pre-specified	
Natural mortality*	0.22 yr^{-1}
Weight-at-age	See Table 19.6
Length-at-age	See Table 19.6
Age-at-maturity	3 yr
Retention probability	Computed from auxiliary information
Standard deviation of variation in recruitment	0.2
Maximum age, *x*	20 yr
Estimated	
Stock-recruitment steepness *	Estimated
Virgin recruitment	Estimated
Recruitment deviations	Estimated (*y*=1916, 17, …, 2004)
Selectivity-at-age	Estimated
Variation in length-at-age	Estimated

19.3.2 Sensitivity tests

A series of sensitivity test is used to examine the sensitivity of the results of the model to some of its assumptions / the data inputs:

Model-related sensitivity tests

1) Vary *M* from 0.1 to 0.3 in steps of 0.5.
2) Steepness = 0.7, Steepness =0.8, Steepness=90.

Data-related sensitivity tests

1) Double and halve the residual standard deviations for the catch-rate indices.
2) Double and halve the effective sample sizes for the size-composition data.
3) Double and halve the effective sample sizes for the age-composition data.
4) Exclude the size-composition information that applies to steam trawl.

The results of the sensitivity tests are summarized by the following summary statistics:

1) The spawning stock biomass in 1915.
2) The spawning stock biomass at the start of 2006.
3) The depletion at the start of 2006.
4) The RBC for 2006 (landed catch) for the F48B40 Tier rule.

19.3.3 Projection and calculation of the Recommended Biological Catch

The SS2 model includes the ability to calculate RBC values based on assessment scenario results and the Australian Tier 1 rule (see Wayte 2006 for details of how the Tier rule is implemented).

19.4 Results

19.4.1 Diagnostic fits to input data for the base case

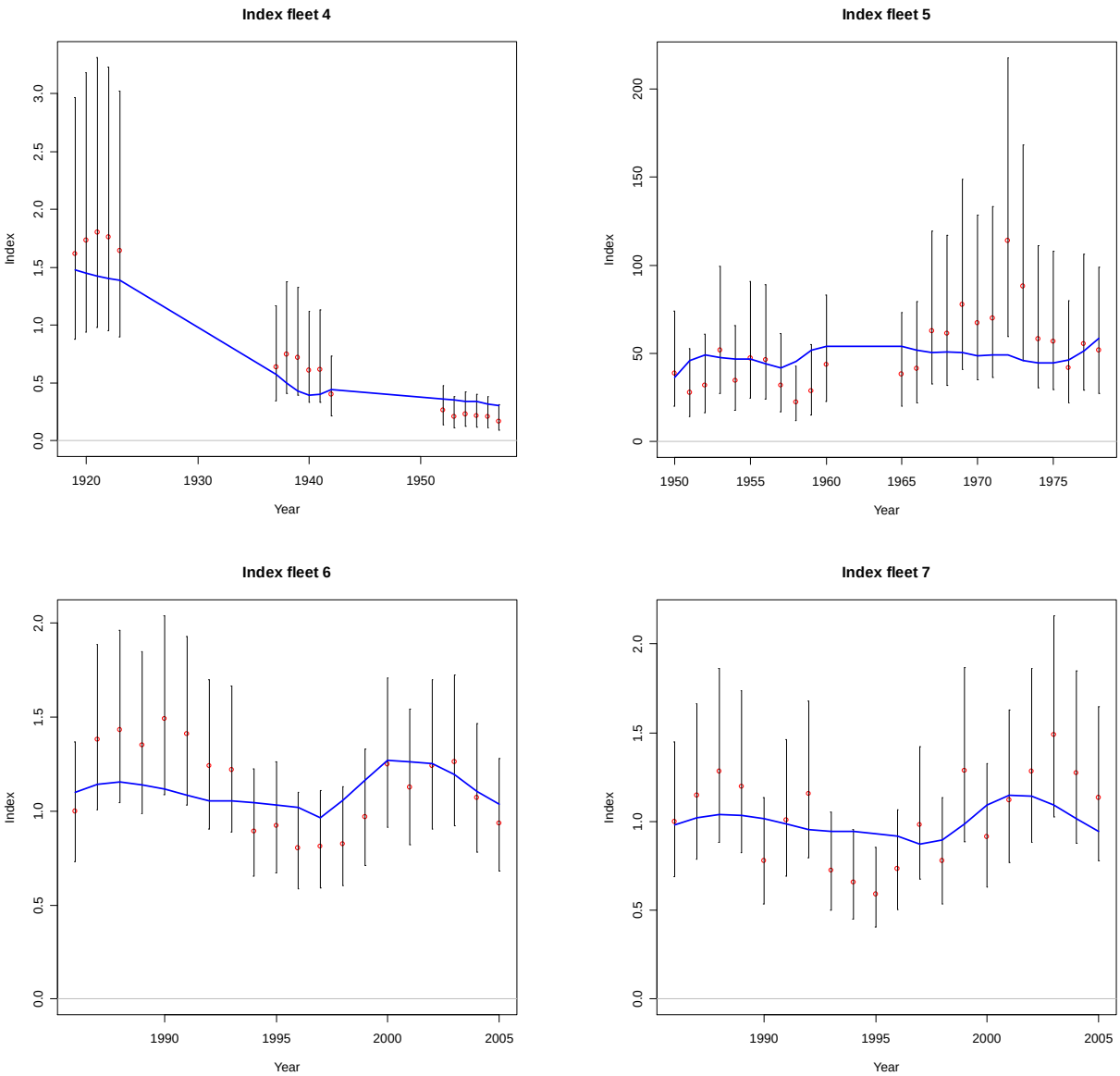


Figure 19.4. Model fits to CPUE series clockwise from top-left are steam trawl, early Danish seine, recent Danish seine, modern diesel trawl.

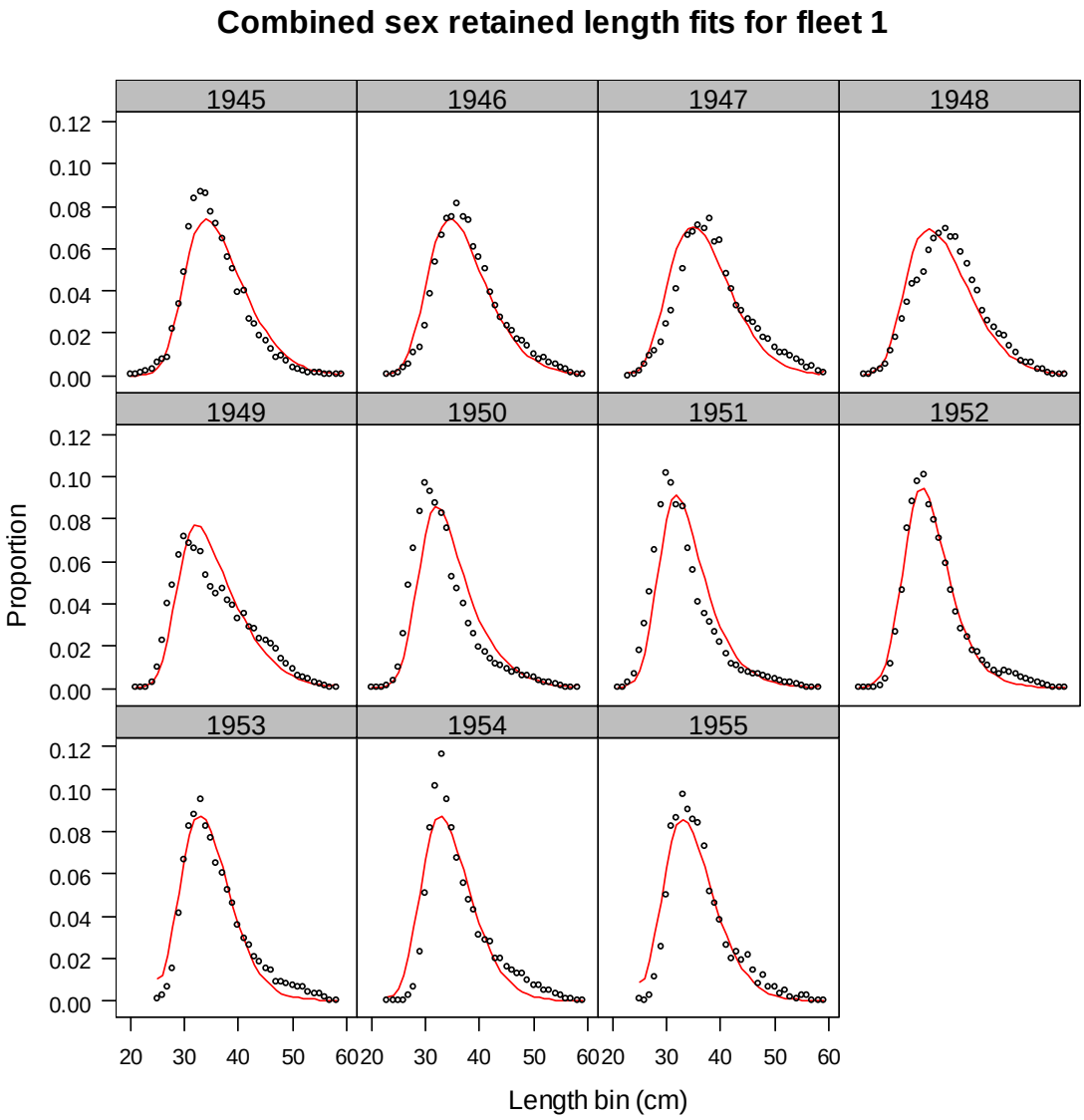


Figure 19.5. Model fits to retained length samples for steam trawl.

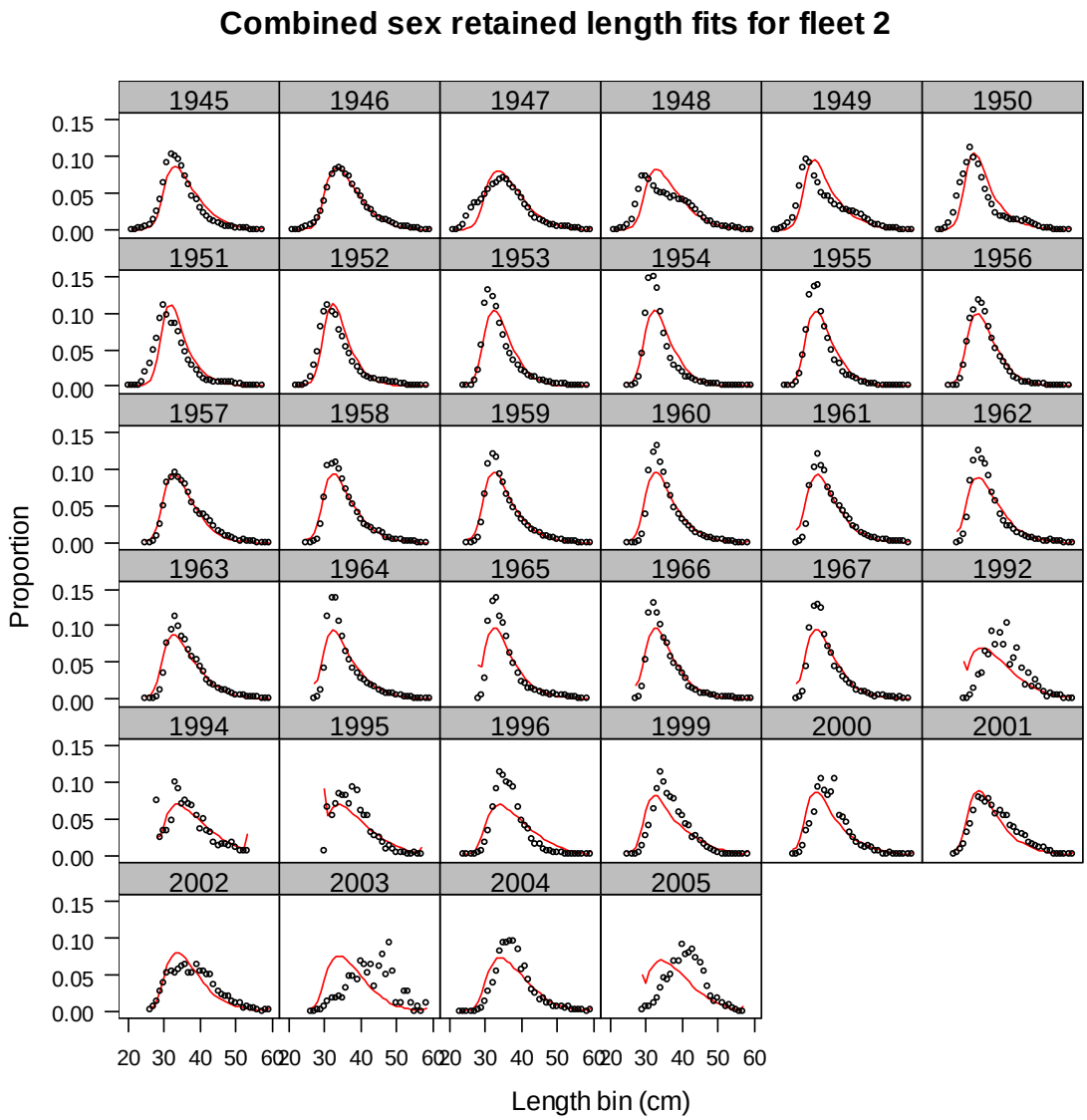


Figure 19.6. Model fits to retained length samples for Danish seine.

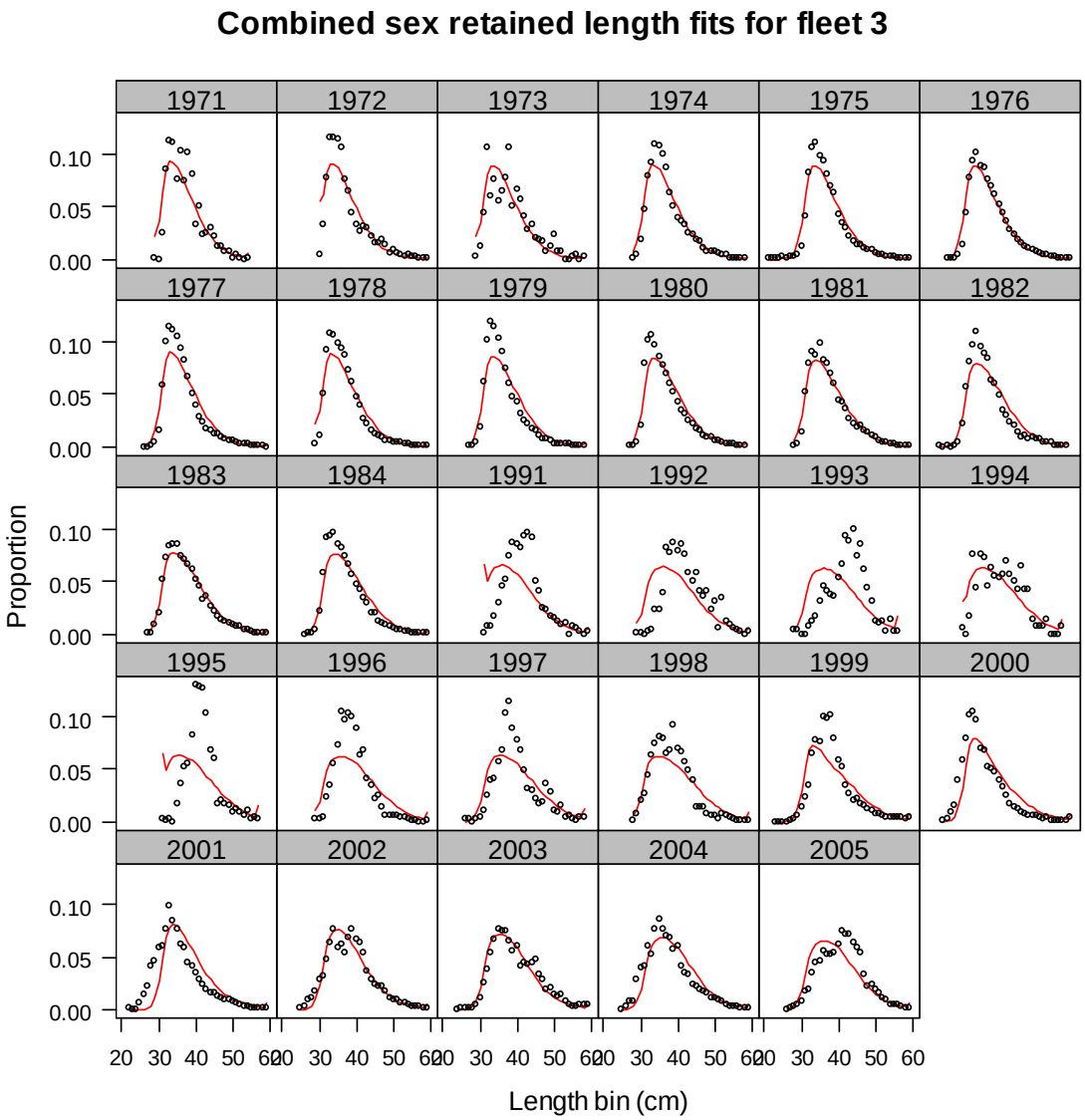


Figure 19.7. Model fits to retained length samples for diesel trawl.

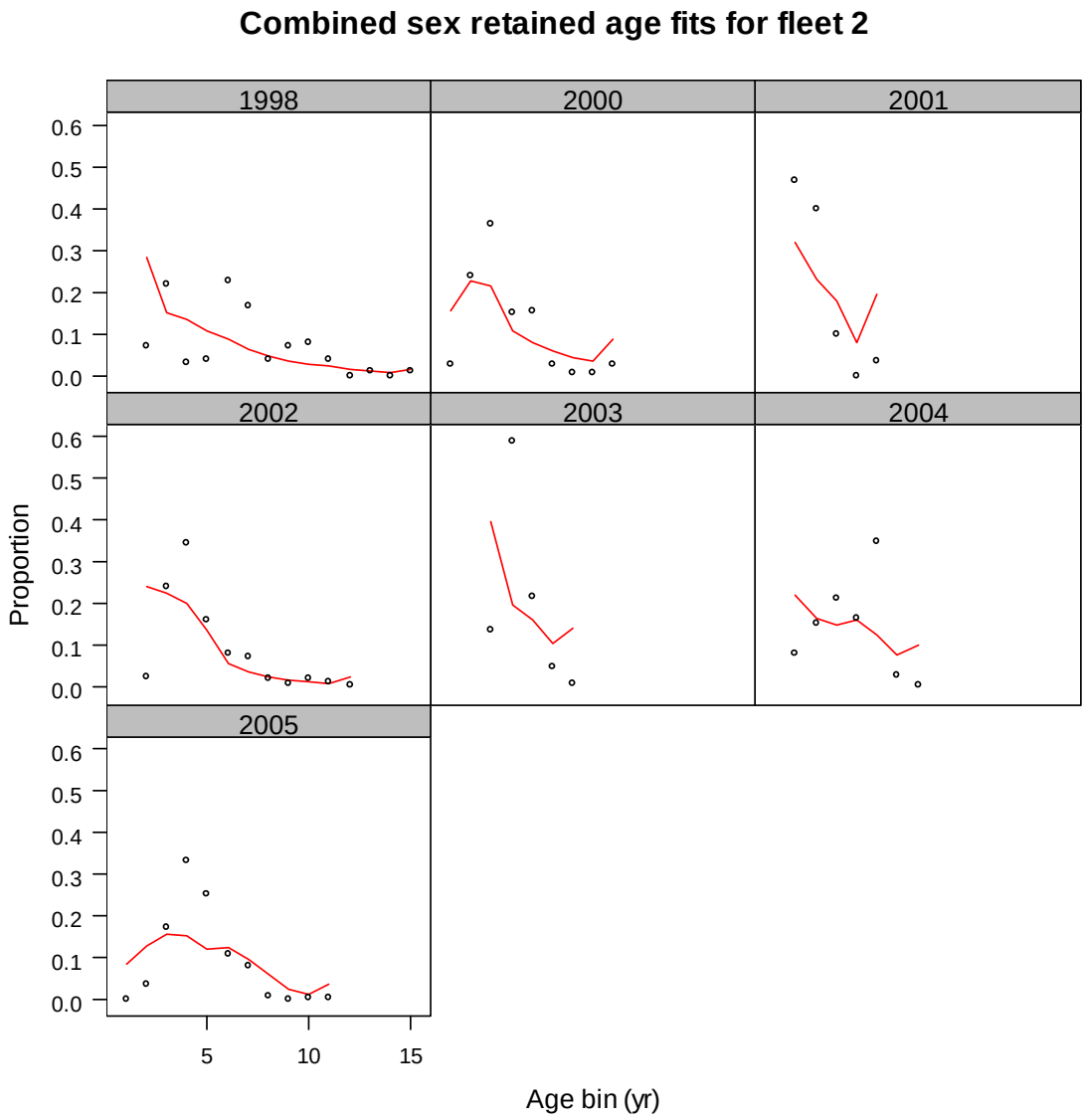


Figure 19.8. Model fits to retained age samples for Danish seine.

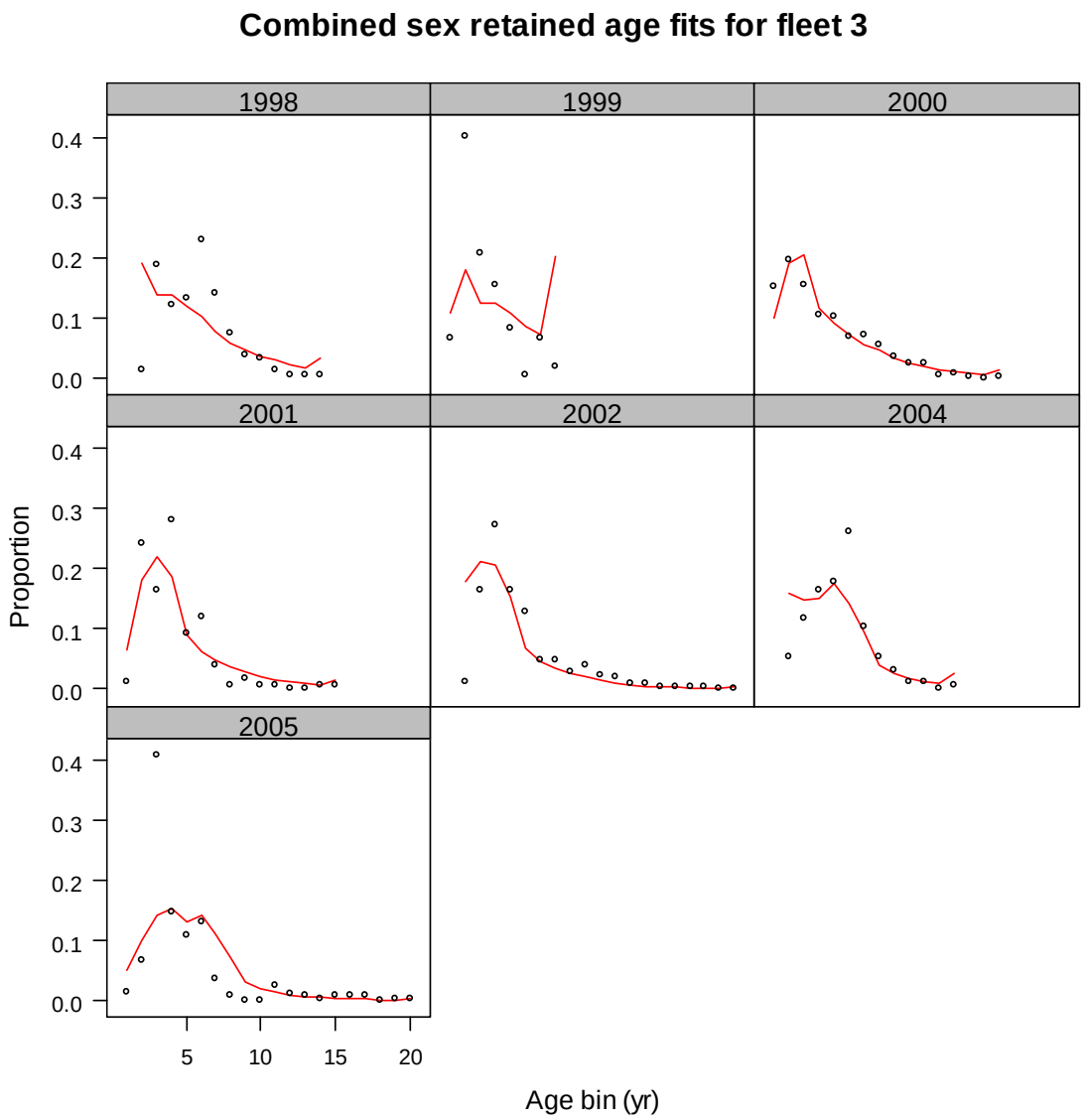


Figure 19.9. Model fits to retained age samples for diesel trawl.

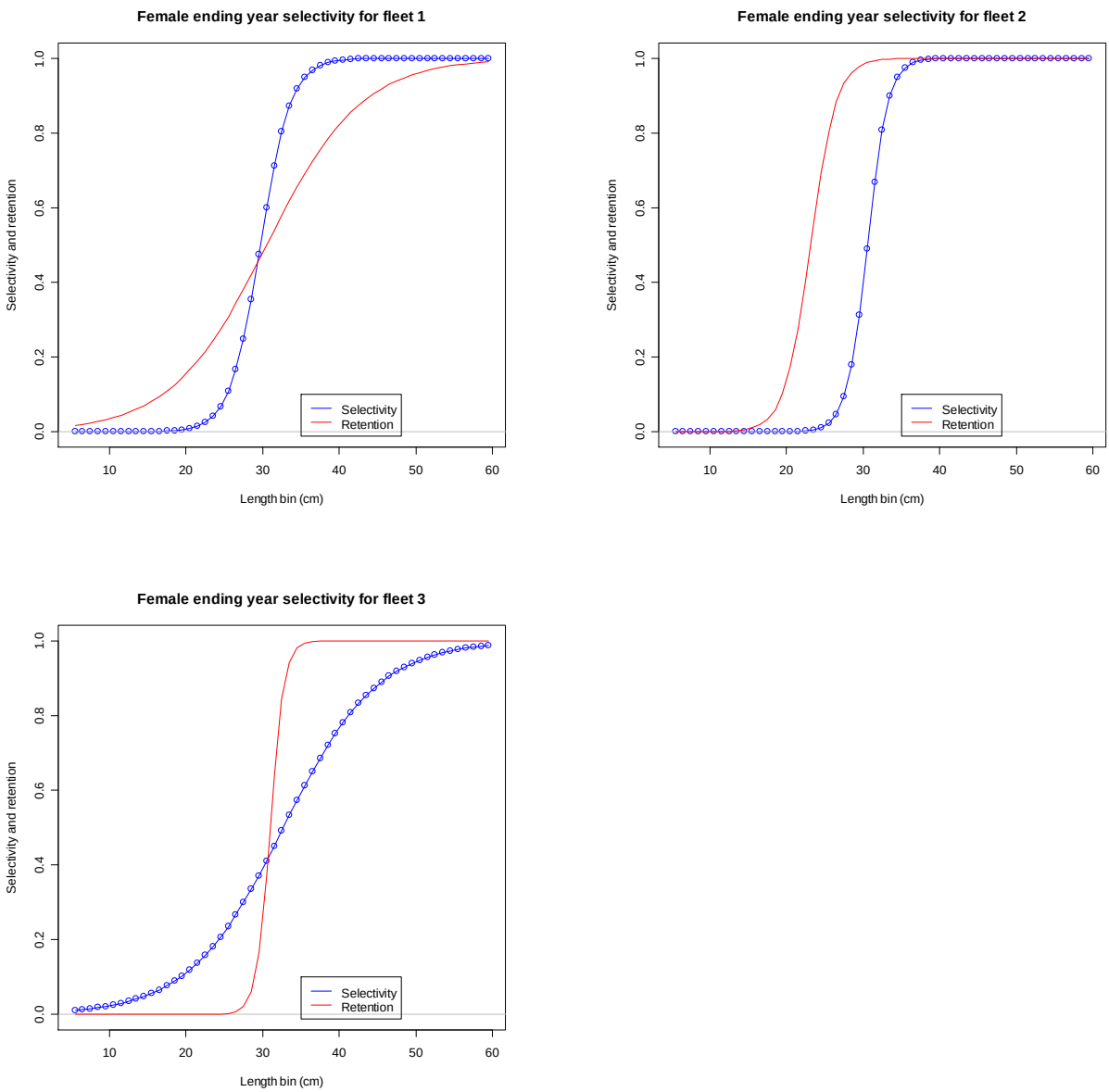


Figure 19.10. Size selectivity fits by fleet (female shown) for steam trawl, Danish seine and diesel trawl.

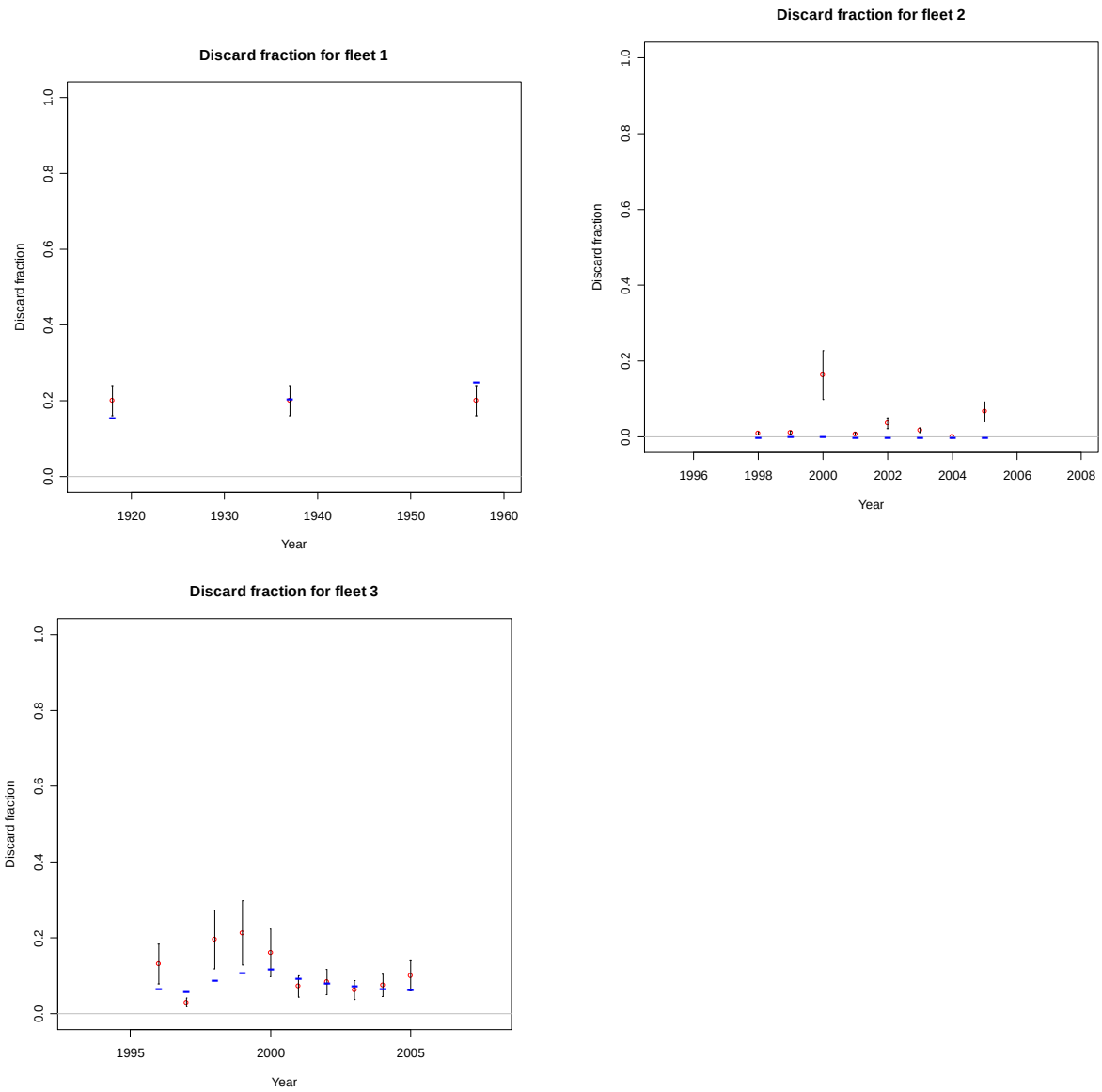


Figure 19.11. Fits to discard fractions by fleet for steam trawl, Danish seine and diesel trawl.

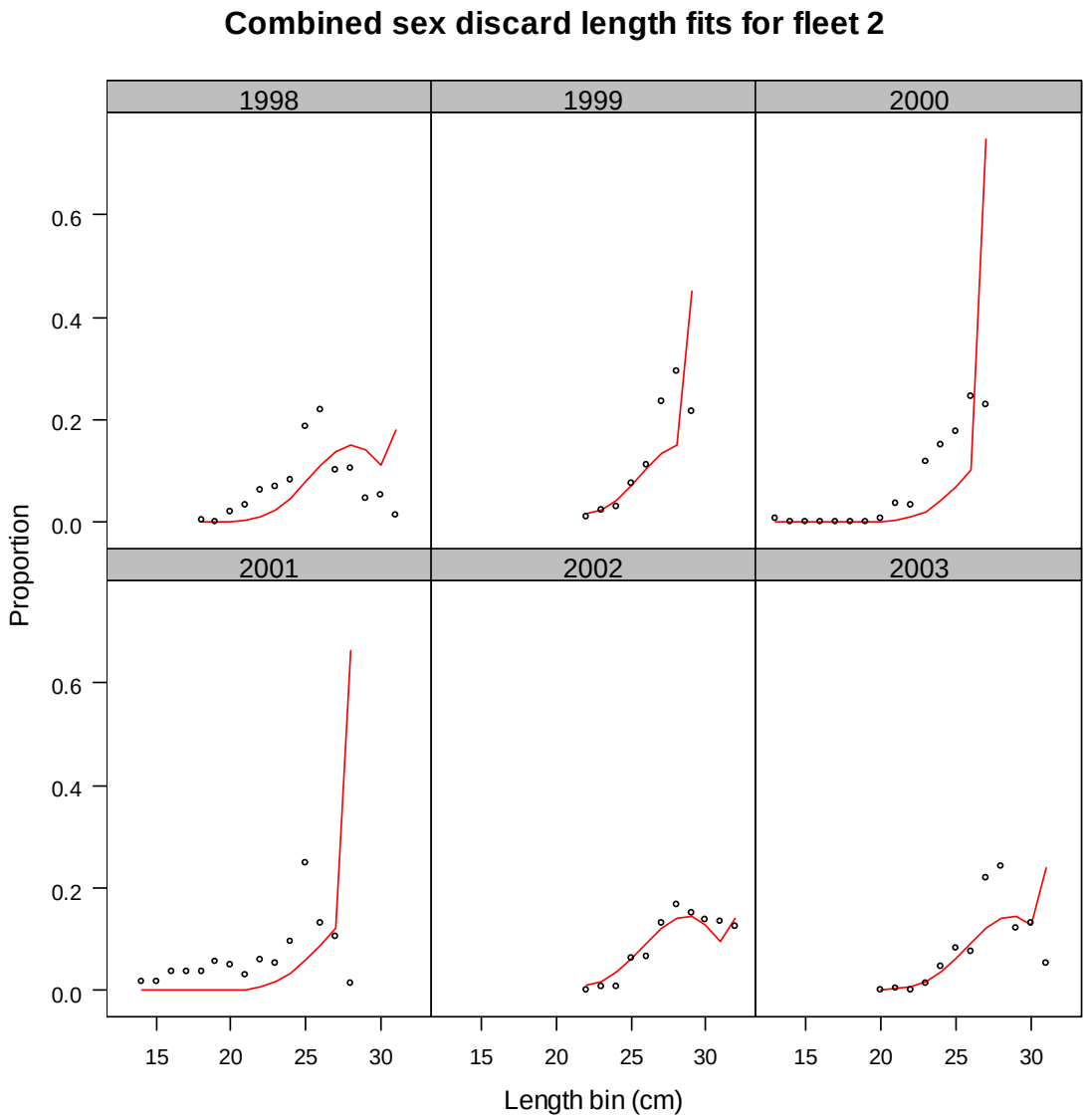


Figure 19.12. Model fits to discard age samples for Danish seine.

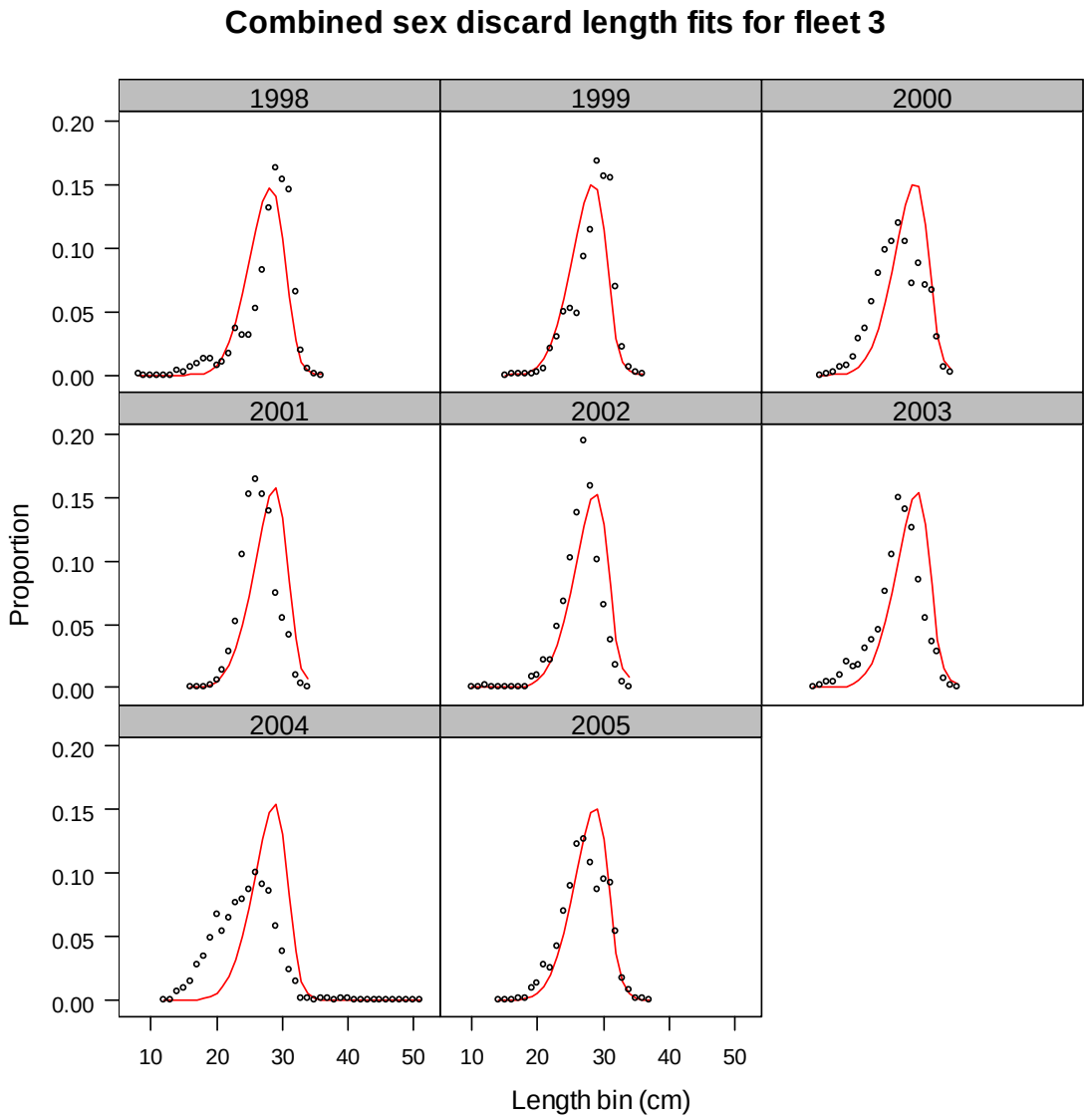


Figure 19.13. Model fits to discard age samples for diesel trawl.

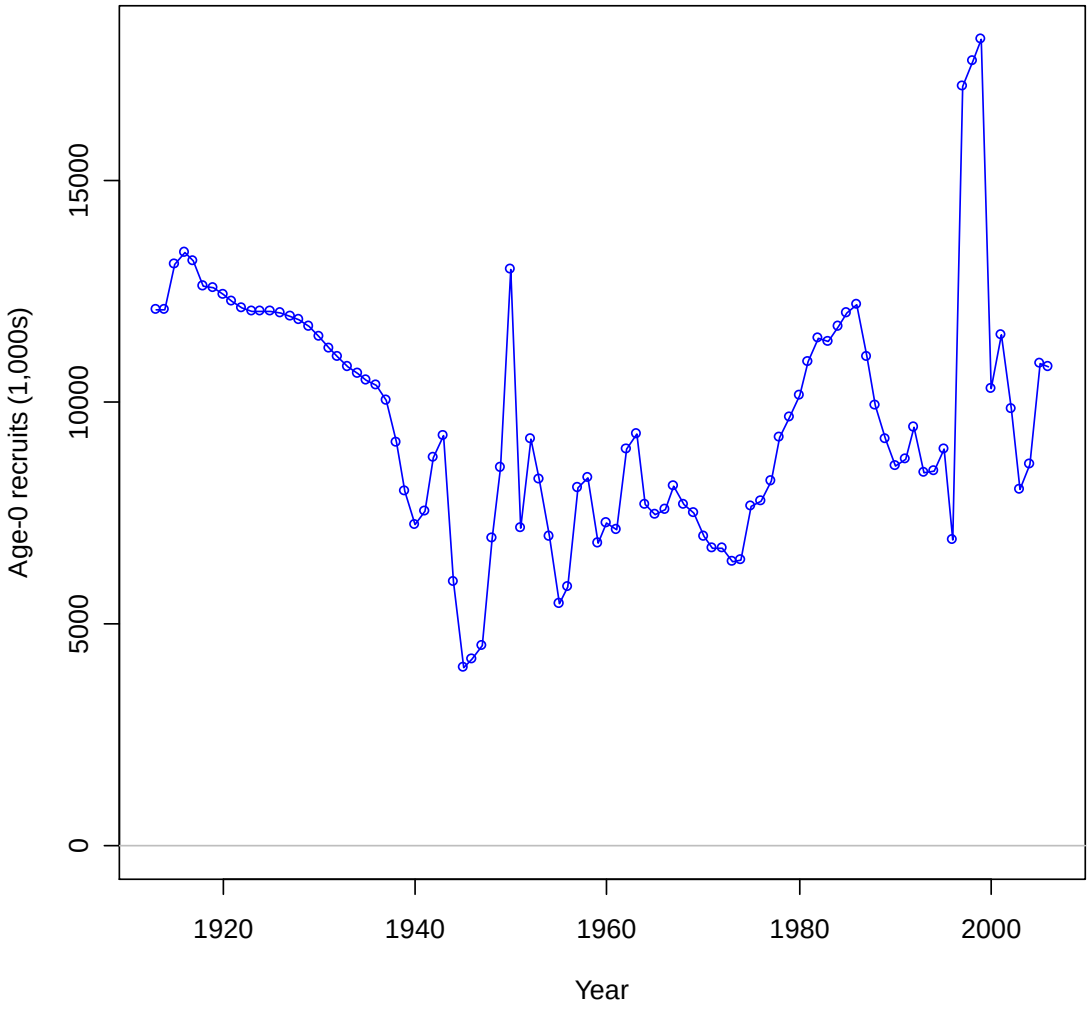


Figure 19.14. Recruitment time series for the base case.

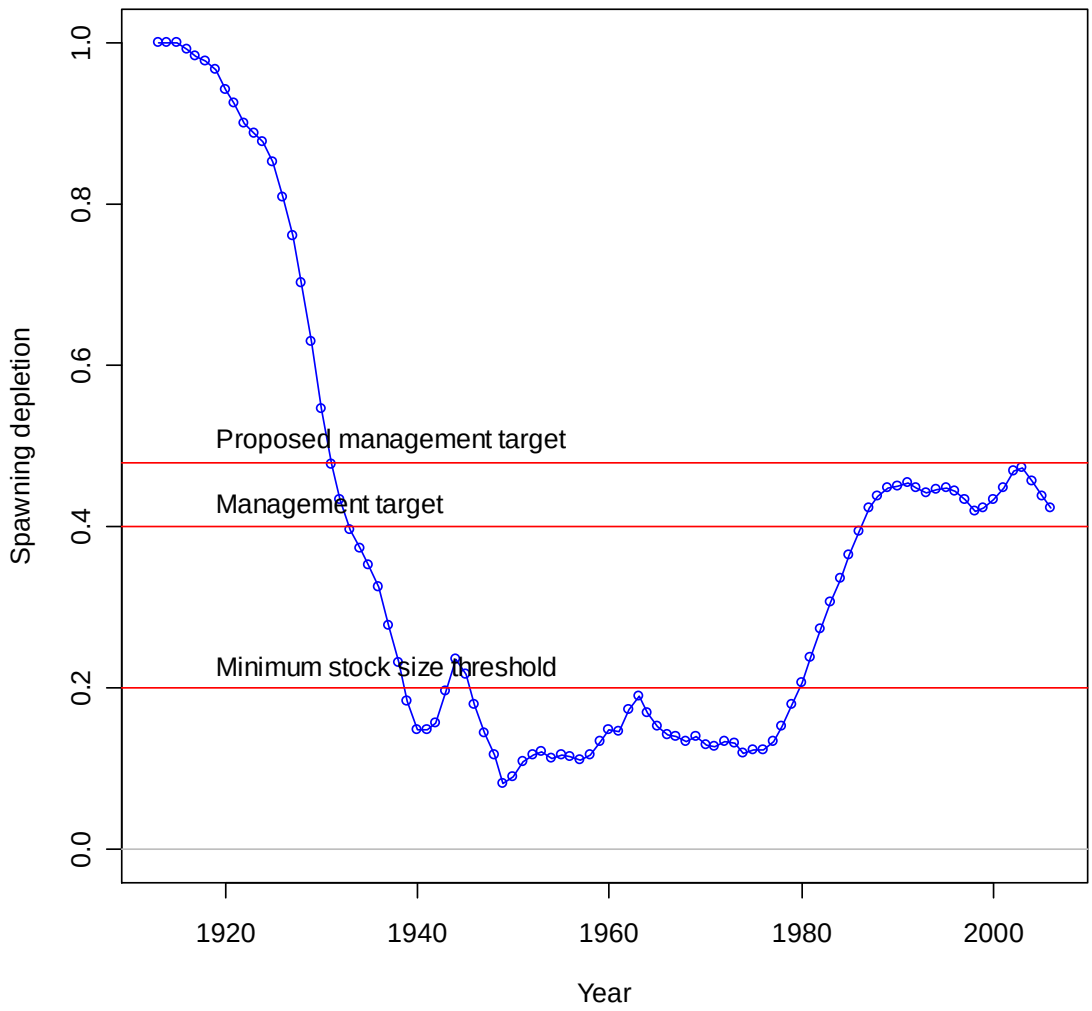


Figure 19.15. Spawning biomass depletion level per year for the base case.

Table 19.8. Summary statistics for the base-case analysis and the sensitivity tests. Values for the negative log-likelihood are only listed for those sensitivity tests that are comparable with the base-case analysis.

	Spawning biomass				
Scenario	1915	2005	2006 Depletion	RBC (+disc) F48B40	$-\ell nL$
Base-case	24364	10685	42.3	2166	904.451
M =0.1yr^{-1}	34035	5390	14.3	0	907.670
M =0.15yr^{-1}	27591	7210	25.2	433	904.828
M =0.2yr^{-1}	24864	9660	37.5	1696	904.146
M =0.25yr^{-1}	24033	12167	48.6	2597	906.154
M =0.3yr^{-1}	24291	14512	57.0	3251	913.004
Steepness = 0.70	25938	11075	41.3	2170	905.294
Steepness = 0.80	22068	10031	43.6	2133	906.722
Steepness = 0.90	19549	9245	44.9	2064	916.689
Halve CPUE σs	23866	11452	46.5	2377	
Double CPUE σs	24198	9717	38.5	1837	
Half length sample sizes	24401	10715	42.5	2180	
Double length sample sizes	24919	10980	42.3	2187	
Half age sample sizes	24244	10698	42.8	2207	
Double age sample sizes	24412	10426	40.9	2041	
Ignore steam trawl length data	24474	10760	42.6	2283	
Tas fleet	25546	11418	42.6	2245	

Table 19.9. Detailed assessment results for the base case and Tas fleet scenario.

Model	SSB_0 (t)	SSB_{cur}/SSB_0	F_{targ}	B_{targ}	RBC 2007 (Commonwealth + State) (t)		
					Landings	Plus discards	
Base	24,364	0.42	40	40	2,663	2,796	(not Tas)
Base	24,364	0.42	48	40	2,063	2,166	(not Tas)
Base	24,364	0.42	48	48	1,819	1,910	(not Tas)
Tas fleet	25,546	0.43	40	40	2,780	2,903	(with Tas)
Tas fleet	25,546	0.43	48	40	2,149	2,245	(with Tas)
Tas fleet	25,546	0.43	48	48	1,883	1,967	(with Tas)

19.5 Future work

The following are some ways in which future assessments of tiger flathead could or should be improved.

- Document historical changes in gear and size limits, and attempt to formally test for their implications using the assessment model.
- Plot the raw data (SEF1, length-frequency, discards) and use this as the basis to evaluate the definitions of "stocks" on which the present assessment is based.
- Obtain pre-1998 age-length keys (re-age pre-1998 otoliths using the break and burn method). Alternatively, obtain readings that compare ageing based on the surface versus the break-and-burn method to enable a comparison to be made between these ageing techniques (this may require additional otoliths to be read using both methods). Include the ability to fit biased age-composition data (i.e. the data collected using the surface method) in the assessment model.
- Investigate ways to incorporate environmental data (such as SOI) into catch rate standardizations.
- Estimate a more realistic maturity ogive (maturity as a function of length rather than of age).
- Revise the growth curve by fully integrating the estimation of the growth curve with that of the free parameters of the population dynamics model
- Include age-reading error when fitting to the age-composition data.
- Investigate re-weighting methods for length and age frequencies
- Improve the discards fit for Danish seine
- Update the Danish seine CPUE to include species association with flathead
- Investigate appropriate bin sizes for length data
- Improve fits to discard fractions for steam trawl
- Implement conditional length at age
- Investigate rejected length frequencies from the automated processing
- Reapply calculation of cvs for discard rates

19.6 Acknowledgements

Matt Koopman, Anne Gason and Kyne Krusic Golub (PIRVic), and Malcolm Haddon (UTas) are thanked for the provision of data. Many of the assumptions considered in this assessment arose during discussions at ShelfAG. I thank Rick Methot (NOAA), Andre Punt (CMAR), and Gavin Fay (U Washington) for their assistance with moving this assessment into SS2. I also thank Jemery Day, Sally Wayte and Geoff Tuck for our fruitful discussions during our regular SS2 modelling workshops.

19.7 References

Allen K.R. 1989. Stock assessments for four species in the Southeastern trawl fishery. SET Report held by BRS, Canberra.

Cui, G., Punt, A.E., Cope, J.M., Knuckey, I.A., Klaer, N.L., Fuller, M.E. and A.D.M. Smith. 2004. Quantitative stock assessment for tiger flathead (*Neoplatycephalus richardsoni*) 2004. In: Stock assessment for the south east and southern shark fishery. Tuck, G.N. and Smith, A.D.M. (Eds.). FRDC report 2001/005. Chapter 11, pp 373-410.

Fairbridge, W.S. 1948. The effect of the war on the East Australian Trawl Fishery. Journal for the Council for Scientific and Industrial Research 21: 75–98.

Haddon, M. 2006. Standardized commercial catch-effort data for selected Shelf Assessment Group species. Document prepared for SESSF RAGs 2006.

Klaer, N. 2004. Preliminary biomass trends for main commercial fish species caught by trawl from the south eastern Australian continental shelf from 1915 to 1961. Report to SESSF ShelfAG, June 2004.

Klaer, N. 2005. Towards an agreed catch history for tiger flathead in the South East Fishery. Document presented to the 9 September 2005 meeting of ShelfAG.

Klaer, N. 2006. Changes in the species composition of fish communities on the SE Australian continental shelf from 1915 to 1960. PhD Thesis, University of Canmberra.

Knuckey, I.A., Grieve, C. and D.C. Smith. 1999. Evolution of the integrated scientific monitoring programme in Australia's South East Fishery. p. 231–248 in C.P. Nolan, editor. Proceedings of the International Conference on Integrated Fisheries Monitoring. FAO, Rome.

Methot, R.D. 2005. Technical Description of the Stock Synthesis II Assessment Program Version 1.17 – March 2005. NOAA Fisheries Internal Report.

Methot, R. 2006. User Manual for the Assessment Program Stock Synthesis 2 (SS2). NOAA Fisheries, Seattle, WA.

Punt, A.E. 2005a. Updated Stock Assessment of Tiger Flathead (*Neoplatycephalus richardsoni*) Based on Data up to 2005.

Punt, A.E. 2005b. Including Catch and Length-Frequency Data for Tasmania in the Stock Assessment for Tiger Flathead.

Thomson, R.B. 2002. South East Fishery data for stock assessment purposes. Draft CSIRO Report.

Wayte, S. 2006. Harvest strategy framework for the SESSF - Tier rules 1 and 2.

20. Revised Standardized Catch-Rate Series for School and Gummy Shark Based on Data up to 2005

André E. Punt[1] and Anne S. Gason[2]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia
[2]Marine and Freshwater Systems, Department of Primary Industries,
P.O. Box 114, Queenscliff, VIC 3225, Australia

20.1 Abstract

The methodology used to standardize the catch and effort data for school and gummy shark is applied to data up to the end of 2005 to provide updated standardized catch-rate series for these two species. The results from this catch-rate standardization exercise are contrasted with those from previous analyses to assess the impact of the addition of new data and the slight changes over time in methodology. In addition to standardized catch-rate indices for gummy shark for Bass Strait and South Australia, this paper also provides standardized catch-rate indices for Tasmania.

20.2 Introduction

One of the key inputs to the assessments of school and gummy shark are time-series of standardized catch-rate data. The approach of Punt *et al*. (2000) is used to standardize the SSF catch and effort data to remove the impact of changes over time in the spatial distribution of the fishery, seasonal changes in availability, and changes over time in the composition of the fleet.

The methodology on which this standardization exercise is based is described in several previous SharkRAG documents and has evolved over time. This document therefore first summarizes the current methodology, and then applies it to determine catch-rate indices for school and gummy shark based on data until the end of 2005.

The nature of catch-effort standardization is such that inclusion of new data can lead to changes in historical indices of abundance. For example, when determining the probability of obtaining a zero catch, it is assumed that there is "statistical cell effect" and that this effect has not changed over time relative to how it has changed over time for other statistical cells[7]. Furthermore, additional data may mean that the standardized catch-rate series is based on a different set of vessels than in the past because some vessels no longer satisfy the criteria for inclusion while other, previously excluded vessels, now do. To examine whether changes to the data have led to notable changes to the catch-rate indices, the updated catch-rate series are contrasted with the results from previous catch-effort standardization exercises.

[7] The term 'statistical cells' is used to refer to the geographic subdivisions of the fishery used in the past for catch reporting (statistical) purposes.

Previous catch-effort standardizations for gummy shark have provided standardized catch-rate indices of abundance for Bass Strait and South Australia. In the past, standardized indices of abundance have not been produced for Tasmania owing to concerns regarding the number of years for which usable data are available. However, there are now sufficient data to warrant attempting to construct a standardized catch-rate index for gummy shark off Tasmania.

20.3 Methodology

The approach of Punt *et al*. (2000) involves first developing a set of criteria to identify those operators whose catch and effort data should provide useful information about trends in the abundance of gummy or school shark. For example, the catch-rates for operators who catch shark during periods when rock lobsters are unavailable to them or incidentally take school or gummy shark as part of other targeted fishing operations are unlikely to provide reliable information about changes over time in abundance. The criteria selected by SharkRAG to identify 'indicative' shark fishers are summarized in Table 20.1. Table 20.2 lists the further restrictions imposed on the data at the level of monthly catch and effort (by statistical cell, depth zone, and vessel). The data are generally analyzed at the level of statistical cell, but some statistical cells are combined with other statistical cells due to lack of detailed catch and effort data or are excluded altogether (e.g. the cells in the South Australian Gulfs are ignored when standardizing the catch and effort data for school shark).

Table 20.3 lists all the statistical cells for which data are available and how each is treated during the standardization procedure.

The data for the selected vessels are standardized using a "delta" approach (Lo *et al*., 1992; Stefánsson, 1996; Punt *et al*., 2000). The questions of whether a catch rate is zero or not, and the size of a non-zero catch rate are therefore treated separately. The non-zero catch rates are modeled using a negative binomial error model and whether the catch rate is zero or not is modeled as a Bernoulli random variable. The factors considered when modeling whether the catch is zero are year, statistical cell, vessel and month. The factors considered when modeling the non-zero catch rates are year, depth[8], statistical cell, vessel, month and the interaction between year and statistical cell. Other factors and interactions (e.g. the factor 'region' and the interaction between year and month) were examined in the past, but found not to be significant. The results from fitting these models are used to compute time-series of standardized catch rate for each statistical cell and these are combined by weighting them by a proxy for the shark 'habitat area' of each statistical cell (the area of each cell between 20 and 80m depth for gummy shark and the area shallower than 200m for school shark) to obtain a single catch-rate time-series for each species for Bass Strait and South Australia.

[8] For gummy shark in Bass Strait and Tasmania only.

There are some combinations of year and statistical cell for which data are unavailable (because, for example, none of the selected vessels fished in them during those years). Rules are therefore used to interpolate missing values for the catch-rate index for year *y* and statistical cell *b*, $I_{y,b}$ [9]:

a) For gummy shark and for school shark, except in the western South Australia region[10], the rule used to specify $I_{y,b}$ if catch-rate estimates are not available for statistical cell *b* for any year prior to year *y* is:

$$I_{y,b} = \frac{\sum_{y^* \in highest3} I_{y_*,b}(y_* - y)^{-2}}{\sum_{y^* \in highest3} (y_* - y)^{-2}} \qquad (1)$$

where $\sum_{highest3}$ indicates summation over the three highest catch rates.

$I_{y,b}$ is set to the maximum catch-rate if catch-rates are missing for all years prior to year *y* for school shark for the cells in the western South Australia region. Equation 1 gives greater weight to estimates for years closer to that for which a catch-rate is needed.

b) If catch-rate estimates are available for statistical cell *b* for at least one year prior to year *y* but not thereafter, $I_{y,b}$ is set equal to the arithmetic mean of the standardized catch rates for the last three years for which catch-rate estimates are available.

c) If neither rule a) nor b) is applicable then standardized catch-rate estimates are available for earlier and later years than year *y*. The value for $I_{y,b}$ is then set using linear interpolation of the standardized catch-rates for the nearest years before and after year *y* for which data are available.

20.4 Results and discussion

20.4.1 The updated catch-rate standardization

Table 20.4 and Table 20.5 summarize the selection of records in terms of whether the raw data are reported at a sufficient level of resolution for possible inclusion in the catch-effort standardization[11]. Results are shown separately for school and gummy shark *inter alia* because the catch-effort standardization for school shark ignores the SAV region and Tasmania (Table 20.3). As expected from previous catch-effort standardizations, the vast bulk of the data from 1995 can be included in the catch-effort

[9] This is the set of rules that is that currently employed. These rules have been modified over time based on comments by SharkFAG.
[10] This exception was selected by SharkRAG.
[11] The results in Table 20.4 and Table 20.5 for 2005 are restricted to data for Commonwealth-licensed operators only.

standardization exercise[12]. It is noteworthy that the data for South Australia were poorer in 2000 than in 1999 and 2001 onwards. The bulk of the data for Tasmania since 1995 are reported at a sufficient level of resolution for inclusion in a catch-effort standardization.

Table 20.6 summarizes the selection of vessels for use in the catch-rate standardization. This table provides information on the total number of (monthly) records considered, how many vessels were included, their total catch, and their (average across vessel) median annual catch (of the species for which catch and effort data are being standardized)**.** Three sets of results are supplied for gummy shark in Table 20.6 This is because the criteria used to select records differ among South Australia, Tasmania and Bass Strait (Table 20.1 and Table 20.2). The number of indicative vessels for the current catch-effort standardization is higher than that on which the analyses of Punt *et al*. (2004) were based and the average number of years in the fishery is also higher.

Table 20.7 lists the frequency with which it was necessary to apply rules a) – c) to specify catch-rates for cell-year combinations for which data are missing. Consistent with the results from previous catch-effort standardizations, these rules are used most for the cells in the SAV region and those in the South Australian Gulfs. The number of years for which it was necessary to apply rule a) to specify missing catch-rates for school shark is much higher this year than in previous years. The exact reasons for this are unclear, but probably relate to some vessels no longer satisfying the criteria for inclusion in the catch-effort standardization owing to lower average catches in recent years.

The updated standardized catch-rate indices are shown in Figure 20.1 and Figure 20.2 (school and gummy shark, respectively). Standardized catch-rates for school shark have been relatively stable over the last eight years (WSA, CSA and EBas regions). However, the catch-rate indices for the last eight years are only a few percentage points of the catch-rates in the 1980s (Figure 20.1). The standardized catch-rates for gummy shark for central South Australia increased continuously since lows in the late 1980s and this leads to increases in standardized catch rate for South Australia as a whole since 1995 (Figure 20.2). There is little evidence for increasing or decreasing trends in gummy shark abundance since 1995 in western Bass Strait and eastern Bass Strait, which is reflected in the standardized catch-rate index for the whole of Bass Strait. There is no obvious trend in catch-rate for gummy shark off Tasmania for the period 1990-2005.

[12] But may, of course, be excluded if the vessels which took the catches do not satisfy the criteria in Table 20.1.

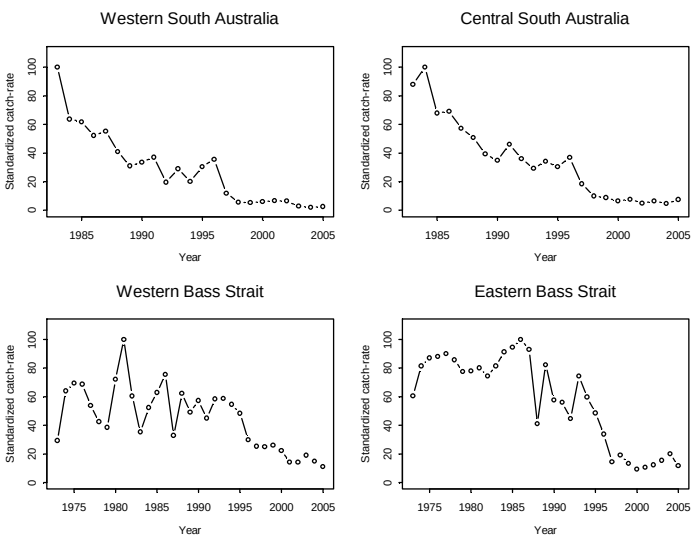


Figure 20.1. Standardized catch-rate series for school shark based on data for 1973–2005.

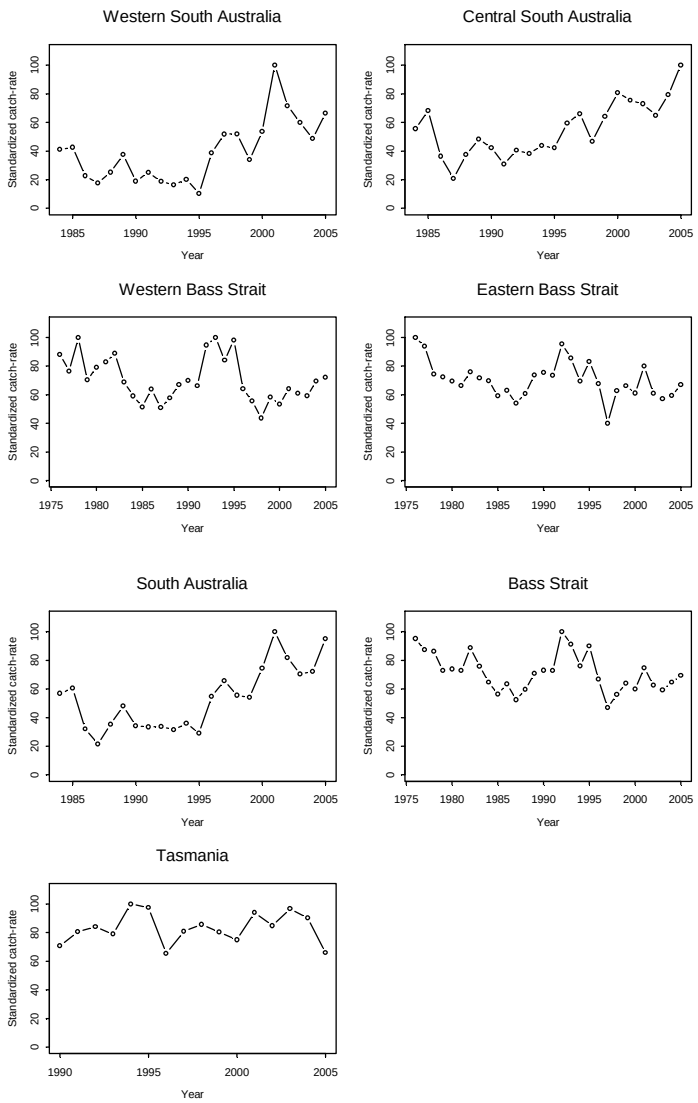


Figure 20.2. Standardized catch-rate series for gummy shark based on data for 1976–2005.

20.4.2 Retrospective analysis

Figure 20.3 shows the time-trajectories of standardized catch-rate for school shark from the present analysis, those based on the analyses of Punt *et al.* (2004), Punt and Pribac (2002), and those on which the 1999 and 2001 assessments of school shark were based. Figure 20.4 shows the time-trajectories of standardized catch-rate for gummy shark from the present analysis, those based on the analyses of Punt *et al.* (2004), Punt and Pribac (2002) and those on which the 2000 assessment of gummy shark were based. The final years for which data were available for the 1999 and 2001 school shark assessments were 1997 and 1999 and the final year for which data were available for the 2000 gummy shark assessment was 1998. The final years for the analyses of Punt and Pribac (2002) and Punt *et al*. (2004) were 2001 and 2003 respectively.

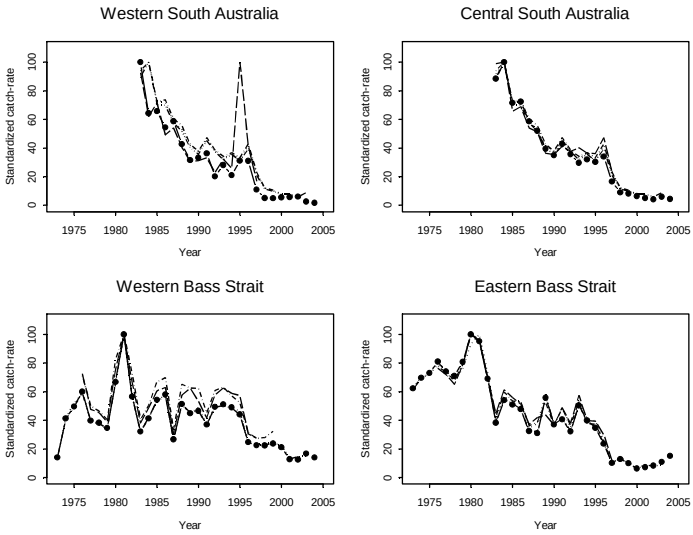


Figure 20.3. Retrospective evaluation of the results of standardizing the catch and effort data for school shark (analyses based on data for 1973–1997, 1973–1999, 1973–2001, 1973–2003, and 1973-2005).

With the notable exception of the 1995 point in western South Australia (which was eventually shown to be an error in the database), there is little evidence for retrospective patterns in the time-series of standardized catch-rate for school shark. This is perhaps surprising because the number of year-cell combinations without standardized catch-rate indices is higher for this study than for previous studies (contrast the results in Table 20.6 for school shark with the corresponding results in Table 7.A.7 of Punt *et al*. (2004)).

The gummy shark catch-rate series for western and central South Australia exhibit restrospective patterns, with the recent catch-rates being higher than expected from the earlier catch-effort standardizations (Figure 20.4). In contrast, there is no evidence for retrospective patterns for school shark in Bass Strait.

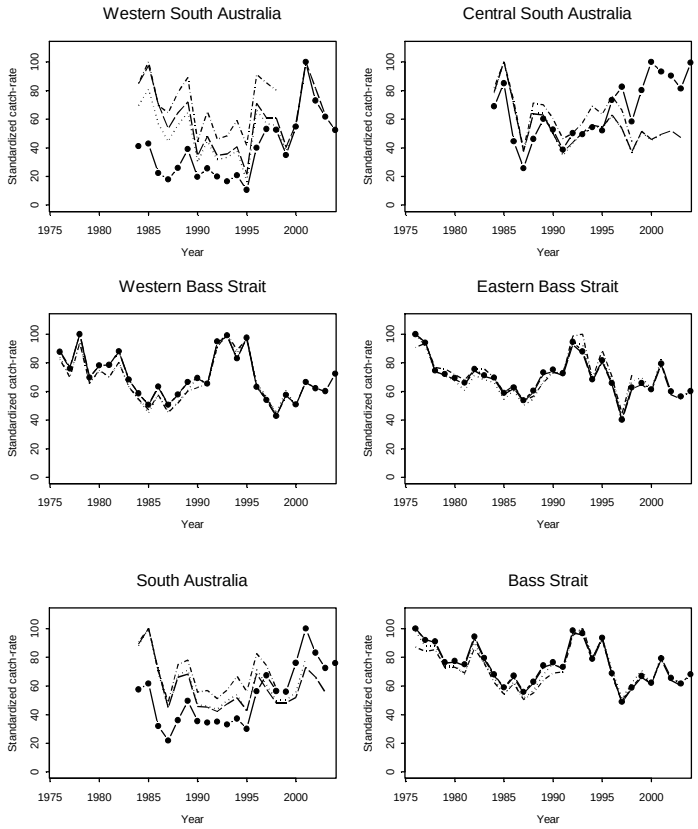


Figure 20.4. Retrospective evaluation of the results of standardizing the catch and effort data for gummy shark (analyses based on data for 1976–1998, 1976–2001, 1976–2003, 1976-2005).

20.5 References

Lo, N.C., Jacobson, L.D. and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 2515–2526.

Punt, A.E. and F. Pribac. 2002. Updated standardized catch-rate series for school and gummy shark. Document presented to the 29-30 September 2002 meeting of SharkFAG.

Punt, A.E., Pribac, F., Walker, T., Gason, A. and G. Fay. 2004. Stock assessment of gummy shark (*Mustelus antarcticus*) based on data up to 2003. In: Stock assessment for the south east and southern shark fishery. Tuck, G.N. and Smith, A.D.M. (Eds.). FRDC report 2001/005. Chapter 7, pp 121-198.

Punt, A.E., Walker, T.I., Taylor, B.L. and F. Pribac. 2000. Standardization of catch and effort data in a spatially-structured shark fishery. *Fisheries Research* 45: 129-145.

Stefánsson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. *ICES Journal of Marine Science* 53: 577–588.

Table 20.1. The criteria used to select 'indicative' shark fishers.

Criterion	School shark	Gummy shark
Years included		
South Australia	1983–2005	1984–2005
Bass Strait	1973–2005	1976–2005
Tasmania	N/A	1990–2005
Minimum median annual catches		
Total (school and gummy) shark	10 t	10 t
School shark	5 t	N/A
Gummy shark	N/A	5 t
Minimum years with data	5	5
Minimum percentage gummy shark		
South Australia	N/A	0
Bass Strait	N/A	60%
Tasmania	N/A	60%
Maximum fraction gummy=school catches		
South Australia	25%	25%
Bass Strait	99%	99%
Tasmania	25%	25%
Minimum usable monthly records per vessel [A]	20	20

A – after excluding records for the reasons outlined in Table 20.2.

Table 20.2. The criteria used to select records for use in the catch effort standardization.

Criterion	School shark	Gummy shark
Years included		
South Australia	1983–2005	1984–2005
Bass Strait	1973–2005	1976–2005
Tasmania	N/A	1990–2005
Gear types	6-, 6.5-, 7-inch mesh	6-, 6.5-, 7-inch mesh
Must have a depth		
Bass Strait	No	Yes
South Australia	No	No
Tasmania	No	Yes
Use records with depth between 20 and 40m for which the catch of school shark is zero	No	Yes
Minimum effort (gillnet m-lifts)	N/A	1000m

Table 20.3. Statistical cells and their treatment in the catch-effort standardization. The symbol '& x' indicates that the data for the cell concerned are pooled with those for cell x.

Cell	School shark	Gummy shark	Cell	School shark	Gummy shark
4	Not used [A]	Used	101	& 104	& 104
5	Not used [A]	Used	102	& 105	& 105
6	Used	Used	103	& 106	& 106
7	Used	Used	104	Used	Used
8	& 7	Used	105	Used	Used
9	& 7	Used	106	Used	Used
10	Used	Used	107	Used	Used
11	& 10	Used	108	& 107	& 107
12	& 10	& 10	112	Used	Used
13	& 10	& 10	113	& 112	& 112
18	Used	Used	114	& 112	& 112
19	& 18	Used	115	Used	Used
20	Used	Used	122	Not Used	Used
21	Used	Used	126	Used	Used
22	Used	Used	128	Used	Used
23	& 22	Used	129	& 139	Used
30	Used	Used	132	Not used	Used
31	& 30	Used	136	Not used	Used
32	Used	Used	138	Used	Used
33	Used	Used	139	Used	Used
34	Used	Used	140	Not used	Used
35	Used	Used	144	Not used	Used
41	Not used [A]	Used	148	Used	Used
42	Not used [A]	Used	149	Used	Used
48	Not used [A]	& 41	150	Used	Used
49	Not used [A]	& 42	151	Not used [A]	Used
54	Not used [A]	& 41	155	Not used [A]	Used
55	Not used [A]	& 42	158	Not used [A]	Used
56	Not used [A]	& 42			

A: The data for Tasmania and the SAV region are not used when standardizing the catch and effort data for school shark.

Table 20.4. Reported catches of gummy shark, total number of catch-effort records, and the percentage of the reported catch of gummy shark rejected for use in the standardization of the catch and effort data because the records concerned did not include: a) information about the amount of effort expended, b) the statistical cell in which the catch was taken and c) the gear-type that was used.

(a) South Australia (WSA, CSA and SAV-W)

Year	Number of Records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	845	71.3	0.00	0.00	4.90	95.10
1977	897	162.5	20.51	0.00	68.16	31.81
1978	808	176.6	19.20	0.00	79.99	19.92
1979	557	207.0	11.27	0.00	92.86	7.14
1980	664	305.2	5.10	0.00	93.82	6.18
1981	694	293.6	7.99	0.00	92.80	7.20
1982	649	276.6	7.43	0.00	96.32	3.68
1983	697	246.2	15.42	0.00	53.76	37.17
1984	1001	417.7	8.72	0.00	0.10	91.17
1985	1131	415.9	22.04	0.00	0.06	77.90
1986	1523	462.2	7.68	0.00	0.04	92.29
1987	2153	520.8	4.13	0.00	0.00	95.87
1988	2131	584.1	3.06	0.00	0.00	96.94
1989	1947	640.8	2.54	0.00	0.05	97.45
1990	2279	529.7	6.00	0.00	1.24	92.80
1991	2406	460.3	6.99	0.00	0.89	92.93
1992	2364	412.4	7.35	0.00	0.42	92.48
1993	2117	413.7	1.81	0.00	0.27	97.92
1994	1937	431.7	2.70	0.00	0.14	97.17
1995	1937	385.0	1.53	0.00	1.53	98.47
1996	1748	500.4	0.80	0.00	0.80	99.20
1997	6924	637.5	6.16	0.00	14.19	80.68
1998	9944	480.0	3.89	0.00	1.01	96.02
1999	8350	546.2	2.36	0.00	1.09	97.53
2000	6596	469.3	18.12	0.00	1.03	81.87
2001	6540	386.7	3.53	0.00	2.62	95.91
2002	5539	372.0	0.48	0.00	2.03	97.78
2003	6152	463.2	0.00	0.00	0.22	99.78
2004	6315	447.6	0.03	0.00	1.75	98.25
2005*	6152	449.9	0.05	0.00	2.37	97.62

* Excludes State catches

(Table 20.4 Continued)

(b) Bass Strait (EBS, WBS and SAV-E)

Year	Number of Records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	3795	758.1	3.07	0.00	23.55	76.17
1977	4019	872.9	7.07	0.00	17.78	82.06
1978	4206	791.8	9.17	0.00	14.97	80.81
1979	4165	673.8	21.18	0.00	13.60	73.23
1980	4652	761.5	22.94	0.00	12.07	73.47
1981	4319	851.7	35.94	0.00	27.28	62.35
1982	5229	972.2	24.93	0.00	22.45	72.39
1983	5435	1007.5	37.17	0.00	31.46	62.80
1984	5241	973.1	42.96	0.00	35.26	57.03
1985	5769	942.6	46.72	0.00	38.12	52.55
1986	6148	1013.2	39.63	0.00	36.45	55.09
1987	6342	900.6	45.35	0.00	38.54	52.85
1988	7143	802.2	26.43	0.00	28.70	65.57
1989	6642	993.0	36.12	0.00	40.56	52.15
1990	5568	849.5	32.36	0.00	27.90	66.42
1991	7740	944.5	21.48	0.00	24.26	66.28
1992	7255	1060.2	16.30	0.00	13.13	76.87
1993	7088	1213.8	19.23	0.00	16.78	71.79
1994	6633	870.3	19.15	0.00	18.27	75.19
1995	7734	1073.9	1.82	0.00	0.00	98.18
1996	9748	836.9	0.54	0.00	0.54	99.46
1997	9752	752.3	4.41	0.00	2.47	94.47
1998	8856	845.6	2.48	0.00	2.29	97.52
1999	10313	1075.7	1.89	0.00	1.65	98.11
2000	9801	1098.9	1.35	0.00	1.45	98.33
2001	8350	1236.6	1.04	0.00	0.75	98.96
2002	7404	1015.7	0.17	0.00	1.09	98.77
2003	7954	1017.1	0.00	0.00	0.03	99.97
2004	7388	977.6	0.11	0.00	2.15	97.83
2005 *	6312	903.6	0.05	0.00	0.86	99.14

* Excludes State catches

(Table 20.4 Continued)

(c) Tasmania

Year	Number of records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1976	247	77.0	24.33	0.00	45.14	54.86
1977	443	99.3	20.20	0.00	39.25	60.75
1978	382	94.0	49.36	0.00	60.52	36.70
1979	512	93.9	97.49	0.00	78.75	2.51
1980	577	137.0	92.21	0.00	77.13	7.79
1981	298	109.7	93.10	0.00	77.45	6.90
1982	188	84.6	92.71	0.00	70.27	7.29
1983	176	83.0	97.53	0.00	69.52	2.47
1984	463	195.0	99.06	0.00	69.32	0.94
1985	983	230.4	97.92	0.00	74.68	2.05
1986	942	162.4	98.38	0.00	72.03	1.62
1987	1384	178.8	98.33	0.00	71.02	1.67
1988	1683	185.3	91.84	0.00	61.75	7.27
1989	1714	173.2	88.09	0.00	63.19	5.86
1990	2143	161.1	84.78	0.00	46.59	14.98
1991	903	140.3	80.29	0.00	52.76	17.35
1992	1168	201.0	76.65	0.00	38.42	21.49
1993	901	268.4	92.72	0.00	51.15	7.01
1994	650	208.2	96.05	0.00	66.63	3.80
1995	1565	111.2	0.22	0.00	0.22	99.78
1996	4915	142.6	1.56	0.00	1.56	98.44
1997	1606	104.2	6.22	0.00	6.81	93.19
1998	1923	103.1	7.16	0.00	6.66	92.84
1999	2368	109.2	3.33	0.00	3.33	96.67
2000	2193	83.6	3.35	0.00	3.45	96.55
2001	1586	73.8	3.97	0.00	3.83	95.93
2002	1376	111.4	1.17	0.00	1.47	98.53
2003	1382	110.4	0.00	0.00	1.24	98.76
2004	1312	129.5	0.04	0.00	4.78	95.22
2005*	1254	97.6	0.00	0.00	8.17	91.83

* Excludes State catches

Table 20.5. Reported catches of school shark, total number of catch-effort records, and the percentage of the reported catch of school shark rejected for use in the standardization of the catch and effort data because the records concerned did not include: a) information about the amount of effort expended, b) the statistical cell in which the catch was taken and c) the gear-type that was used.

(a) South Australia (WSA and CSA)

Year	Number of Records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	1203	158.4	5.46	0.00	5.54	94.46
1974	1265	188.8	0.00	0.00	1.88	98.12
1975	1158	231.8	0.00	0.00	2.48	97.52
1976	590	158.5	0.26	0.00	9.08	90.92
1977	705	270.1	11.19	0.00	64.85	35.15
1978	704	333.8	17.94	0.00	83.19	16.67
1979	509	334.5	14.33	0.00	92.38	7.62
1980	572	458.7	4.98	0.00	87.28	12.72
1981	650	607.0	4.58	0.00	79.48	20.52
1982	626	608.8	2.18	0.00	89.37	10.63
1983	614	481.5	8.25	0.00	54.66	41.34
1984	865	540.7	4.46	0.00	0.00	95.54
1985	960	612.6	9.03	0.00	0.10	90.87
1986	1342	693.8	2.67	0.00	0.22	97.12
1987	1936	828.3	2.36	0.00	0.01	97.63
1988	1910	809.6	1.94	0.00	0.43	97.64
1989	1781	688.8	2.29	0.00	0.23	97.57
1990	2002	555.2	1.18	0.00	0.11	98.72
1991	2118	520.2	1.42	0.00	0.10	98.50
1992	2125	319.5	0.45	0.00	0.00	99.55
1993	1902	375.0	0.83	0.00	0.00	99.17
1994	1740	383.4	2.27	0.00	0.00	97.73
1995	1695	361.2	0.16	0.00	0.16	99.84
1996	1565	419.3	0.06	0.00	0.06	99.94
1997	6041	418.2	6.05	0.00	6.49	88.22
1998	9268	231.7	2.77	0.00	0.71	97.22
1999	7457	166.3	1.31	0.00	1.22	98.67
2000	5873	93.9	7.87	0.00	1.88	92.13
2001	5950	91.6	2.01	0.00	1.49	97.38
2002	4917	64.4	0.53	0.00	1.84	98.09
2003	5593	98.6	0.00	0.00	0.06	99.94
2004	5784	89.7	0.07	0.00	4.33	95.60
2005*	5421	95.4	0.04	0.00	0.66	99.34

* Excludes State catches

(Table 20.5 Continued)

(b) Bass Strait (EBS and WBS)

Year	Number of Records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	3670	153.7	0.18	0.00	6.55	93.45
1974	3466	248.6	3.32	0.00	13.81	86.19
1975	3523	422.1	6.47	0.00	11.70	88.23
1976	3273	403.5	0.94	0.00	10.68	89.29
1977	3595	316.9	8.05	0.00	18.39	81.56
1978	3902	277.2	17.00	0.00	6.01	79.09
1979	3885	354.6	47.81	0.00	14.20	43.33
1980	4418	537.6	49.73	0.00	12.20	45.56
1981	4145	453.6	53.25	0.00	25.70	45.11
1982	4925	398.9	40.55	0.00	24.40	58.69
1983	5179	428.3	45.80	0.00	34.33	54.20
1984	4915	518.1	51.49	0.00	40.73	48.51
1985	5445	621.3	47.76	0.00	38.84	51.59
1986	5761	633.2	42.66	0.00	30.89	52.75
1987	5875	471.9	49.66	0.00	30.59	48.67
1988	6659	494.6	26.09	0.00	26.44	65.09
1989	6183	474.7	32.57	0.00	35.31	51.91
1990	5238	365.1	36.77	0.00	25.72	59.28
1991	7025	414.9	32.49	0.00	24.77	53.78
1992	6677	348.8	34.75	0.00	17.87	55.81
1993	6643	348.8	21.29	0.00	13.69	71.98
1994	6208	281.8	22.91	0.00	14.18	75.04
1995	7058	223.2	0.08	0.00	0.01	99.92
1996	9308	174.2	2.48	0.00	2.48	97.52
1997	8979	129.3	8.14	0.00	2.33	91.42
1998	8221	195.9	2.98	0.00	2.95	97.02
1999	9560	125.4	3.46	0.00	3.46	96.54
2000	9000	85.4	4.17	0.00	3.42	95.13
2001	7625	52.6	2.81	0.00	2.96	96.89
2002	6631	78.7	0.32	0.00	0.47	99.39
2003	7165	64.9	0.00	0.00	0.53	99.47
2004	6766	72.1	0.14	0.00	1.56	98.36
2005*	5597	79.2	0.00	0.00	0.46	99.54

* Excludes State catches

(Table 20.5 Continued)

(c) Tasmania

Year	Number of Records	Catch (*t*)	Percentage rejected			Percentage accepted
			No Effort	No Cell	Gear	
1973	396	70.9	24.85	0.00	24.85	75.15
1974	513	159.1	18.78	0.00	25.73	74.27
1975	219	91.9	33.74	0.00	33.83	66.17
1976	247	127.7	18.90	0.00	24.26	75.74
1977	443	196.7	12.33	0.00	17.67	82.33
1978	382	104.8	29.26	0.00	25.82	61.12
1979	512	183.3	96.84	0.00	25.64	3.16
1980	577	207.6	96.34	0.00	23.77	3.66
1981	298	259.8	94.65	0.00	31.32	5.35
1982	188	162.5	99.39	0.00	53.91	0.61
1983	176	111.0	100.00	0.00	59.33	0.00
1984	463	442.2	99.63	0.00	47.31	0.37
1985	983	584.4	95.91	0.00	59.58	4.03
1986	942	500.5	96.59	0.00	46.67	3.41
1987	1384	470.7	99.40	0.00	43.42	0.60
1988	1683	221.8	77.07	0.00	50.93	22.29
1989	1714	167.4	52.22	0.00	34.46	41.05
1990	2143	242.6	73.83	0.00	19.23	25.88
1991	903	156.6	64.65	0.00	26.86	22.66
1992	1168	253.2	80.93	0.00	15.10	15.44
1993	901	207.4	80.45	0.00	32.82	17.69
1994	650	119.6	77.96	0.00	15.53	21.97
1995	1565	117.4	1.12	0.00	1.12	98.88
1996	4915	91.3	1.41	0.00	1.41	98.59
1997	1606	86.2	1.25	0.00	3.79	96.21
1998	1923	88.4	3.23	0.00	3.23	96.77
1999	2368	79.1	6.19	0.00	3.62	93.81
2000	2193	59.1	2.87	0.00	2.91	97.09
2001	1586	15.3	8.30	0.00	8.30	91.70
2002	1376	32.5	4.77	0.00	4.77	95.23
2003	1382	19.6	0.00	0.00	9.96	90.04
2004	1312	12.2	0.00	0.00	27.56	72.44
2005*	1254	13.7	0.11	0.00	15.63	84.37

* Excludes State catches

Table 20.6 Statistics related to the vessels included in the catch-effort standardization. Results are shown separately for the vessels chosen to standardize the gummy shark data for South Australia, Bass Strait, and Tasmania.

Quantity	**School shark**	**Gummy shark**		
		Bass Strait	South Australia	Tasmania
Number of records	16,132	30206	36753	30909
Number of vessels	66	72	94	73
Total catch (t)	8,332	19,634	23,008	20,079
Average # of years in the fishery	17.0	15.9	16.0	15.8
Median annual catch per vessel	11,958 kg	4,847kg	7,340kg	4,924 kg

Table 20.7. Diagnostic statistics by statistical cell.

(a) Gummy shark

Bass Strait (30 years - 1976–2005)				**South Australia (22 years - 1984–2005)**			
Cell	**Rule a**	**Rule b**	**Rule c**	**Cell**	**Rule a**	**Rule b**	**Rule c**
4	0	0	7	101	3	0	1
5	0	0	0	102	5	0	0
6	1	0	0	103	0	0	0
7	0	0	0	107	0	0	0
8	0	0	0	112	0	0	0
9	0	0	0	115	0	0	0
10	0	0	0	122	8	4	6
11	0	0	0	126	0	0	0
18	0	0	1	128	0	0	0
19	0	0	0	129	0	2	2
20	0	0	0	132	1	4	4
21	0	0	0	136	2	5	7
22	0	0	0	138	0	0	0
23	0	0	0	139	0	0	0
30	2	0	0	140	0	0	0
31	0	0	0	144	0	0	0
32	0	0	0	148	0	0	1
33	4	0	1	149	0	0	0
34	0	0	0	150	0	0	0
35	0	0	0	151	0	0	0
				155	0	0	0
				158	1	0	0

Tasmania (16 years - 1990–2005)			
Cell	**Rule a**	**Rule b**	**Rule c**
41	0	0	0
42	0	0	2

(Table 20.7 Continued)

(b) School shark

Bass Strait (33 years – 1973–2005)				South Australia (23 years – 1983–2005)			
Cell	**Rule a**	**Rule b**	**Rule c**	**Cell**	**Rule a**	**Rule b**	**Rule c**
6	4	0	1	101	0	0	2
7	1	0	0	102	0	0	3
10	15	0	0	103	0	0	0
18	0	0	0	107	0	0	0
20	0	0	0	112	0	0	0
21	15	0	0	115	0	0	0
22	15	0	0	126	0	0	0
30	0	0	0	128	1	0	0
32	0	0	0	138	1	0	0
33	15	0	1	139	1	0	0
34	15	0	0	148	1	0	0
35	15	0	0	149	0	0	0
				150	0	0	0

21. Updated Stock Assessment of Gummy Shark (*Mustelus antarcticus*) Based on Data Up to 2005

André E. Punt[1], Fred Pibac[1], Terence I. Walker[2] and Anne S. Gason[2]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia
[2]Marine and Freshwater Systems. Primary Industries Research Victoria,
Box 114, Queenscliff, VIC 3225, Australia

21.1 Abstract

The assessment of gummy shark is updated using data for 2005. Unlike previous stock assessments of gummy shark, the present stock assessment explicitly considers the population of gummy shark off Tasmania (under the assumption that productivity and availability of gummy shark off Tasmania is the same as that off South Australia and in Bass Strait). The results of this assessment are used to apply the Tier 1 rules.

21.2 Introduction

Assessments of the populations of gummy shark (*Mustelus antarcticus* Günther) in Bass Strait and off South Australia and Tasmania are needed to determine the current status of this resource relative to agreed target and limit reference points, and as the basis for applying the Commonwealth harvest policy. The Tasmanian, South Australian and Bass Strait populations of gummy shark are assumed to be demographically independent because a) tagging data suggest low rates of movement across the South Australia / Victoria border (Walker *et al*., 2000); b) there are differences in habitat among regions; and c) there appear to be differences in the proportion of gummy shark breeding in Bass Strait and South Australia (Walker *et al*., 1989). Other reasons for treating the populations of gummy shark in these three regions differently are not biological. For example, the existence of political boundaries and hence past management jurisdictions, and differences in targeting practices over time (gummy shark have been targeted extensively using gill-nets in Bass Strait since the early 1970s, whereas gummy shark have only recently become the primary target species in South Australia).

Recent assessments of gummy shark (e.g. Punt *et al*. 2004; Pribac and Punt, 2005) have been based on fitting an age- and sex-structured population dynamics model to data on catches, catch-rates, catch length-composition data, catch age-composition data, and tagging data, and using Bayesian methods to determine the variances of the estimates of the model parameters and other quantities of interest.

This paper updates the assessment of gummy shark conducted by Pribac and Punt (2005) using the data for 2005 and applies the Tier 1 rules for calculating Recommended Biological Catches for 2007. Unlike previous assessments of gummy shark, this assessment includes the population of gummy shark off Tasmania as well as those off South Australia and in Bass Strait.

21.3 Data

The data available for assessment purposes include catches by gear-type (1927–2005), catch-rates (1976–2005), length-frequency data (1970–2005), age-composition data (1986–87, 1990–93) and tagging data (1943–2005).

The data are presented for ten 'sub-regions' off southern Australia: i) western Australia (WA), ii) western South Australia (WSA), iii) central South Australia (CSA), iv) eastern South Australia (SAV-W), v) far western Bass Strait (SAV-E), vi) western Bass Strait (WBas), vii) eastern Bass Strait (EBas), viii) western Tasmania (WTas), ix) eastern Tasmania (ETas), and x) New South Wales (NSW). These regions (Figure 21.1) were selected by the Shark Fishery Assessment Group (SharkFAG) on the basis of their physiography, the history of the fishery, movement patterns of gummy sharks inferred from tag release-recapture data, and the spatial distribution of the various age-classes inferred from available length-at-age and length-frequency data. The region Bass Strait comprises sub-regions SAV-E, EBas and WBas; the region South Australia comprises sub-regions WSA, CSA and SAV-W; and the region Tasmania comprises sub-regions WTas and ETas.

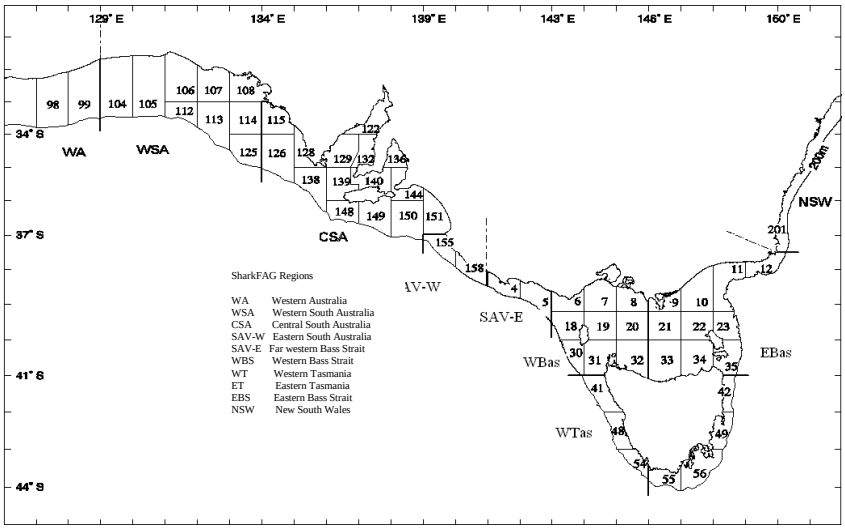


Figure 21.1. Sub-regions of the shark fishery.

21.3.1 Catch data

The catches of gummy shark have been updated to include information for 2005 (although State catches for 2005 are not yet available). Table 21.1 and Table 21.2 list the catches by the traditional southern shark sectors (longline and

gillnet) while Table 21.3 lists the catches by the South East Trawl Fishery (SETF), and the Great Australian Bight Trawl Fishery (GABTF). Taylor *et al*. (1996) and Punt *et al*. (2004) describe the methods used to construct the catch series. As in previous assessments, the selectivity pattern for the catches by the SETF and the GABTF is set to that assumed for longlines, because longlines take the broadest range of sizes of gummy shark. Figure 21.2 summarizes the time-series of catches by gear-type and region used in the analyses of this document. Estimates of the catches for 2006 are required to calculate Recommended Biological Catches, RBCs, for 2007. In the absence of data for all of 2006, the 2006 catch, and the split of this catch to gear-type, has been set to that for 2005.

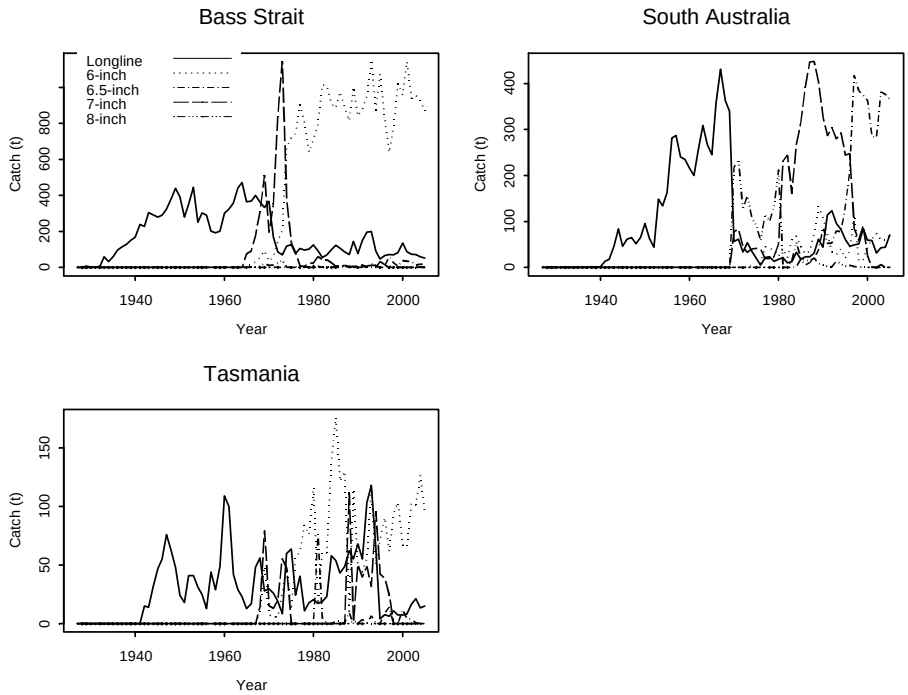


Figure 21.2. Catch series (carcass weight, tones) by gear-type and region.

21.3.2 Catch-rate Indices

The standardized catch-rate indices are given in Table 21.4 (Punt and Gason, Chpt 20).

21.3.3 Tagging Data

Consistent with previous assessments of gummy shark, tag release-recapture data are included in the assessment. Table 21.5 lists the various tag-types represented in the tagging database and Table 21.6 lists the tag-shedding rates for the tag-types for which the methods outlined by Xiao *et al.* (1999) allow reliable estimation (see Punt *et al*. (2004) for details regarding how the tag-shedding rates have been estimated).

21.3.4 Length- and age-composition data

Length-frequency and sex-composition data for commercial gummy shark landings have been collected routinely by a team of part-time fish measurers

operating in several fishing ports and regional fish processing plants. Only a few gummy shark have been collected since the last assessment so there are no additional length-frequency data for Bass Strait and South Australia compared to the 2005 assessment. The only length-frequency data for Tasmania are 1261 animals caught using 6-inch gear in 1995, and 1025 animals caught using 7-inch mesh gear in 1996. There are no age-composition data for Tasmania and no new age-composition for South Australia and Bass Strait since 1993.

21.4 Analytical Approach

21.4.1 Population dynamics model

The basic population biology of gummy shark and the selectivity of the gear used in the shark fishery are reasonably well understood. Population dynamics models, based on that used by Punt and Walker (1998) to assess the school shark resource off southern Australia, are applied to gummy shark (see Appendix 7.B of Punt *et al*. (2004) for the specifications of the population dynamics model). These models include the nature of the pupping process, the selectivity patterns of the various gears used in the fishery, and the growth rates of gummy shark. Pup production is assumed to be related closely to the number of pregnant females, although allowance is also made for (limited) variability in pregnancy rates / pup survival rates. Density-dependence is assumed to act through an impact on the natural mortality rate of a range of age-classes (e.g. all ages, ages 0–4 and pups) consistent with previous assessments of gummy shark (e.g. Walker, 1994a, 1994b).

The population dynamics model includes both length-specific gear-selectivity and length-specific availability. The values for the parameters of the selectivity functions are based on experimental results (Kirkwood and Walker, 1986). Differentiating availability from selectivity allows animals to be vulnerable to the gear (i.e. the selectivity of the gear allows them to be captured), but not to be available to the fishery (e.g. because, for example, they are not where the fishery operates) and hence not to be caught.

Table 7.B.1 of Punt *et al*. (2004) summarizes the biological parameters for gummy shark in terms of the relationships between length and age, mass and age, and pup production (the product of the number of pups per mature female and the proportion of females of each age that are mature) and age.

21.4.2 The base-case assessment

The base-case assessment reflects a ‘most likely’ set of assumptions, and sensitivity tests examine sensitivity to changing these assumptions. The following are the base-case assumptions:

a) Density-dependence impacts the instantaneous rate of natural mortality and is functionally related to the total (1+) biomass.
b) The variance in length-at-age increases linearly with expected length.
c) The residual variation for the catch-rate indices is 0.15, the effective sample sizes for the length-frequency data are 50 (Bass Strait), 25 (South Australia)

and 10 (Tasmania) respectively, and the effective sample for age-composition data is 25.

d) Any recaptures within 60 days of release are treated as 'early recaptures'
e) Natural mortality is independent of age above age 2.

21.4.3 Parameter and variance estimation

The values for all of the parameters of the population dynamics model, except those related to the virgin biomass (B_0), the magnitude of density-dependence, natural mortality (M_2), the parameters that determine the relationship between effort and fishing mortality, the parameter that determines the width of the function that relates availability to length, and the recruitment residuals are fixed using ancillary information. The values for natural mortality, availability and productivity are assumed to the same for gummy shark in Bass Strait and off South Australia and Tasmania whereas the remaining parameters (B_0, the parameters of the relationship between effort and fishing mortality and the annual recruitment residuals) are assumed to differ between South Australia, Bass Strait, and Tasmania.

Parameter values not determined using ancillary information are estimated by maximizing a likelihood function that includes contributions from the catch-rate, length-frequency, age-composition and tagging data (see Appendix 7.B of Punt *et al*. (2004)). Recruitment residuals are estimated for the years 1927–2004.

The variances for the estimates of the model parameters and for the other quantities of interest are determined using Bayesian methods. The Metropolis-Hastings variant of the Markov-Chain Monte Carlo (MCMC) algorithm (Hastings, 1970; Gilks *et al*., 1996; Gelman *et al.*, 1995) with a multivariate normal jump function is used to sample 900 equally likely parameter vectors from the joint posterior density function. This sample implicitly accounts for correlation among the model parameters and considers uncertainty in all parameter dimensions simultaneously. The samples on which inference is based were generated by running 2,000,000 cycles of the MCMC algorithm, discarding the first 200,000 as a burn-in period and selecting every 2,000th parameter vector thereafter. The initial parameter vector is taken to be the vector of maximum posterior density (MPD) estimates. A potential problem with the MCMC algorithm is how to determine whether convergence to the actual posterior distribution has occurred, and the selection of 2,000,000, 200,000 and 900 was based on generating a sample which showed no noteworthy signs of lack of convergence to the posterior distribution. Whether convergence had occurred was examined by applying the diagnostic statistics developed by Geweke (1992), Heidelberger and Welch (1983), and Raftery and Lewis (1992) and by examining the extent of auto-correlation among the samples in the chain.

21.5 Results and discussion

21.5.1 Fits to the data

21.5.1.1 Bass Strait

The base-case model estimates that there is severe gear competition in Bass Strait so that essentially the same *expected* exploitation rate results for all levels of standardized fishing effort during 1976–2005 (Figure 21.3). Gear competition is estimated to be substantial primarily because the effort data are negatively correlated with exploitation rate for some years. For example, the higher exploitation rates since 1990 and the lower exploitation rates during 1983–91 (solid lines in Figure 21.3) correspond to periods when effort was low and high, respectively. The estimated extent of gear competition is fairly robust to the weight placed on the effort data.

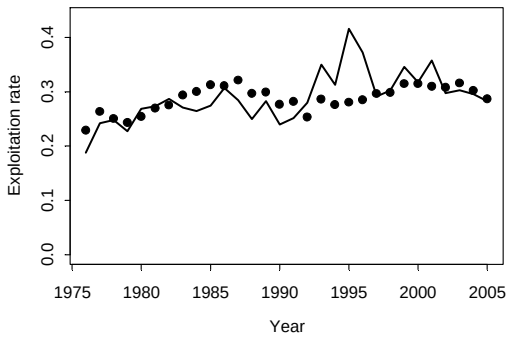


Figure 21.3. Estimated exploitation rate time-trajectory for 6-inch mesh gear in Bass Strait (solid line), and the values inferred from the effort information (dots).

The fits to the length-frequency (Figure 21.4 and Figure 21.5) and age-composition data (Figure 21.6) capture the general patterns. The fits to the data for the years for which sample size is large tend to be better than to the data for those years for which the sample size is low. However, as in previous assessments, there is a tendency to overestimate the mean length of the catch, particularly for 7-inch mesh (Figure 21.5) and 6-inch mesh in recent years (Figure 21.4).

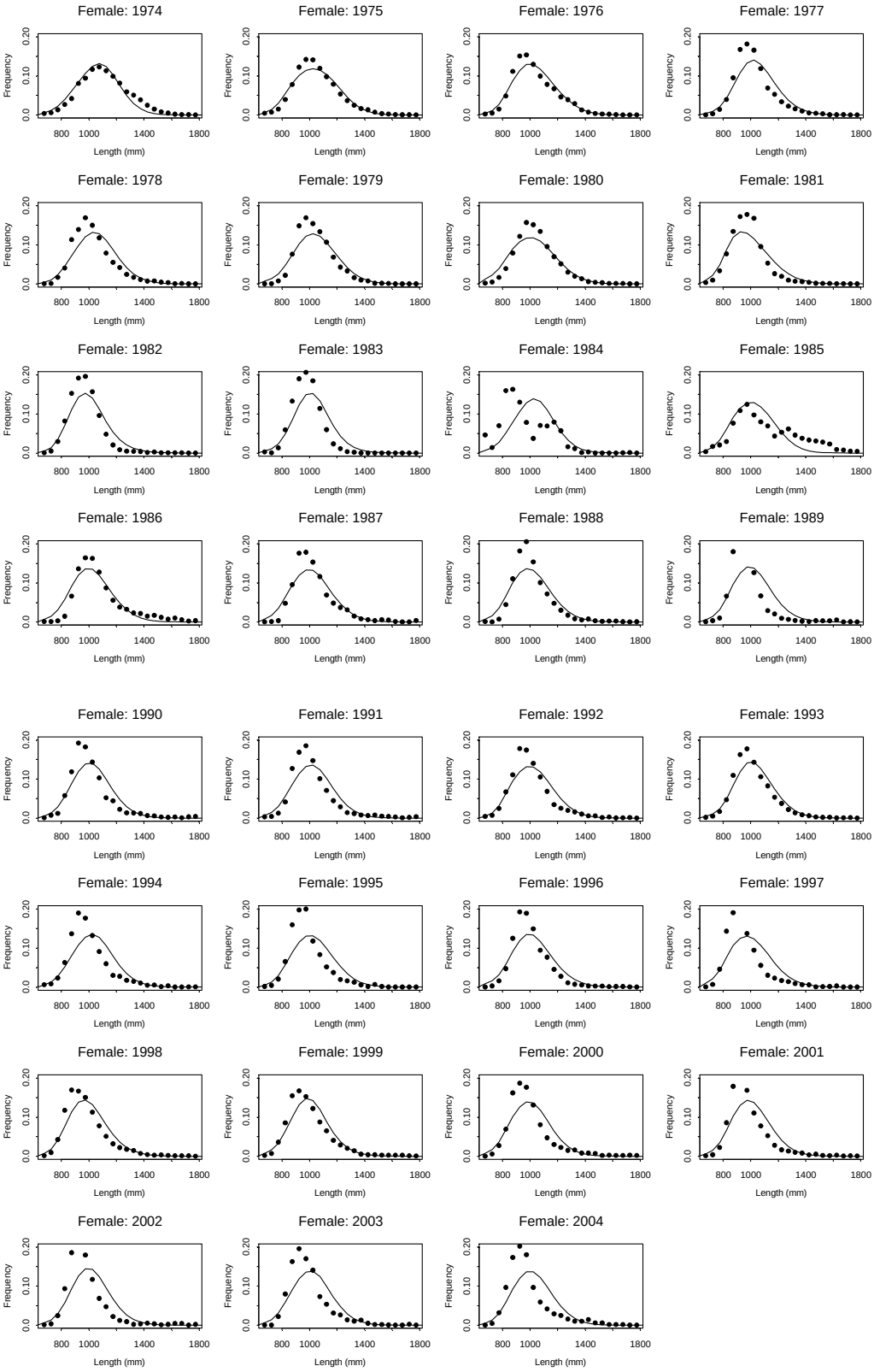


Figure 21.4a. Observed (solid dots) and model-predicted (solid lines) female length-frequency data for 6-inch mesh catches in Bass Strait.

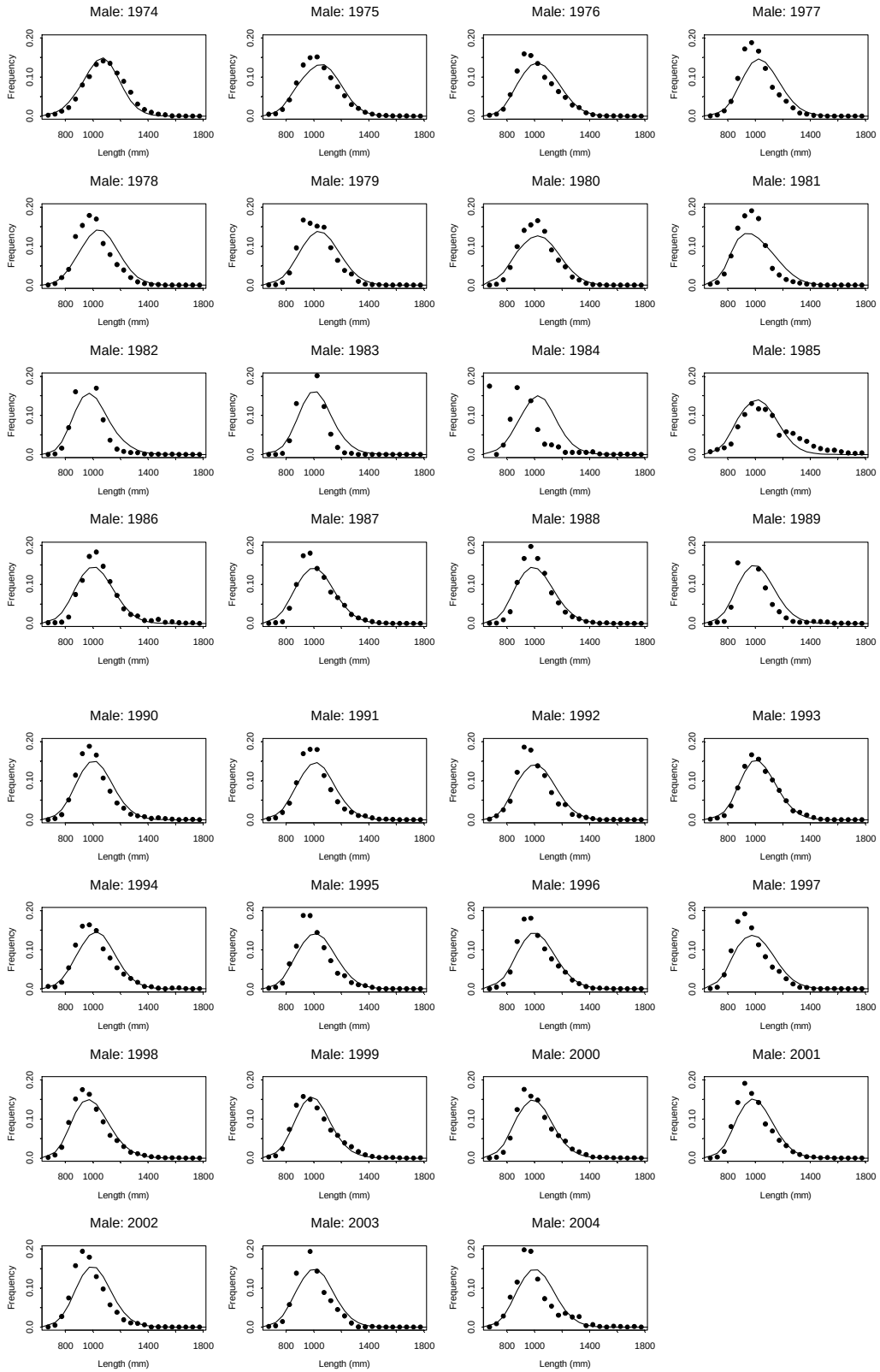


Figure 21.4b. Observed (solid dots) and model-predicted (solid lines) male length-frequency data for 6-inch mesh catches in Bass Strait.

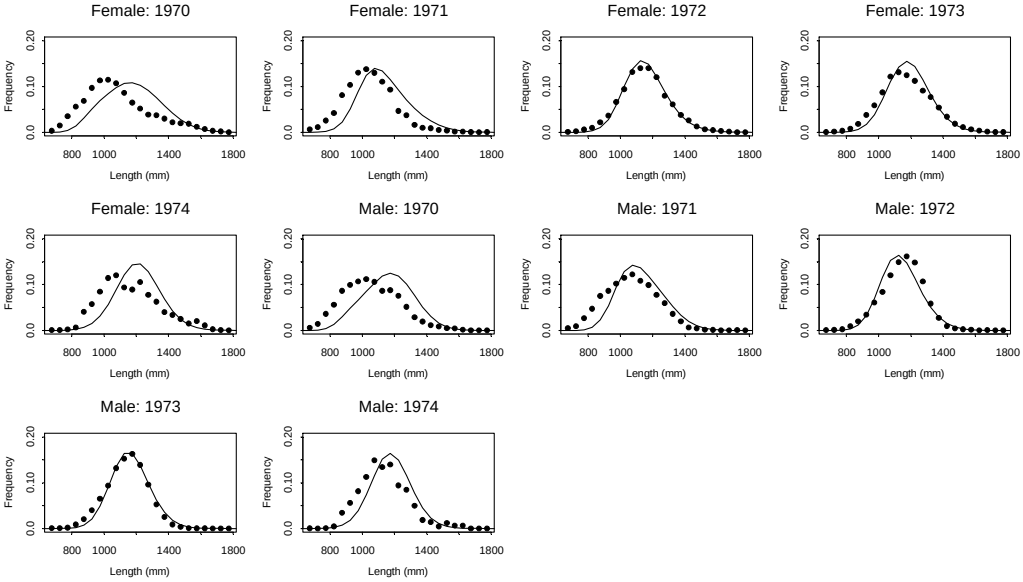


Figure 21.5. Observed (solid dots) and model-predicted (solid lines) male length-frequency data for 7-inch mesh catches in Bass Strait. Results are shown separately for females and males.

The fits to the age-composition data, although generally adequate, are remarkably poor for some years (1990 and 1991 for females and 1986 for males). The model is able to mimic the recent pattern in tag recaptures adequately (Figure 21.7). However, the model over-estimates the number of recaptures during the 1970s. Whether this is a consequence of poor choices for the tag-reporting rates or a structural problem with the underlying population dynamics model is, however, unclear.

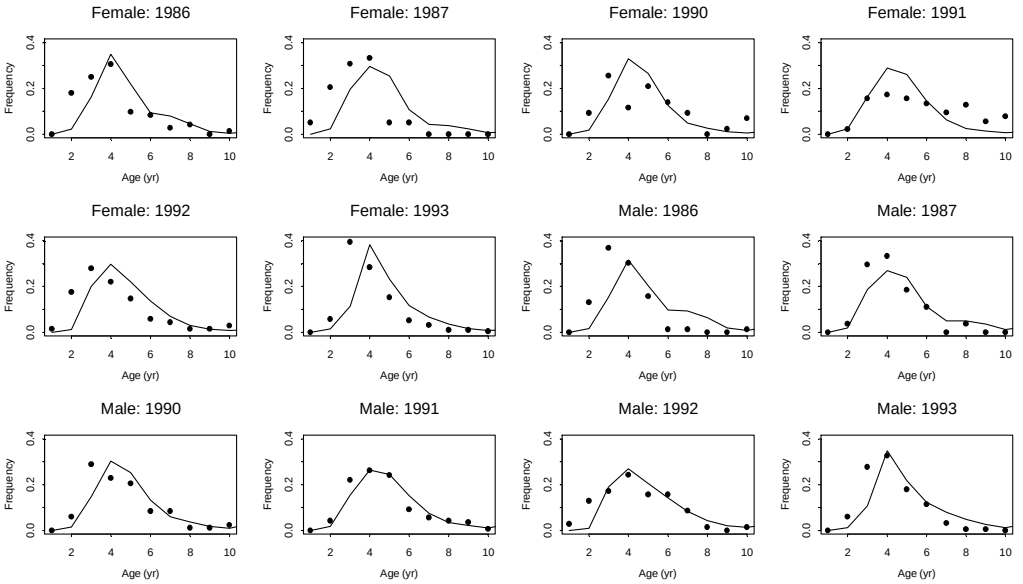


Figure 21.6. Observed (solid dots) and model-predicted (solid lines) age-composition data (6-inch mesh catches) in Bass Strait. Results are shown separately for females and males.

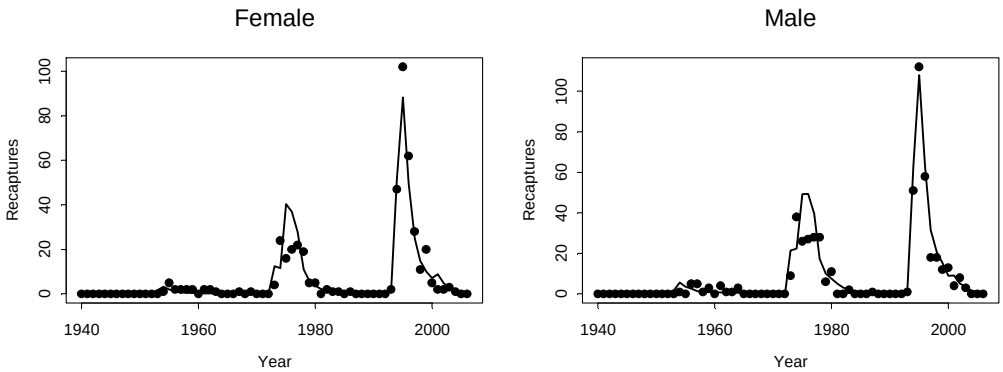


Figure 21.7. Observed (solid dots) and model-predicted (solid lines) number of tag recaptures in Bass Strait (by sex).

21.5.1.2 South Australia

The model mimics the trend in exploitation rate well (Figure 21.8). The fits to the length-frequency and age-composition data are, however, notably poorer for South Australia than was the case for Bass Strait (Figure 21.9 – Figure 21.11). There are some cases in which the model fails to capture even the predominant lengths in the catch (e.g. 1997 for 6.5-inch mesh – Figure 21.10, 1990 for 7-inch mesh – Figure 21.9). The reasons for this are unclear, but are probably related to the very small sample sizes for some years. The fit to the tag recapture information (Figure 21.12) is also not as good as was the case for Bass Strait, although the model is able to capture the recent trend in tag recaptures.

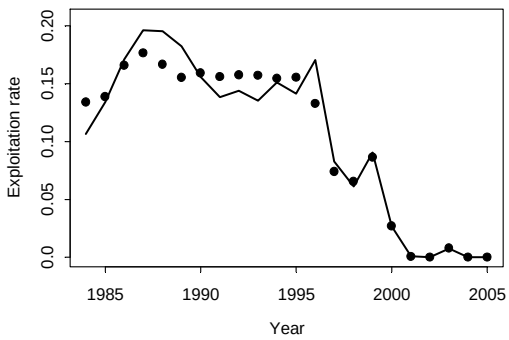


Figure 21.8. Estimated exploitation rate time-trajectory for 7-inch mesh gear for South Australia (solid line) and the values inferred from the effort information (dots).

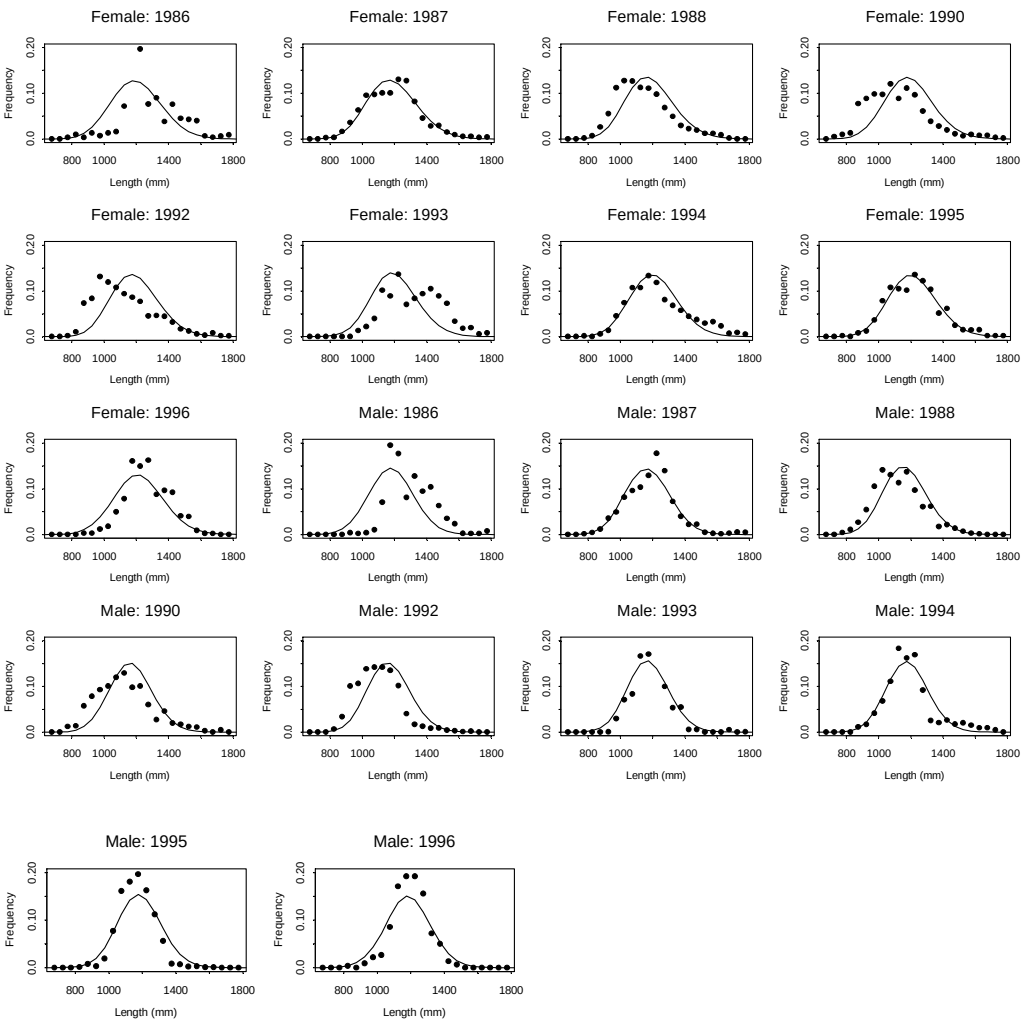


Figure 21.9. Observed (solid dots) and model-predicted (solid lines) length-frequency data (7-inch mesh catches) for South Australia. Results are shown separately for females and males.

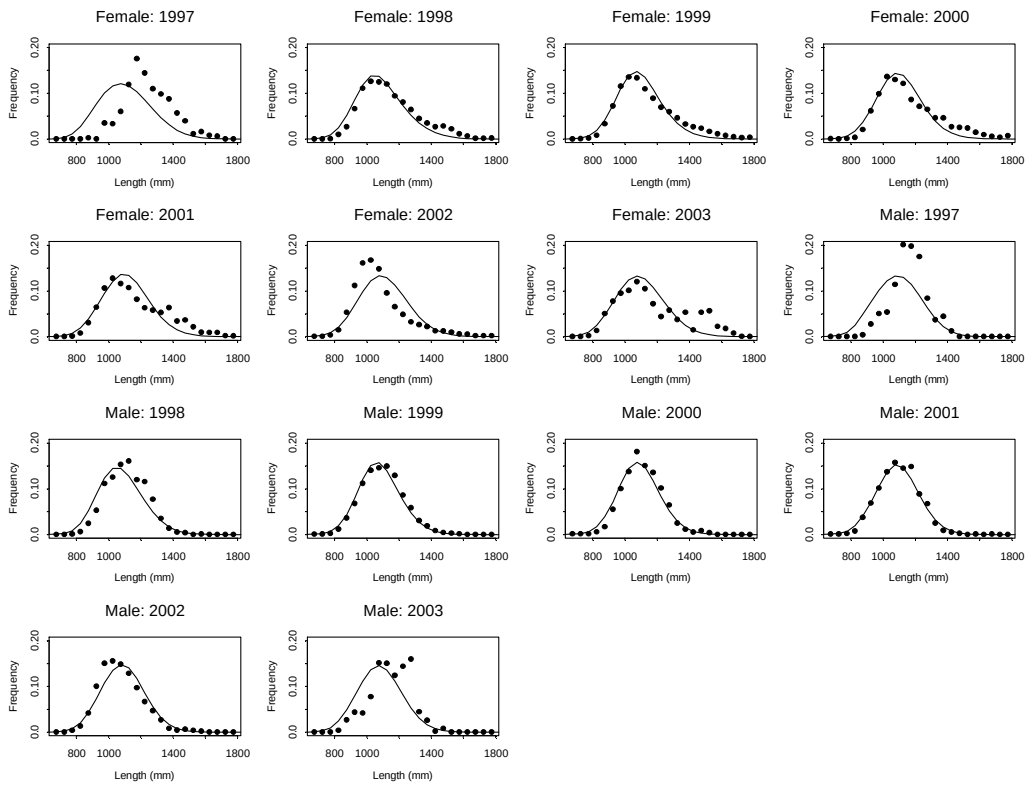


Figure 21.10. Observed (solid dots) and model-predicted (solid lines) length-frequency data (6.5-inch mesh catches) for South Australia. Results are shown separately for females and males.

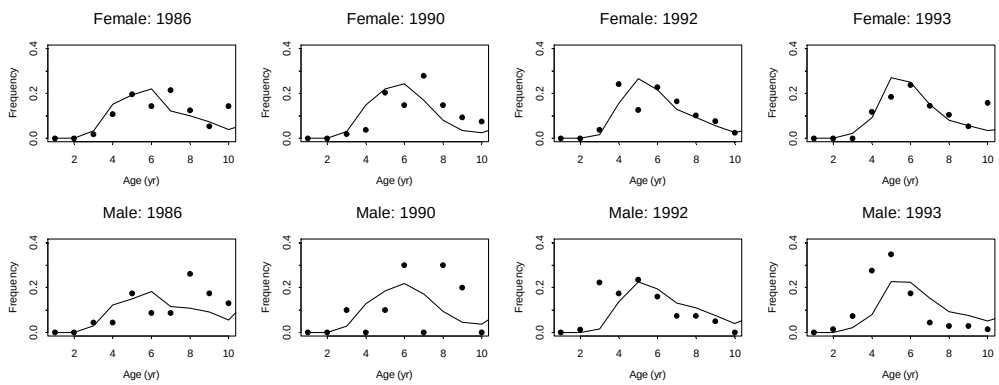


Figure 21.11. Observed (solid dots) and model-predicted (solid lines) age-composition data (7-inch mesh catches) for South Australia. Results are shown separately for females and males.

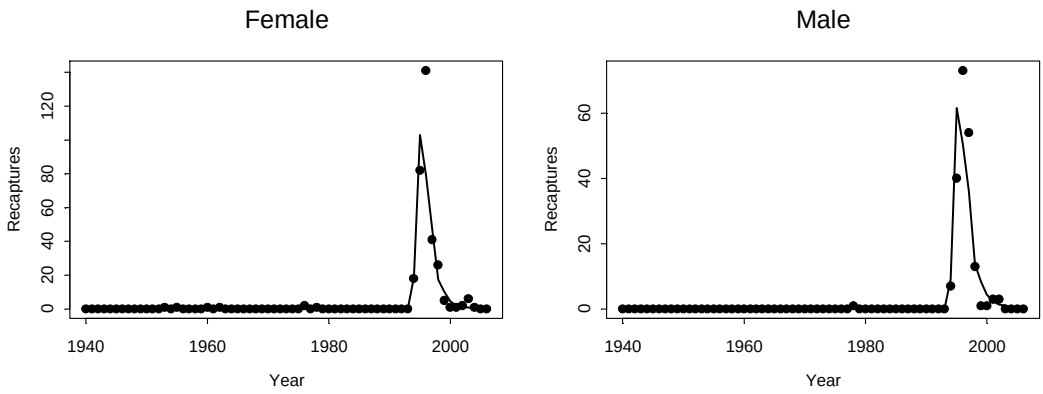


Figure 21.12. Observed (solid dots) and model-predicted (solid lines) number of tag recaptures for South Australia (by sex).

21.5.1.3 Tasmania

The model mimics the trend in exploitation rate well (Figure 21.13). The fits to the length-frequency data (Figure 21.14) are reasonable, but the length-frequency data set for Tasmania is very small. The model is able to mimic the tag recapture information for Tasmania fairly adequately (Figure 21.15).

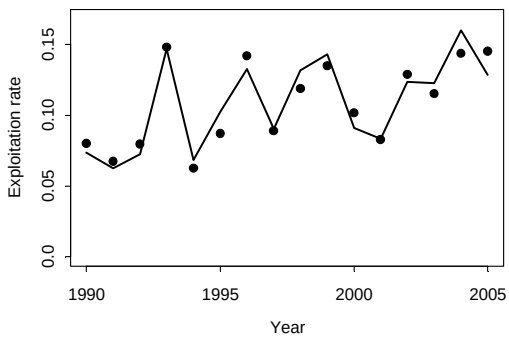
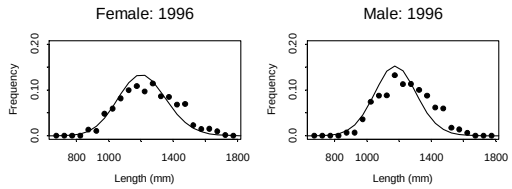


Figure 21.13. Estimated exploitation rate time-trajectory for 6-inch mesh gear for Tasmania (solid line) and the values inferred from the effort information (dots).

(a) 7-inch mesh



(b) 6-inch mesh

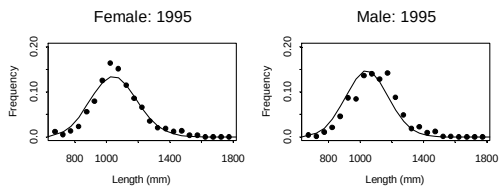


Figure 21.14. Observed (solid dots) and model-predicted (solid lines) length-frequency data for Tasmania. Results are shown separately for females and males.

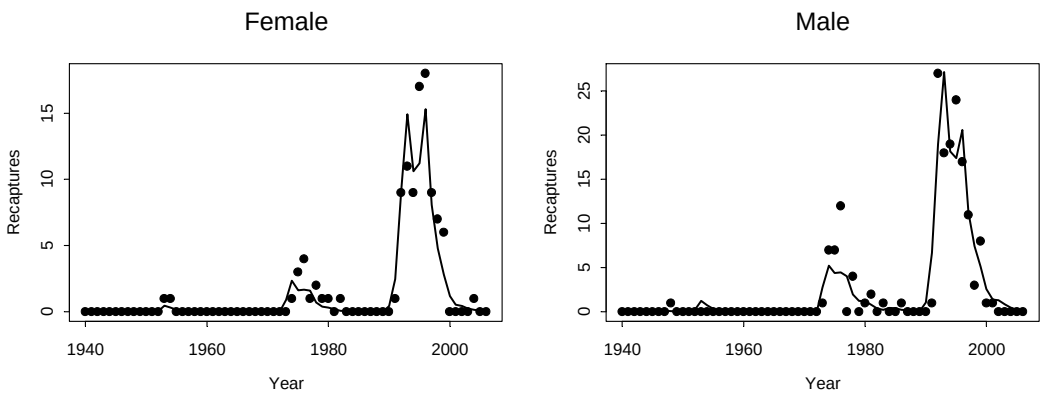


Figure 21.15. Observed (solid dots) and model-predicted (solid lines) number of tag recaptures for Tasmania (by sex).

21.5.2 Markov Chain Monte Carlo

Figure 21.6 summarizes the convergence statistics for six of the key model outputs (the objective function, the logarithm of virgin biomass for Bass Strait, South Australia, and Tasmania, the natural mortality rate for animals 2 and older, and the parameter that determines the productivity of the resource) in terms of the trace of the MCMC chain. Figure 21.16 does not exhibit any evidence that the MCMC algorithm failed to converge adequately to the posterior distribution.

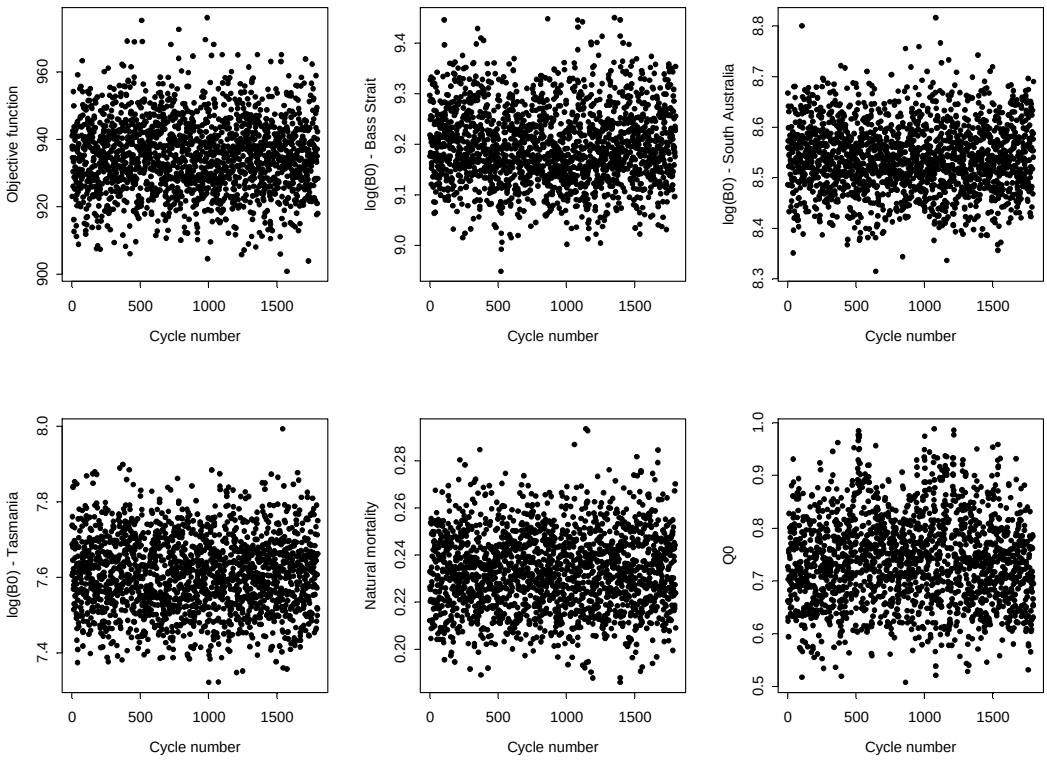


Figure 21.16. Traces for six key model outputs.

21.5.3 The base-case assessments

The results of the assessment are summarized by the values for 10 quantities of interest to management:

a) Pup_0 the pup production in a virgin state (separately for Bass Strait, South Australia and Tasmania),

b) M_2 the instantaneous rate of natural mortality for fish of age 2 (at pre-exploitation equilibrium when natural mortality is density-dependent),

c) *MSYR* the *MSY* rate (the ratio of *MSY* to the biomass at which *MSY* is achieved), separately for Bass Strait, South Australia, and Tasmania.

d) $\mathrm{Pup}_{73}/\mathrm{Pup}_0$ the ratio of the pup production[13] at the start of 1973 to that in a virgin state, expressed as a percentage (separately for Bass Strait, South Australia, and Tasmania),

f) $\mathrm{Pup}_{07}/\mathrm{Pup}_0$ the ratio of the pup production at the start of 2007 to that in a virgin state, expressed as a percentage (separately for Bass Strait, South Australia, and Tasmania), and

g) $-\ell\mathrm{n}L$ the negative of the logarithm of the likelihood function (ignoring constants independent of the model parameters).

[13] Results are reported for pup production because pup production is the closest analogy to "reproductive output", which is the population size measure that is used in the Tier 1 rules. Pup production is also a measure of the number of mature females, the component of the population that determines its rate of recovery from depleted levels.

Figure 21.17 shows the time-trajectories of exploitable biomass and exploitation rate (by gear-type) for the gummy shark populations in the three regions. A noteworthy result in Figure 21.17 is that the exploitable biomass in Bass Strait was relatively stable from 1980 to the mid-1990s, dropped substantially and has recovered somewhat. The exploitable biomass off South Australia declined after 1980 and some recovery is evident in recent years. The exploitable biomass off Tasmania is estimated to have been stable since about 1980.

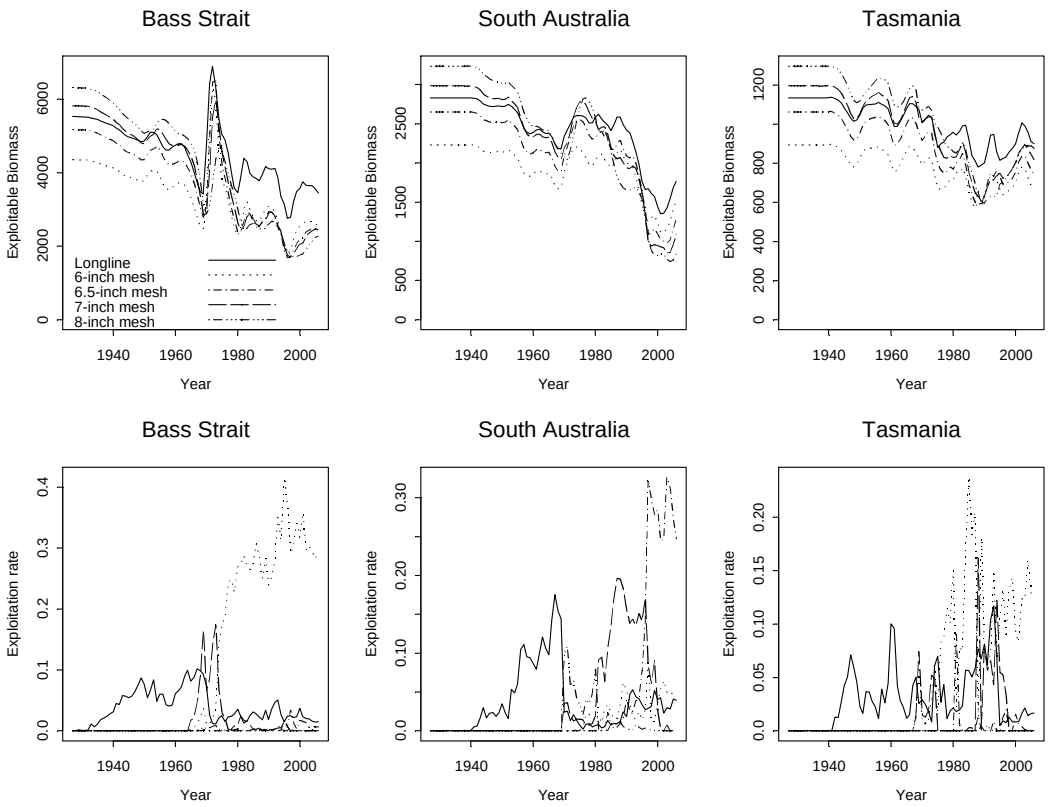


Figure 21.17. Time-trajectories of exploitable biomass and exploitation rate for the three regions.

Figure 21.18 - Figure 21.20 show time-trajectories (with asymptotic 90% probability intervals) for the pup production, the total (1+) biomass, the number of 1-year-olds, and the number of 3-year-olds for the gummy shark populations in the three regions. The narrow 90% probability intervals for 1927 (age-1 abundance) and 1927–1929 (age-3 abundance) in Figure 21.18 - Figure 21.20 arise because the population is assumed to be in deterministic equilibrium at the start of 1927.

Figure 21.21 shows the time-trajectories of pup production (expressed relative to the pup production in 1927) for the three regions, along with the thresholds that define the three variants of the Tier 1 harvest control rule. As expected from Table 21.7, Figure 21.21 shows that pup production in all three regions is presently above the limit reference point of 20% of the unfished pup production.

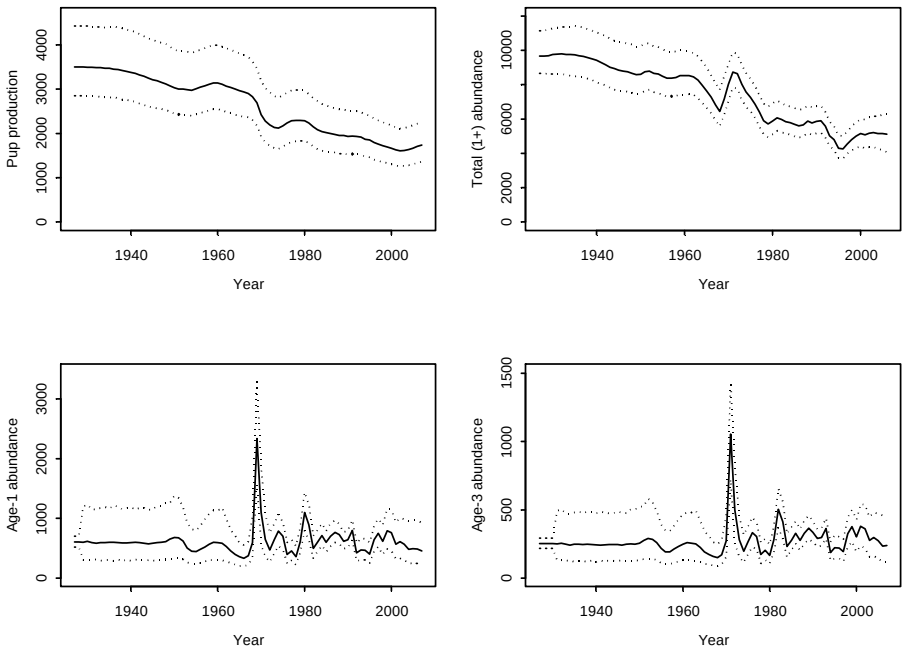


Figure 21.18. Time-trajectories for Bass Strait (with 90% probability intervals) for: pup production, 1+ biomass, number of 1-year-olds, and number of 3-year-olds.

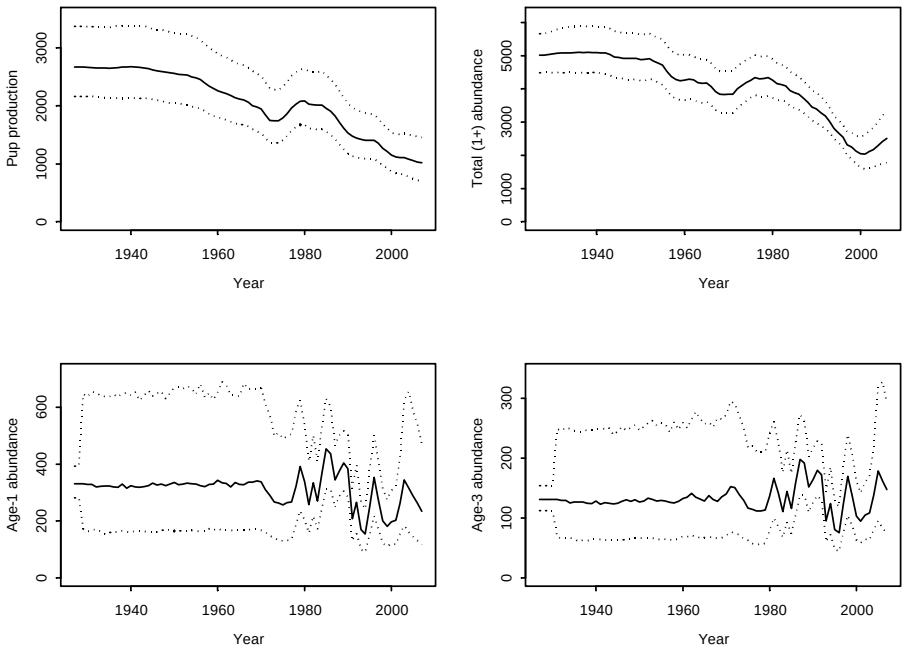


Figure 21.19. Time-trajectories for South Australia (with 90% probability intervals) for: pup production, 1+ biomass, number of 1-year-olds, and number of 3-year-olds.

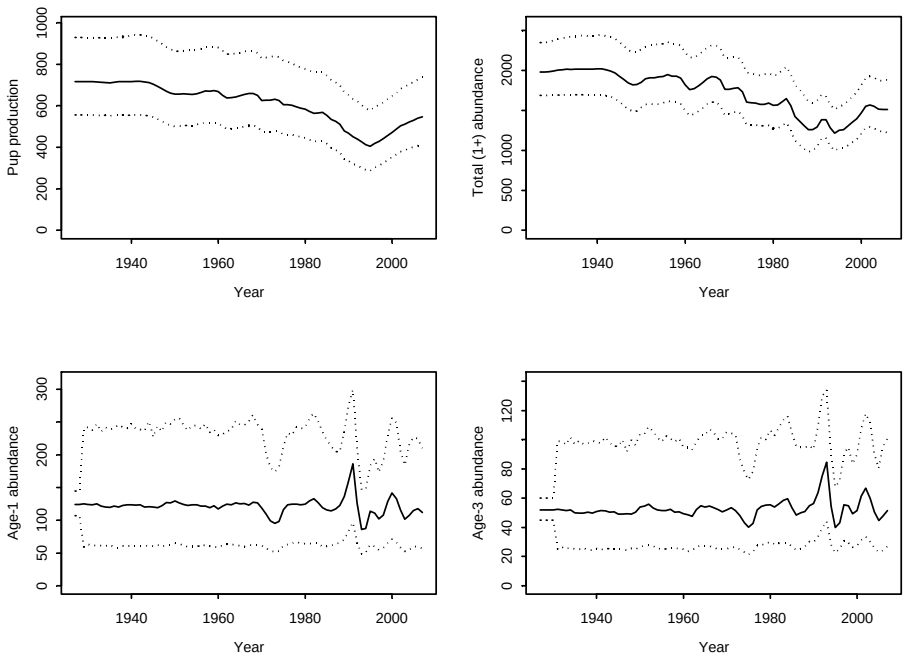


Figure 21.20. Time-trajectories for Tasmania (with 90% probability intervals) for: pup production, 1+ biomass, number of 1-year-olds, and number of 3-year-olds.

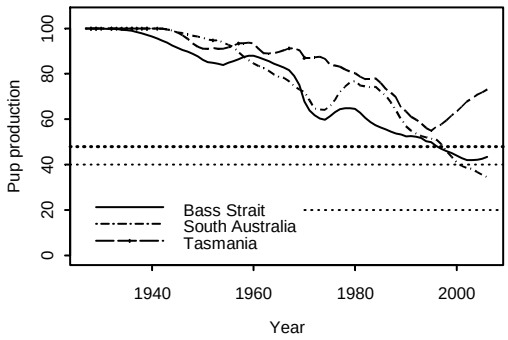


Figure 21.21. Time-trajectories of pup production (expressed relative to the pup production in 1927) by region, along the thresholds on which the Tier 1 rules are based.

21.5.4 Sensitivity tests

Table 21.7 lists the values of the 10 summary statistics for the base-case analysis and a subset of the sensitivity tests included in past assessments. The estimates of the ratio of the pup production at the start of 2007 to that in 1927, $\mathrm{Pup}_{07}/\mathrm{Pup}_{0}$, are highly sensitive to changes to how density-dependence is modeled. Reducing the range of ages over which density-dependent natural mortality operates leads to a markedly more depleted population (Table 21.7 rows “Dens-dep-pups” and “Dens-dep M (ages 0-4)”).

21.5.5 RBC Calculations

There is currently uncertainty regarding the exact mathematical specifications for the Tier 1 rule and three variants that differ in terms of the depletion[14] at which the exploitation rate begins to decline (40% or 48% of the virgin level) and the target stock size exist at present (all three variants set the exploitation rate for targeted fishing to 0 at 20% of the virgin level). The three variants (in terms of decreasing amounts of conservatism) are:

a) 20-48-48; a target stock size of 48% of the 1927 level, with the exploitation rate dropping off once the stock drops below the target level.
b) 20-40-48; a target stock size of 48% of the 1927 level, with the exploitation rate dropping off once the stock drops below 40% of the 1927 level.
c) 20-40-40; a target stock size of 40% of the 1927 level, with the exploitation rate dropping off once the stock drops below the target level.

The RBC calculations assume the split of the catch among gear-types in the future will be the same as that for 2006, the last year for which data are available. The following table lists the RBCs by region for each of the three Tier 1 rules. As expected, the RBCs under the 20-40-40 variant are highest and those under the 20-48-48 variant lowest. The 2007 RBCs for Tasmania are higher than the long-term RBC under the Tier 1 rule because the resource in this region is assessed to be well above the target level (Table 21.7). The long-term RBCs for Tasmania are 189 / 197t for a target stock respectively of 48% and 40% of the 1927 pup production respectively. In contrast, the RBCs for South Australia are predicted to increase over time (Figure 21.22) because the population of gummy shark in this region is estimated to be below the target level at present (especially when the target level is set to 48% of the 1927 pup production).

Variant	Bass Strait	South Australia	Tasmania	Total
20-48-48	750	210	234	1194
20-40-48	870	291	234	1395
20-40-40	1016	343	273	1632

[14] Consistent with past SharkFAG practice, depletion is defined in terms of the status of the pup production relative to that at the start of 1927.

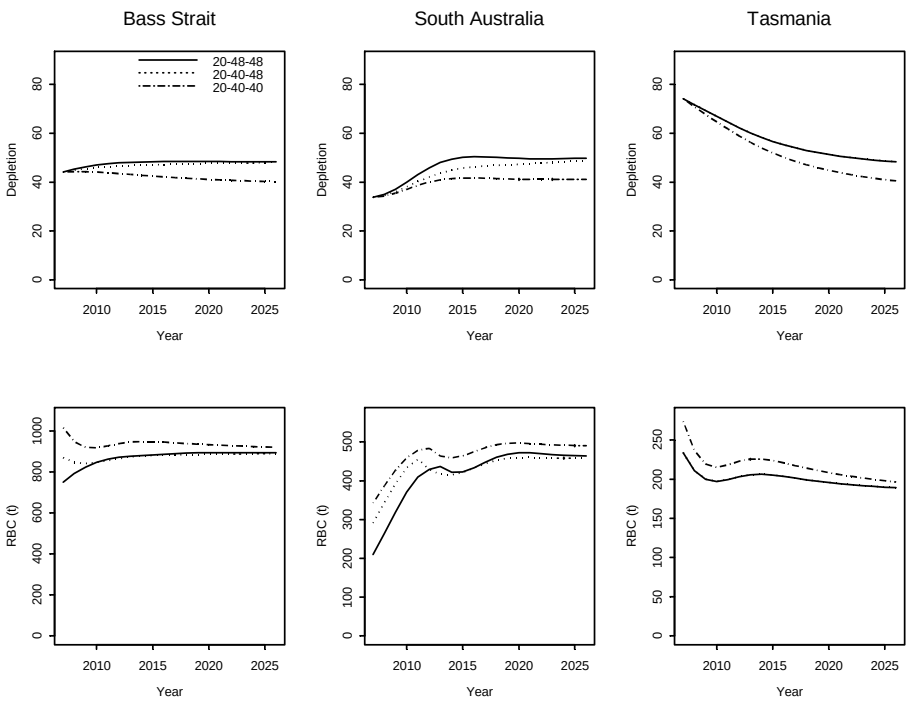


Figure 21.22. Time-trajectories of RBC and depletion for each of the three variants of the Tier 1 rule by region.

21.6 Future work

The analyses of this document could be extended in future in several ways.

1. The values for *MSYR*, M_2, etc., could be assumed to differ between South Australia and Bass Strait (with a constraint on the extent of difference).

2. Data on the mean mass of the catch in Bass Strait are available for part of the 1950s and the early 1960s. These data have been used in some previous assessments of gummy shark (e.g. Walker, 1994a). They should be reviewed by SharkFAG and perhaps included in the likelihood function on which future assessments are based.

3. The assumptions regarding tag-reporting rates may be the cause of the inability to adequately replicate the number of tag recaptures during the 1970s. These assumptions should be reviewed by SharkRAG and sensitivity to alternative assumptions examined in future assessments.

4. This assessment is based on very few data for 2005. The declining amount of information for 2005 continues a trend of declining amounts of new information (length-frequency data and tag recaptures) over recent years. The ability to provide reliable assessments depends on the data collection scheme providing sufficient information to support estimation of, for example, recruitment.

5. The dependence of the assessment on catch-rates (even after standardization) remains a concern given changes over time in, for example, fishing practices in the shark fishery. This problem can only be rectified if fishery-independent data begin to be collected systematically across the fishery. However, the use of fishery-independent data in stock assessment may take up to 5-7 years even if a program of fishery-independent surveys is started now.

6. Consideration should be given to including indices of abundance based on the ISMP program in future assessments.

21.7 References

Gelman, A, Carlin, J.B. Stern, H.S. and D.B. Rubin. 1995. Bayesian data analysis. Chapman and Hall. London.

Geweke, J. 1992. Evaluating the accuracy of sampling-based approaches to the calculation of posterior moments. p. 169–193 *in* J.M. Bernardo, J. Berger, A.P. Dawid and A.F.M. Smith. [Ed.] Bayesian Statistics 4, Oxford University Press, Oxford.

Gilks, W.R., Richardson, S., and D.J. Spiegelhalter. 1996. Markov Chain Monte Carlo in Practice. Chapman and Hall, London.

Hastings, W.K. 1970. Monte Carlo sampling methods using Markov chains and their applications. *Biometrika* 57: 97–109.

Heidelberger, P. and P.D. Welch. 1983. Simulation run length control in the presence of an initial transient. *Operations Research* 31: 1109–1144.

Kirkwood, G.P. and T.I. Walker 1986. Gill net mesh selectivities for gummy shark, *Mustelus antarcticus* Günther, taken in south-eastern Australian waters. *Australian Journal of Marine and Freshwater Research* 37: 689–697.

Pribac, F. and A. Punt. 2005. A note on gummy shark RBCs for 2006 to 2025. In: Tuck, G.N. (Ed.) 2006. Stock assessment for the southern and eastern scalefish and shark fishery 2005-2006. AFMA and CSIRO Marine and Atmospheric Research, Hobart. p278-286.

Punt, A.E. and T.I. Walker. 1998. Stock assessment and risk analysis for the school shark (*Galeorhinus galeus*) off southern Australia. *Marine and Freshwater Research* 49: 719–731.

Punt, A.E., Pribac, F., Walker, T., Gason, A. and G. Fay. 2004. Stock assessment of gummy shark (*Mustelus antarcticus*) based on data up to 2003.. In: G.N. Tuck, and A.D.M. Smith (Eds.). Stock Assessment for the South East and Southern Shark Fishery. FRDC report 2001/005. p121–198.

Raftery, A.E. and S. Lewis. 1992. How many iterations in the Gibbs sampler? p. 763–773. In: J.M. Bernardo, J. Berger, A.P. Dawid and A.F.M. Smith. [Ed.] Bayesian Statistics 4, Oxford University Press, Oxford.

Taylor, B.L., Punt, A.E., Walker, T.I. and C. Simpfendorfer. 1996. Catches of school shark *Galeorhinus galeus* (1927 - 1994). SharkFAG Document *SS/96/D7*.

Walker, T.I. 1994a. Fishery model of gummy shark, *Mustelus antarcticus*, for Bass Strait. p. 422–438 *in* I. Bishop, editor. Resource Technology '94 New Opportunities Best Practice, The Centre for Geographic Information Systems & Modelling, The University of Melbourne, Melbourne.

Walker, T.I. 1994b. Stock assessments of the gummy shark, *Mustelus antarcticus* Günther, in Bass Strait and off South Australia. p. 173–187 *in* D.A. Hancock, editor. Population Dynamics for Fisheries Management, Australian Society for Fish Biology Workshop Proceedings, Perth 24–25 August 1993, Australian Society for Fish Biology, Perth.

Walker, T.I., Moulton, P.L. and S.R. Saddlier 1989. Reproduction studies of four species of shark and one species of elephant fish commercially fished in southern Australia. Southern Shark Assessment Project – Final FIRTA Report, Marine and Fisheries Resources Institute, Queenscliff.

Xiao, Y., Brown, L.P., Walker, T.I. and A.E. Punt. 1999. Estimation of instantaneous rates of tag shedding for school shark, *Galeorhinus galeus*, and gummy shark, *Mustelus antarcticus*, by conditional likelihood. *Fishery Bulletin, US*. 97: 170–184.

Table 21.1. Estimates of catch (carcass weight, tonnes) by sub-region, year and gear-type for 1927–72 for the directed shark fisheries and the Commonwealth non-trawl fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1927				1		1			1
1928				1		1			1
1929				4		4			8
1930				2		2			3
1931				2		2			5
1932				3		3			6
1933				30		30			61
1934				17		17			34
1935				30		30			60
1936				57	5	35			97
1937		0	0	64	12	39			116
1938		1	1	54	15	59			129
1939		0	0	48	40	64			153
1940		1	1	71	40	57			171
1941		7	7	76	50	114			254
1942		9	9	58	77	94		15	260
1943		23	23	60	133	112		14	364
1944	8	39	37	46	126	120		31	407
1945	16	16	14	65	107	107		47	372
1946	42	12	8	67	79	144		55	406
1947	26	21	18	75	88	161		76	465
1948	27	13	12	63	128	189		63	495
1949	31	23	11	52	105	282		48	552
1950	22	45	29	53	123	216		24	511
1951	27	30	6	30	90	160		18	361
1952	29	11	4	40	129	182		41	436
1953	115	17	17	49	148	248		41	635
1954	110	12	12	26	96	129		31	415
1955	136	17	10	49	108	146		25	490
1956	181	60	41	60	112	119		13	586
1957	84	109	94	38	80	83	5	39	533
1958	70	91	79	41	69	83	3	26	462
1959	69	89	77	36	84	82	5	44	486
1960	63	82	71	42	147	111	12	97	623
1961	58	76	66	51	148	125	11	89	623
1962	75	98	85	80	120	158	5	37	658
1963	90	117	102	106	134	201	3	26	779
1964	78	101	88	117	138	217	3	20	762

(Table 21.1 Continued)

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1965	153	60	32	37	116	212	0	13	624
1966	223	88	47	82	135	151	4	13	743
1967	269	106	56	52	142	206	23	25	879
1968	227	89	47	55	145	163	15	41	782
1969	212	83	45	47	194	92	2	26	701
1970	13	24	20	24	193	149	7	23	453
1971	14	26	22	13	47	109	19	7	256
1972	8	14	12	3	34	49	13	6	138

(b) Mesh catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1965					28	64			92
1966				0	31	79			111
1967				0	68	148			217
1968				3	84	290	0	24	400
1969				43	88	495	3	125	753
1970	161	107	28	48	41	151	3	20	558
1971	173	116	30	56	133	241	4	15	768
1972	94	62	16	90	396	526	11	15	1211

Table 21.2. Estimates of catch (carcass weight, tonnes) by sub-region, year and gear-type for 1973–2005 for the directed shark fisheries and the Commonwealth non-trawl fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1973	20	17	17	0	23	47	1	8	133
1974	15	18	2	1	81	36	7	53	213
1975	2	14	4	11	106	11	24	40	211
1976	0	3	2	11	52	15	0	24	108
1977	10	7	5	8	43	54	14	26	168
1978	12	11	0	3	40	53	2	9	131
1979	10	2	1	4	50	47	5	13	132
1980	8	9	1	3	58	63	8	13	163
1981	9	12	1	2	33	60	5	12	132
1982	3	7	0	2	31	23	2	17	85
1983	8	5	0	4	26	39	16	8	105
1984	2	28	3	9	25	66	17	41	191
1985	4	11	3	10	53	57	16	37	193
1986	4	10	6	5	34	56	15	28	159
1987	4	14	5	2	18	63	15	34	155
1988	8	16	6	6	15	49	25	37	160
1989	11	25	23	13	48	76	30	25	251
1990	12	24	2	4	30	37	23	44	175
1991	23	53	24	17	56	72	8	47	300
1992	20	64	30	20	77	83	77	22	392
1993	23	45	23	9	97	78	76	39	389
1994	15	55	6	2	48	26	31	31	213
1995	9	35	4	3	5	28	1	0	86
1996	10	22	3	8	15	25	2	4	88
1997	14	21	2	2	15	36	1	4	93
1998	16	23	2	1	19	24	1	9	95
1999	31	38	3	0	4	49	2	5	131
2000	16	21	2	1	2	101	1	4	148
2001	21	16	2	0	7	52	1	3	102
2002	2	7	6	2	9	33	3	2	64
2003	1	8	7	1	15	31	2	6	72
2004	2	8	2	0	8	23	0	2	46
2005	2	10	1	0	6	15	1	3	38

(Table 21.2 Continued)

(b) Mesh catches

Year	Sub-region								Total
	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	
1973	30	135	25	95	350	942	15	67	1658
1974	44	73	36	87	206	748	10	84	1286
1975	23	86	24	108	190	559	0	12	1002
1976	7	68	33	101	178	550	3	54	995
1977	13	114	53	69	275	567	8	53	1154
1978	18	100	43	46	295	472	3	81	1058
1979	21	132	40	32	234	401	9	67	937
1980	46	213	28	25	282	434	17	99	1145
1981	36	196	41	35	317	508	9	83	1226
1982	49	196	22	50	461	546	15	51	1389
1983	48	169	18	27	335	689	21	39	1348
1984	62	313	15	15	260	661	31	106	1463
1985	47	302	50	19	219	659	70	107	1473
1986	24	363	55	20	275	698	40	83	1559
1987	58	398	51	29	331	547	48	82	1543
1988	46	474	43	30	268	523	20	109	1514
1989	58	464	60	28	289	682	14	104	1699
1990	55	394	77	22	299	525	21	77	1470
1991	75	265	71	54	348	493	18	69	1393
1992	74	281	37	36	355	572	21	84	1460
1993	46	283	72	36	408	727	36	118	1726
1994	64	286	69	45	335	515	34	112	1460
1995	49	308	42	84	494	559	17	97	1650
1996	96	355	46	43	280	526	14	124	1484
1997	111	446	62	63	252	394	23	77	1428
1998	95	339	26	50	166	587	14	79	1356
1999	76	368	37	53	214	760	19	85	1611
2000	85	319	27	55	146	794	13	66	1505
2001	79	236	33	51	154	973	15	54	1595
2002	70	236	50	72	228	672	18	88	1435
2003	116	295	36	53	238	679	21	81	1519
2004	89	299	49	52	233	662	19	108	1510
2005	88	305	44	61	210	614	21	73	1416

Table 21.3. Reported catches (kg) by SETF and GABTF trawlers of gummy shark by year and sub-region.

(a) SETF

Year	Sub-region								Total
	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
1985	0	131	154	214	2309	0	0	2023	4831
1986	0	2875	1649	310	9329	80	298	9829	24370
1987	0	215	15	0	3001	0	65	9798	13094
1988	0	60	0	0	2561	60	650	6924	10255
1989	0	241	0	90	6179	0	50	7077	13637
1990	0	240	635	30	4306	0	1012	6700	12923
1991	0	141	122	35	4682	190	281	8548	13998
1992	9	4195	2203	772	10979	890	3642	5900	28590
1993	0	2542	1324	1290	12932	683	2240	8297	29306
1994	9	4905	2916	464	10791	587	1634	11367	32674
1995	246	3294	1159	583	8031	1277	1218	7745	23553
1996	47	3103	1949	395	14664	69	1701	11591	33520
1997	20	3383	1953	470	15379	107	1488	10891	33691
1998	0	2975	1838	307	21420	76	889	9823	37328
1999	5	4920	1645	478	24373	65	1180	7322	39988
2000	0	10792	1751	530	26155	500	1915	8832	50475
2001	1	8695	958	173	25952	393	3535	7064	46771

(b) GABTF

Year	Sub-region								Total
	WA	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WBas	
1987	0	0	205	0	0	0	0	0	205
1988	1255	0	1591	0	0	0	0	0	2846
1989	1472	1744	120	0	0	0	0	0	3336
1990	1510	6386	285	0	0	0	0	0	8181
1991	4864	12055	170	0	0	0	0	0	17089
1992	2365	5115	10	0	0	0	0	0	7490
1993	2546	2446	40	0	0	0	0	0	5032
1994	2351	2320	27	0	0	0	0	0	4698
1995	6460	8065	18	0	0	0	0	0	14543
1996	10267	7361	35	0	0	0	0	0	17663
1997	11401	8089	17	0	0	0	0	0	19507
1998	7167	6231	16	0	0	0	0	0	13414
1999	5668	6111	213	0	0	0	0	0	11992
2000	4107	8015	36	0	0	0	0	0	12158
2001	11649	9904	0	0	0	0	0	0	21583

(Table 21.3 Continued)

(c) SETF and GABTF

Year	Sub-region										Total
	WA	WSA	CSA	SAV-W	SAV-E	WBas	EBas	WTas	ETas	NSW	
2002	11048	7965	12	6953	898	674	25934	698	9508	10970	74658
2003	17730	21049	56	3741	1326	650	20893	1428	10236	13012	90119
2004	24402	22808	187	5938	1042	1343	22498	886	9310	11681	100095
2005	33302	47974	63	4728	1951	1390	24904	660	9746	13236	137955

Table 21.4. The standardized catch-rate indices for Bass Strait, South Australia, and Tasmania.

Year	Bass Strait	South Australia	Tasmania
1976	95.17		
1977	87.30		
1978	86.21		
1979	72.95		
1980	73.89		
1981	72.92		
1982	88.78		
1983	75.82		
1984	64.76	56.96	
1985	56.44	60.48	
1986	63.48	32.10	
1987	52.45	21.50	
1988	59.61	35.35	
1989	70.89	48.12	
1990	72.97	34.19	70.71
1991	72.84	33.51	80.64
1992	100.00	33.75	84.13
1993	91.22	31.49	78.98
1994	76.04	35.97	100.00
1995	89.95	29.14	97.50
1996	66.78	54.80	65.48
1997	46.89	65.76	80.96
1998	56.17	55.64	85.79
1999	64.01	54.15	80.39
2000	59.95	74.49	75.03
2001	74.75	100.00	94.09
2002	62.62	81.79	84.89
2003	59.26	70.49	96.69
2004	64.72	72.20	90.24
2005	69.39	95.06	66.00

Table 21.5. The tag-types represented in the tagging database. The column 'direct' indicates whether the double-tagging experiments can be used to estimate tag-shedding rates for the tag-type concerned. The columns '#rel' and '#rec' contain the total number of gummy sharks released and recaptured, respectively. Note that the total number of releases in this table exceeds the actual number (see row 'total') because some fish were double-tagged. An asterisk indicates a tag-type for which the tag-shedding rate is assumed to be 1 (i.e. no tags are shed).

Tag-type	Years	Details	#Rel	#Rec	Direct
Nesbit (S-tag)	1942-56	Internal — 35mm long, 10mm wide	98	5	Yes*
Nesbit (L-tag)	1942-56	Internal — 50mm long, 22mm wide	488	52	Yes*
W-tag	1942-56	External — white Peterson disc (16mm diameter, 1mm thick)	58	2	No
G-tag	1942-56	External — gray Peterson disc (16mm diameter, 1mm thick)	306	26	No
Roto	1987-02	External — 36 mm long, 9 mm wide	3061	765	Yes
Jumbo	1993-96	External — 45 mm long, 18 mm wide	1869	709	Yes
Mini	1995-96	External — 21 mm long, 5 mm wide	78	3	No
Dart – muscle	1991-96	External — 95 mm long, 2 mm diameter	1779	355	Yes
Dart – fin	1991-96	External — 95 mm long, 2 mm diameter	1260	194	Yes
Steel	1993-96	External — 140 mm long, 2 mm diameter	78	7	No
T-Bar	1986-90		84	7	No
A-Int	1994-96	Dummy archival tag – internal	5	1	No
A-Block	1994-96	Dummy archival tag – block	1	1	No
A-Torp	1994-96	Dummy archival tag – torpedo	4	1	No
Nesbit (MAFRI)	1973-76	Internal – white (equivalent to S-tag)	89	7	Yes*
Nesbit (MAFRI)	1973-76	Internal – yellow (equivalent to J / L tags)	1436	373	Yes*
Total			9595	2181	

Table 21.6. Tag-shedding rates for gummy shark (yr^{-1}) with asymptotic standard errors in parenthesis. Results are shown separately for males and females. The column '$-\ell nL$' lists the negative of the logarithm of the likelihood function corresponding to the estimates provided.

	N	Jumbo / Roto / Dart (fin)	Dart (muscle)	$-\ell nL$
Males	136	0.135 (0.036)	0.589 (0.091)	125.65
Females	156	0.066 (0.026)	0.811 (0.106)	120.28
Both	294	0.106 (0.023)	0.712 (0.070)	252.60

Table 21.7. Results of the base-case assessment and those of the sensitivity tests. The values in square parentheses are 95% probability intervals.

Scenario	Pup_0			M_2	*MSYR*			Pup_{73} / Pup_0 (%)			Pup_{07} / Pup_0 (%)			$-\ell nL$
	BS	SA	TAS	(yr^{-1})	BS	SA	TAS	BS	SA	TAS	BS	SA	TAS	
Base-case	3719 [2727, 4627]	2812 [2071, 3516]	763 [528, 977]	0.231 [0.203, 0.266]	0.162	0.175	0.162	60.2 [56.0, 66.8]	64.2 [58.2, 72.1]	87.6 [82.9, 93.2]	44.1 [39.6, 59.1]	33.7 [25.9, 51.7]	74.0 [68.3, 83.2]	812.3
Dens-dep M (ages 0-4)	5513	4160	1179	0.179	0.155	0.168	0.155	51.8	54.1	83.9	27.9	20.4	61.9	816.8
Dens-dep pups	4637	3812	942	0.176	0.113	0.104	0.113	53.9	55.3	86.4	29.1	16.1	68.2	812.6

22. Implications of a Change to the Mix of Gear-Types Used When Fishing for Gummy Shark

André E. Punt[1] and Terry I. Walker[2]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia
[2] Marine and Freshwater Systems, Department of Primary Industries, P.O. Box 114, Queenscliff, VIC 3225, Australia

22.1 RBCs for gummy shark

RBCs have been calculated for gummy shark in Bass Strait and off South Australia and Tasmania using the results of the 2006 stock assessment and the Tier 1 rule (Punt *et al*., Chpt 23). RBCs are presented in Punt *et al*. (Chpt 23) for three variants of the Tier 1 rule (20-40-40, 20-40-48 and 20-48-48). The RBC calculations for gummy shark are based on the following steps:

i) Determine the relative exploitation rates by gear-type. The assessment of gummy shark is based on five gear-types (longlines, and 6-inch, 6.5-inch, 7-inch and 8-inch gillnets); the relative exploitation rate among these five gear-types is assumed to be the same for 2007 as in 2006. This assumption is consistent with those made for other SESSF species for which there are multiple gear-types (e.g. blue warehou, tiger flathead, ling).
ii) Calculate the fraction by which the relative exploitation rates must be changed so that the stock will equilibrate at the target level (40% or 48% of the unfished pup production) if recruitment is related deterministically to the number of pups produced (the "exploitation rate multiplier").
iii) Reduce the "exploitation rate multiplier" if the pup production at the start of 2007 is predicted to be below the threshold at which the exploitation rate needs to be reduced (40% of the unfished pup production for the 20-40-40 and 20-40-48 variants and 48% of the unfished pup production for the 20-48-48 variant).
iv) Multiply the gear-specific exploitable biomasses by the relative exploitation rates by gear-type and by the "exploitation rate multiplier" to obtain gear-specific RBCs.
v) Sum the gear-specific RBCs to determine the total RBC.

It should be noted that the gear-type "longline" includes catches by longlines as well as by trawl because selectivity patterns are not available for trawl gear, and because the range of sizes taken using longlines is the broadest of all the gear-types for which information on selectivity is available and trawls take a fairly wide range of sizes of gummy shark.

To determine the impact of some of the catch being taken using auto-longlines, the RBC calculations were repeated increasing the relative exploitation rate for

longlines (see step i) above). Figure 22.1 plots the 2007 RBC (solid line) and the 2046 RBC (dashed line) against the proportion of the catch assumed to be taken by the gear for which the selectivity pattern is set to that assumed for longlines ("proportion by non-gillnet"). The calculations in Figure 22.1 are based on the 20-40-40 variant of the Tier 1 rule because the TAC recommended by SharkRAG was put forward based on this variant. The 2046 RBC is included in Figure 22.1 as a proxy for the long-term (equilibrium) yield once the stock reaches the target level. The results in Figure 22.1 are based on the assumption that only catches by 6"-inch and 6.5" mesh gear are impacted by "behavioural selectivity", where there is a tendency to target middle-sized gummy shark on grounds where small and very large sharks are least abundant. The 2046 RBC exceeds the 2007 RBC if the stock is currently assessed to be below the target level for the 20-40-40 variant of the Tier 1 rule of 40% of the unfished pup production. Note that the 2046 RBC should be interpreted with some caution because gummy shark recruitment is variable and so the stock is unlikely ever to be exactly in equilibrium.

There is a declining trend in the 2007 (and 2046) RBC with an increasing proportion of the catch taken by gears other than gillnet (such as trawls and longlines). This trend occurs because, given the selection pattern of longline gear (which takes a higher proportion of juveniles and older animals than gillnets), one unit of catch by longline has a larger impact on pup production than one unit of catch by 6-inch and 6.5-inch mesh gillnets (i.e. this is a yield-per-recruit effect).

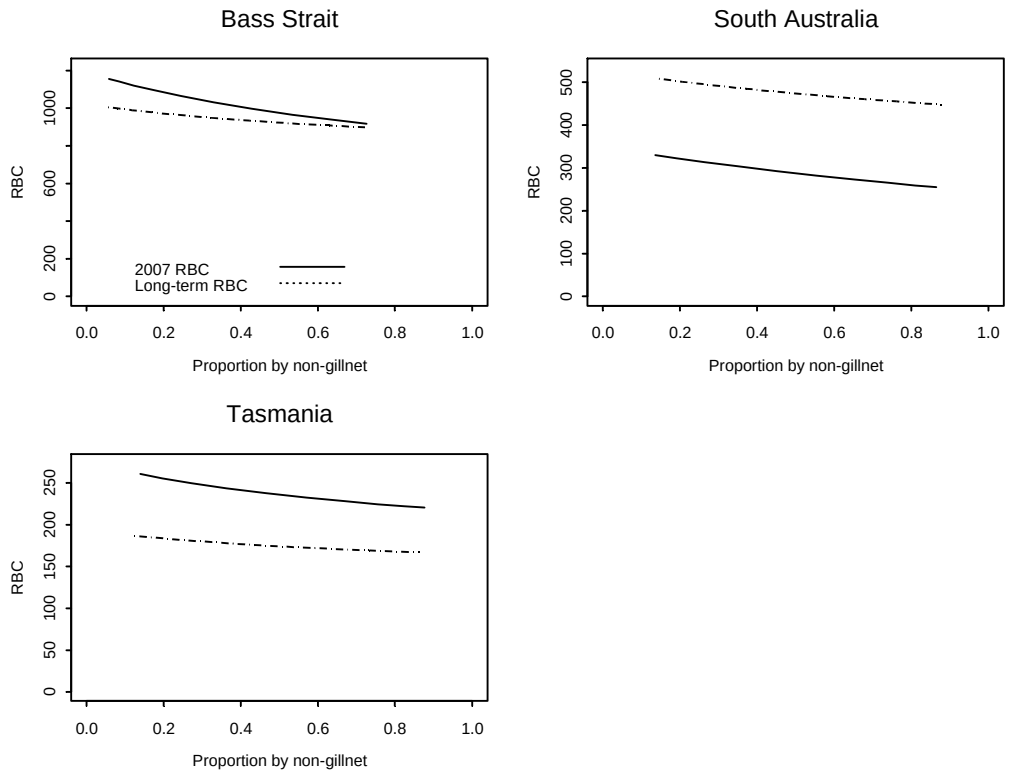


Figure 22.1. 2007 and 2046 RBCs for gummy shark by region under the 20-40-40 variant of the Tier 1 rule versus the proportion of the catch taken by gears other than gillnet.

22.2 Impact of the by-catch of school shark

The by-catch rate of school shark when fishing for gummy shark depends on gear-type and region (Table 22.1). The values in Table 22.1 were calculated using logbook data from 1999–2005. The results in Table 22.1 confirm that the ratio of school to gummy shark has been declining over the last seven years.

Figure 22.2 plots the expected by-catch of school shark during 2007 (the gear-specific RBCs for 2007 multiplied by the school shark by-catch rate (kgs of school shark per kg of gummy shark)) as a function of the proportion of the catch taken using gear-types other than gillnets. The ratios of school to gummy shark used for Figure 22.2 were calculated from the data for 2003–05 owing to the fairly small sample sizes for some gear-types for recent years, and the bycatch rates for gears other than gillnet are set to those for longlines. The calculations implicitly assume that the depth distribution of gear usage does not change markedly with a change to the mix of gear-types as there is a depth-dependence of school shark by-catch on depth.

School shark bycatch in Bass Strait and off Tasmania increases with an increase to the proportion of the total catch taken using gears other than gillnet because school shark bycatch rates for longlines are higher than for 6-inch mesh gear off Tasmania. In contrast, the bycatch of school shark off South Australia decreases with an increasing proportion of catch by gears other than longlines because the bycatch of school shark in 6.5-inch mesh exceeds that in longlines in Bass Strait.

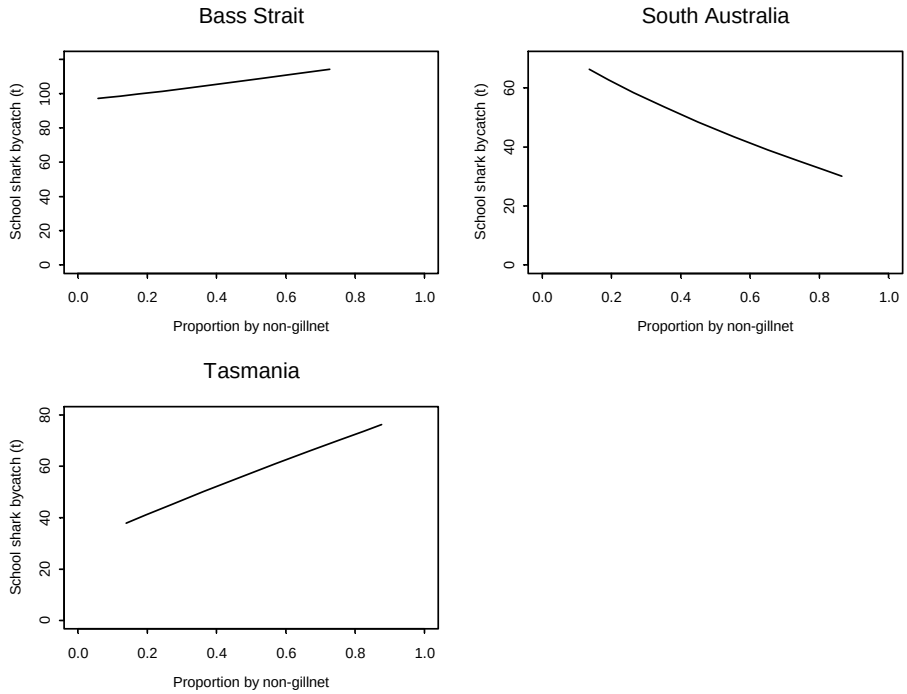


Figure 22.2. Estimated school shark by catch during 2007 as a function of the proportion of the catch taken by gears other than gillnet

Table 22.1. Catches of school and gummy shark by year, gummy shark region and gear-type (1999–2005).

	Bass Strait				South Australia				Tasmania			
Year	No shots	Gummy Catch	School Catch	Ratio	No shots	Gummy Catch	School Catch	Ratio	No shots	Gummy Catch	School Catch	Ratio
Longline												
1999	424	54251	8645	0.159	386	70797	21690	0.306	136	6114	9345	1.528
2000	647	102050	5285	0.052	350	39169	6784	0.173	84	4649	9079	1.953
2001	501	58772	3348	0.057	497	37725	3414	0.090	51	3944	3934	0.997
2002	267	41908	3125	0.075	219	16762	3294	0.197	47	5213	5034	0.966
2003	325	44590	11301	0.253	289	15032	2357	0.157	57	8967	3572	0.398
2004	195	30198	1560	0.052	255	11969	1020	0.085	35	2344	1778	0.759
2005	141	21416	707	0.033	289	12923	734	0.057	23	3377	229	0.068
6.5-inch mesh												
1999	32	5459	134	0.025	6392	384716	148232	0.385	0	0	0	0.000
2000	141	15992	17637	1.103	4499	379228	84097	0.222	0	0	0	0.000
2001	95	10265	8629	0.841	4099	300362	85043	0.283	166	11431	22543	1.972
2002	68	9275	11229	1.211	3782	299462	51979	0.174	40	4250	2647	0.623
2003	126	12339	1087	0.088	4089	361945	89743	0.248	16	3312	5749	1.736
2004	179	16795	884	0.053	4271	355614	76566	0.215	2	500	0	0.000
2005	192	15404	1168	0.076	3827	361664	90745	0.251	3	130	11	0.085
6-inch mesh												
1999	6969	995025	119505	0.120	657	68275	7536	0.110	1040	103540	70153	0.678
2000	6588	910895	59550	0.065	970	74953	8820	0.118	684	64609	25800	0.399
2001	5884	1109033	39082	0.035	1070	86638	11165	0.129	493	62765	7448	0.119
2002	5915	879760	64012	0.073	1422	121785	21217	0.174	678	101214	20203	0.200
2003	6517	926788	61269	0.066	786	56047	6659	0.119	803	90407	13229	0.146
2004	5979	869577	70163	0.081	610	56013	4519	0.081	854	115859	6998	0.060
2005	5468	859000	82765	0.096	677	64985	6327	0.097	672	87476	11368	0.130

23. Stock Assessment of School Shark Based on Data Up To 2005[15]

André E. Punt[1], Fred Pibac[1], Terence I. Walker[2], and Anne S. Gason[2]

[1]CSIRO Marine Research, GPO Box 1538, Hobart, TAS 7001, Australia
[2]Marine and Freshwater Systems. Primary Industries Research Victoria,
Box 114, Queenscliff, VIC 3225, Australia

23.1 Abstract

The 2001 stock assessment of school shark is updated based on catch data from 2000-2005, new tagging data, and catch-rate indices of relative abundance based on ISMP sampling on trawl vessels. The results of this assessment provide no evidence for an increase in the abundance of school shark since 2000, although there is some evidence that the biomass and pup production have stabilized. Pup production in 2005 is estimated to have been below 20% of the pre-fishery pup production, so the Recommended Biological Catch under both the Tier 1 and Tier 2 rules is zero.

23.2 Introduction

The most recent stock assessment of the school shark resource off southern Australia was conducted in 2001 (Punt and Pribac, 2001) based on data up to the end of 1999. This assessment was, following Punt *et al*. (2000), based on a spatially-structured population dynamics model fitted to data on catches, catch-rates, tag release-recapture data, mean catch lengths and the sex-ratios of the annual catches. The 2001 assessment examined the sensitivity of the results to accounting for the movement of school sharks from New Zealand to Australia.

Only a few data that can be used to update the stock assessment of school shark have been collected since 2001. Specifically, although the catch and effort data can be standardized to produce an index of relative abundance (e.g. Punt and Gason, Chpt 20), little faith can be placed in this index for the years since 2000 owing to changes in targeting practices. Moreover, changes in catches now mean that standardized catch-rates cannot be estimated for more year-cell combinations than in the past. In principle, the data on the length-frequency of the catch provides some information on stock trends, but only a few school sharks have been measured since the last assessment in 2001. The only data source that has the promise of providing a useable index of abundance is the ISMP programme. The results from this programme can be used to determine standardized indices of abundance for parts of the fishery based on catches of school sharks by trawlers.

This document therefore updates the 2001 assessment of school shark by incorporating the catches that have been recorded since 2000 (Table 23.1 to Table 23.3) using the latest tagging information (although the tagging information is virtually unchanged from

[15] Paper presented to the Shark Resource Assessment Group in August, 2006

that on which the 2001 assessment was based; Table 23.4 and indices of relative abundance from the ISMP programme. Note that the catches for 2005 do not include State catches and no information is available on catches off Western Australia and by NSW State vessels. Data for Western Australia and NSW were included in past stock assessments of school shark. Although catch-rate indices are available for the period 2000-2005 (Punt and Gason, 2006), these catch-rates are not included in this assessment for the reasons outlined above – rather this stock assessment is based on the catch-rates indices used for the 2001 assessment.

23.3 Method

The ISMP indices of relative abundance (Table 23.5 and Figure 23.1) were developed by applying the delta method (Lo et al., 1992; Stefánsson, 1996). The probability of a non-zero catch was modeled using the binomial distribution while the non-zero catch rates were modeled assuming a log-gamma error structure (the log-gamma error structure fits the data better than the normal distribution and, unlike the normal error structure, never leads to negative indices of abundance). The model adopted to standardize the non-zero catch rates is:

$$\text{Log(CPUE)} = \text{Year} + \text{Month} + \text{LongLat} + \text{Depth} + \text{Vessel} + \varepsilon$$

where CPUE is catch divided by area swept, weighted by habitat area,
Month is calendar month,
Longlat is 1^0 longitude band for the areas west of 147^0E and 1^0 latitude band for the area east of 147^0E,
Depth is a categorical variable denoting depth classes (only data within the depth range 80-600m were considered in the analyses on which Table 23.5 was based), and
ε is log-gamma error term.

Three indices of relative abundance are provided in Table 23.5a) school shark taken by the SETF west of 147^0E (1994-2005), b) school shark taken by the GABTF (2000-2005), and c) school shark taken by the SETF east of 147^0E (1994-2005).

The three indices of abundance in Table 23.5 were included in the stock assessment by assuming that the "West" series pertains to the SharkRAG regions Central South Australia, South Australia-Victoria, Western Bass Strait and Western Tasmania, the "East" series pertains to the SharkRAG regions Eastern Bass Strait and Eastern Tasmania, and the "Far West" series pertains to the SharkRAG region Western South Australia. The indices of abundance have associated confidence intervals (Figure 23.1). However, these measures of precision were ignored when fitting the model; rather the model was permitted to estimate the variance between the model predictions and the indices. The ISMP-based indices of relative abundance are assumed to relate to the biomass available to longline gear. This is because, of the gear-types included in the stock assessment for school shark, longlines capture the broadest range of sizes and because, when conducting stock assessments for school and gummy shark, the selectivity pattern for the trawl catches is assumed to the same as that for the longline catches (in the absence of experimental data to estimate a selectivity pattern for trawl).

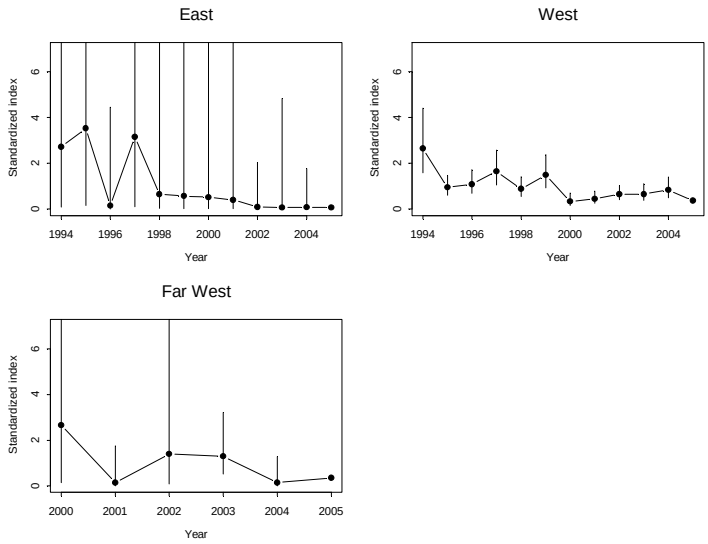


Figure 23.1. Standardized indices of school shark abundance with asymptotic 95% confidence intervals. The indices have been scaled to average 1 for presentational simplicity.

23.4 Results and Discussion

23.4.1 Diagnostic fits

Figure 23.2 shows the fits of the model to the catch-rate series and Figure 23.3 shows the fits to the tagging data. The model is able to mimic the tag-recaptures very well and is generally able to follow the trends in abundance inferred from the catch-rates. One exception to this is the fit to the data for the WBas region where the model predicts a decline in abundance which has not been observed. The same pattern was evident in the 2001 assessment (see Figure 1 of Punt and Pribac (2001)). The fits to two of the three ISMP-based indices ("East" and "Far West") are very poor, but this is not unexpected given the considerable uncertainty associated with these indices (see Figure 23.1). Results are not shown for the fits to the mean length and sex ratio data as these are virtually identical to those reported by Punt and Pribac (2001).

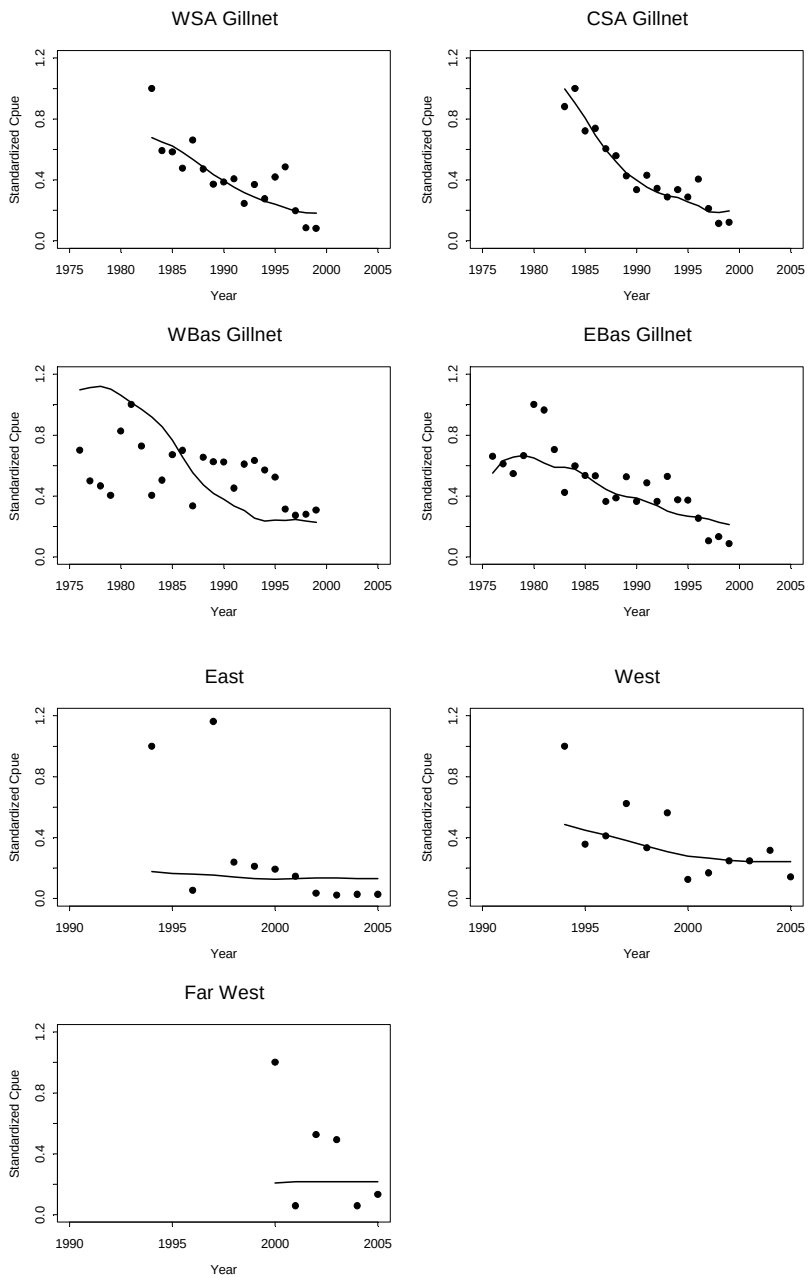


Figure 23.2. Observed and model-predicted catch-rates.

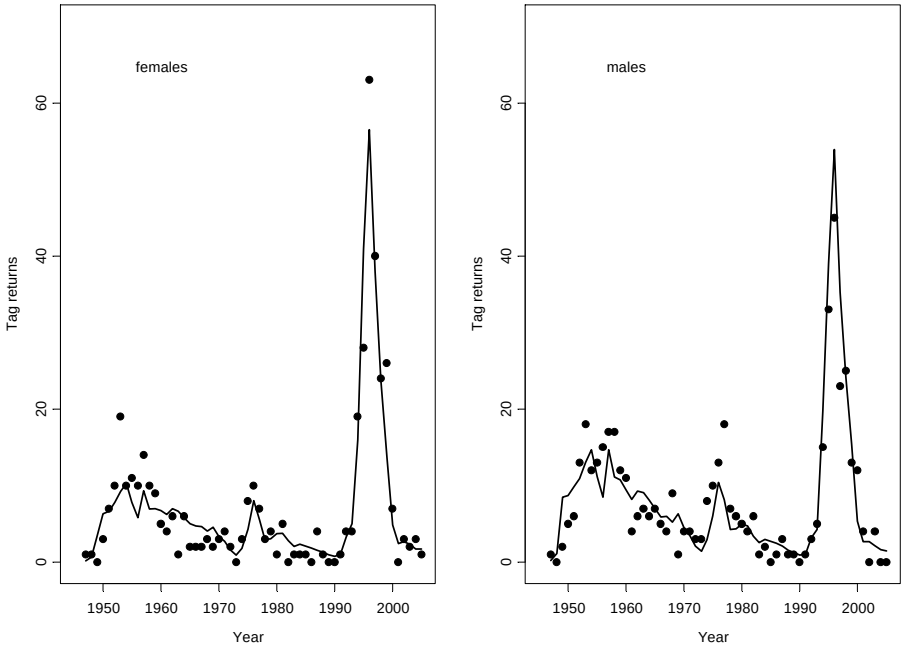


Figure 23.3. Observed and model-predicted tag-recapture numbers. Results are shown for females and males in the left and right panels respectively.

23.4.2 Stock status

Figure 23.4 shows the time-trajectories of 1+ biomass and pup production (in absolute terms and expressed as a percentage of that in 1927). The lower panels indicate the target level for the Commonwealth harvest policy (48% of the virgin spawning biomass) and B_{lim} (solid and dotted horizontal lines respectively). The size of the school shark resources is estimated to somewhat larger in the 2006 assessment than in the 2001 assessment, but there is little evidence for an increase in abundance since 2000.

23.4.3 Application of the Tier rules

The results of the present assessment suggest that pup production (the "reproductive potential" of the population and hence the closest analogy to spawning stock biomass) was below 20% of the estimated virgin level at the end of the period considered (2005). Under the Tier 1 (and Tier 2) rules, the Recommended Biological Catch for school shark is therefore estimated to be zero.

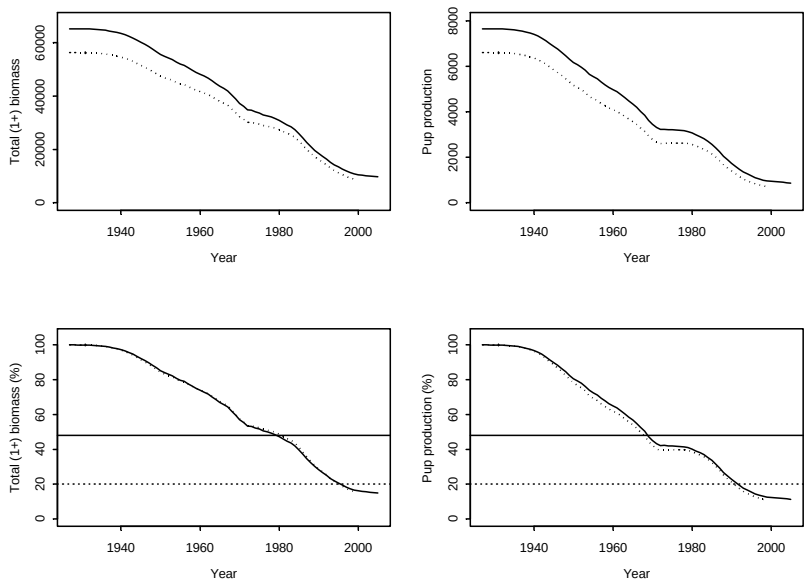


Figure 23.4. Time-trajectories of 1+ biomass (left panels) and pup production (right panels) in absolute terms (upper panels) and expressed as a percentage of that in 1927 (lower panels). The results for the 2006 assessment are shown by solid lines and those for the 2001 assessment by dotted lines.

23.5 References

Lo, N.C., Jacobson, L.D. and J.L. Squires. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences 49: 2515–2526.

Punt, A.E. and F. Pribac. 2001. An assessment of school shark for 2001. SharkFAG Document SharkFAG/01/D03 (16pp).

Punt, A.E., Pribac, F., Walker, T.I., Taylor, B.L. and J.D. Prince. 2000. Stock assessment of school shark Galeorhinus galeus based on a spatially-explicit population dynamics model. Marine and Freshwater Research 51: 205–220.

Punt, A.E. and A.S. Gason. 2006. Revised standardized catch-rate series for school and gummy shark based on data up to 2005. Document presented the 18 August 2006 meeting of SharkFAG (18pp).

Stefánsson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES Journal of Marine Science 53: 577–588.

Table 23.1. Estimates of catch (carcass weight, tonnes) by region, year and gear-type for 1927–72 for the Southern Shark Fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Region							Total
	WSA	CSA	SAV	WBas	EBas	WTas	ETas	
1927	0	0	1	0	1	0	0	2
1928	0	0	2	0	2	0	0	4
1929	0	0	9	0	9	0	0	18
1930	0	0	4	0	4	0	0	8
1931	0	0	6	0	6	0	0	12
1932	0	0	7	0	7	0	0	14
1933	0	0	72	0	72	0	0	144
1934	0	0	40	0	40	0	0	80
1935	0	0	71	0	71	0	0	142
1936	0	0	134	13	82	0	0	229
1937	0	1	153	28	91	0	0	273
1938	0	1	129	36	140	0	0	306
1939	0	0	115	94	152	0	0	361
1940	0	4	172	95	135	0	0	406
1941	0	17	196	119	269	0	0	601
1942	0	20	157	182	222	0	35	616
1943	0	54	195	314	265	0	32	860
1944	18	92	197	298	284	0	74	963
1945	39	38	186	254	254	0	111	882
1946	99	29	178	188	340	0	129	963
1947	63	49	219	208	381	0	181	1101
1948	64	31	177	304	447	0	149	1172
1949	74	55	150	249	667	0	113	1308
1950	52	106	195	290	512	0	56	1211
1951	63	71	86	213	378	0	43	854
1952	57	21	89	256	362	0	82	867
1953	194	29	113	250	419	0	69	1074
1954	357	39	124	311	419	0	101	1351
1955	255	32	110	201	273	0	46	917
1956	264	89	148	164	174	0	19	858
1957	189	137	251	356	358	22	145	1458
1958	150	109	233	299	346	14	90	1241
1959	144	105	212	329	326	21	137	1274
1960	138	101	178	312	270	24	158	1181
1961	129	94	211	276	321	12	81	1124
1962	166	121	290	331	435	9	62	1414
1963	198	144	318	348	457	10	66	1541
1964	171	124	317	363	485	10	63	1533
1965	224	88	189	342	535	8	42	1428
1966	327	128	195	362	341	15	50	1418
1967	395	155	174	372	448	55	75	1674
1968	335	131	245	405	351	88	131	1686
1969	318	125	269	650	507	40	103	2012
1970	20	36	113	428	423	40	77	1137
1971	21	38	68	230	230	40	52	679
1972	16	28	65	73	156	36	24	398

(Table 23.1Continued)

(b) Mesh catches

Year	Region							Total
	WSA	CSA	SAV	WBas	EBas	WTas	ETas	
1965	0	10	0	7	9	0	0	26
1966	0	12	0	6	13	0	0	31
1967	0	13	0	13	28	0	0	54
1968	0	4	0	41	89	0	0	134
1969	0	4	0	48	242	35	47	376
1970	240	160	41	201	20	8	11	681
1971	253	187	41	403	61	3	14	962
1972	190	132	33	335	152	19	33	894

Table 23.2. Estimates of catch (carcass weight, tonnes) by region, year and gear-type for 1973–2005 for the Southern Shark Fishery (estimates for the four gill-net mesh sizes used in the fishery have been pooled).

(a) Longline catches

Year	Region							Total
	WSA	CSA	SAV	WBas	EBas	WTas	ETas	
1973	25	10	88	19	21	9	50	220
1974	23	36	77	44	31	50	93	355
1975	5	34	35	89	8	10	82	262
1976	0	13	16	52	15	24	128	248
1977	21	20	35	36	22	47	119	300
1978	11	36	14	76	45	13	57	252
1979	10	16	22	131	42	79	52	352
1980	7	51	20	145	103	122	28	477
1981	4	121	17	90	45	83	81	442
1982	2	63	3	54	13	30	44	209
1983	3	31	45	37	20	25	20	180
1984	0	50	72	32	36	124	107	422
1985	0	66	50	49	35	102	112	414
1986	0	17	80	34	66	132	129	459
1987	1	34	48	57	71	99	168	477
1988	6	13	53	27	59	41	52	252
1989	4	22	78	52	62	41	35	293
1990	3	24	29	40	27	88	84	294
1991	2	32	34	99	35	28	70	301
1992	1	19	36	88	34	137	56	370
1993	1	30	22	49	21	75	51	248
1994	1	28	22	24	11	65	15	166
1995	1	13	11	15	5	58	28	130
1996	1	15	10	10	6	3	10	55
1997	1	16	11	12	7	3	4	53
1998	2	18	11	10	3	1	7	52
1999	5	13	5	5	4	3	6	40
2000	1	4	3	3	3	6	3	22
2001	0	3	0	2	2	1	4	11
2002	0	1	3	2	1	2	3	12
2003	0	1	9	3	1	1	4	19
2004	0	1	0	1	1	2	0	5
2005	0	1	0	1	0	0	0	2

(Table 23.2 Continued)

(b) Mesh catches

Year	Region							Total
	WSA	CSA	SAV	WBas	EBas	WTas	ETas	
1973	58	191	56	34	98	20	17	474
1974	87	177	85	87	135	8	15	594
1975	47	215	45	99	264	0	0	671
1976	21	172	36	157	261	2	13	663
1977	28	207	50	150	154	31	11	630
1978	38	249	65	73	117	1	34	578
1979	58	251	52	84	130	11	42	628
1980	91	309	26	127	211	31	26	821
1981	55	427	31	146	210	14	82	965
1982	146	398	20	119	243	32	57	1014
1983	192	261	29	148	264	36	31	961
1984	104	392	21	184	291	125	85	1204
1985	152	395	32	203	385	217	161	1544
1986	194	483	35	200	378	129	115	1533
1987	302	504	42	201	181	108	97	1435
1988	438	359	28	205	251	53	90	1424
1989	262	400	46	210	198	53	38	1208
1990	259	330	23	178	137	34	41	1002
1991	234	326	23	165	149	42	20	958
1992	186	205	31	131	125	51	17	746
1993	181	247	34	154	155	33	50	853
1994	165	234	27	134	138	25	14	738
1995	179	213	40	99	121	16	16	683
1996	177	259	25	72	95	29	49	706
1997	160	256	38	68	44	44	35	645
1998	98	122	14	113	71	53	27	497
1999	51	102	10	83	35	38	33	350
2000	39	50	10	60	20	29	21	229
2001	31	58	10	27	23	8	3	159
2002	20	44	11	53	23	20	7	178
2003	29	69	9	40	21	13	2	182
2004	24	65	9	45	26	6	4	179
2005	25	70	11	44	35	11	3	198

Table 23.3. Reported catches (kg) by SETF and GABTF trawlers of school shark by year and SharkRAG region

Year	SharkRAG region								Total
	WSA	CSA	SAV	WBas	EBas	WTas	ETas	NSW	
1985	0	0	8459	888	3529	4668	2305	145	19994
1986	0	40	18230	1132	7718	3562	255	1580	32517
1987	472	135	3562	540	5442	1205	30	2559	13945
1988	4135	5064	2447	291	3885	2575	310	1666	20373
1989	4362	778	1063	2472	3616	5925	418	3483	22117
1990	7971	1483	3297	10480	2889	350	804	1392	28666
1991	6290	362	3347	486	3978	2583	426	1878	19350
1992	3087	91	7734	804	12942	1060	4286	7132	37136
1993	816	110	4600	993	15389	812	2665	9895	35280
1994	1235	321	9307	553	12842	699	1945	13527	40429
1995	2125	422	5300	694	9547	1520	1449	9216	30273
1996	5804	1680	8262	944	3172	3600	1721	2529	27712
1997	3497	2901	8986	892	2825	1129	1291	3061	24582
1998	3152	1168	3828	840	4318	3325	2185	3278	22094
1999	1647	648	3691	741	1365	4620	1199	1779	15690
2000	3608	51	3467	769	2129	4476	1565	3125	19190
2001	1497	135	2830	402	2768	6310	1046	1480	16468
2002	536	195	4673	1271	2107	5430	2533	810	17555
2003	825	92	4538	581	778	3965	2132	576	13487
2004	1138	646	4805	446	2509	2832	1470	302	14148
2005	2389	273	3108	500	829	1088	1165	442	9794

Table 23.4. The tag-types represented in the tagging database. The column 'direct' indicates whether the double-tagging experiments can be used to estimate tag-shedding rates for the tag-type concerned. The columns '#rel' and '#rec' contain the total number of school sharks released and recaptured, respectively. Note that the total number of releases in this table exceeds the actual number (see row 'total') because some fish were double-tagged. An asterisk indicates a tag-type for which the tag-shedding rate is assumed to be 1 (i.e. no tags are shed).

Tag-type	Years	Details	#Rel	#Rec	Direct
Nesbit (S-tag)	1942-56	Internal — 35mm long, 10mm wide	1772	235	Yes*
Nesbit (L-tag)	1942-56	Internal — 50mm long, 22mm wide	1163	287	Yes*
W-tag	1942-56	External — white Peterson disc (16mm diameter, 1mm thick)	3259	114	No
G-tag	1942-56	External — gray Peterson disc (16mm diameter, 1mm thick)	2907	427	No
Roto	1987-02	External — 36 mm long, 9 mm wide	506	134	Yes
Jumbo	1993-96	External — 45 mm long, 18 mm wide	931	232	Yes
Mini	1995-96	External — 21 mm long, 5 mm wide	228	43	No
Dart – muscle	1991-96	External — 95 mm long, 2 mm diameter	590	96	Yes
Dart – fin	1991-96	External — 95 mm long, 2 mm diameter	438	83	Yes
Steel	1993-96	External — 140 mm long, 2 mm diameter	23	4	No
T-Bar	1986-90		27	3	No
A-Int	1994-96	Dummy archival tag – internal	65	23	No
A-Block	1994-96	Dummy archival tag – block	88	13	No
A-Torp	1994-96	Dummy archival tag – torpedo	82	16	No
Nesbit (MAFRI)	1973-76	Internal – white (equivalent to S-tag)	169	15	Yes*
Nesbit (MAFRI)	1973-76	Internal – yellow (equivalent to J / L tags)	459	102	Yes*
Total			9849	1291	

Table 23.5. The indices of abundance based on the application of the delta-method to the data from ISMP programme.

Year	**East**	**West**	**Far West**
1994	0.2602	1.3001	
1995	0.3373	0.4637	
1996	0.0142	0.5327	
1997	0.3020	0.8104	
1998	0.0622	0.4315	
1999	0.0546	0.7297	
2000	0.0497	0.1633	0.1200
2001	0.0383	0.2187	0.0066
2002	0.0091	0.3207	0.0631
2003	0.0064	0.3218	0.0585
2004	0.0069	0.4096	0.0066
2005	0.0068	0.1836	0.0159

24. A Note Regarding the Sensitivity of the School Shark Assessment to the Last Year for Which Catch-rate Data Are Used

André E. Punt[1]

[1]CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

SharkRAG requested an examination of the sensitivity of the results of the school shark assessment to the last year for which catch-rate data are included in the analysis. Figure 24.1 contrasts the time-trajectories of 1+ biomass and pup production for three assessment scenarios: a) the 2006 base-case assessment (Punt *et al.*, Chpt 23); b) the 2001 base-case assessment (Punt and Pribac, 2001), and c) a variant of the 2006 base-case assessment in which the catch-rate series based on standardizing the logbook catch and effort data are restricted to data up to 1997 only (see Figure 20.3 of Punt and Gason (Chpt 20))[16].

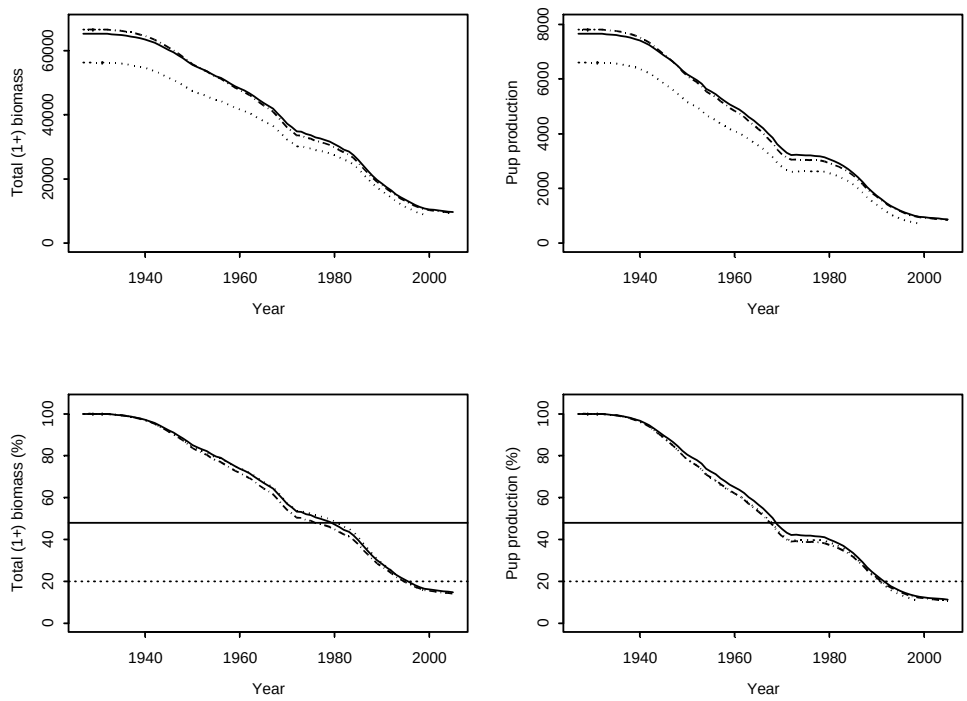


Figure 24.1. Time-trajectories of 1+ biomass (left panels) and pup production (right panels) in absolute terms (upper panels) and expressed as a percentage of that in 1927 (lower panels). The results for the 2006 base-case assessment are shown by solid lines, those for the 2001 base-case assessment by dotted lines, and those for the variant of the base-case assessment that uses logbook catch-rate data until 1997 by dashed lines.

24.1 References

Punt, A.E. and F. Pribac. 2001. An assessment of school shark for 2001. SharkFAG Document SharkFAG/01/D03 (16pp).

[16] This variant therefore uses all the recent catches and tagging information.

25. Stock Assessment of the Cascade Plateau Orange Roughy 2006[17]

Sally Wayte[1] and Nic Bax[1]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

25.1 Summary

This paper updates the quantitative assessment of the Cascade Plateau orange roughy population first performed in 2004. An integrated assessment model, with age- and sex-structured population dynamics was used. All available data have been included – catch records, length-frequency data from 1998-2004, age-frequency samples from 1999 and 2004, and the 2005 absolute acoustic biomass estimate. The changes from last year's assessment are: addition of catch data for 2005; use of the 2005 absolute acoustic biomass estimate instead of 2003 and 2004 estimates; and the software for conducting the assessment has been updated to Stock Synthesis 2 (SS2).

The 2005 acoustic biomass estimate is approximately three times higher than the 2003 and 2004 estimates, so clearly does not form a consistent series with the previous estimates. The difference between these biomass estimates is in keeping with qualitative observations from earlier surveys that have observed a substantial variability between seasons (Prince 2004). This means that we cannot use the acoustic estimates as a relative index (as is the case for the Eastern Zone), but include the largest observed biomass as an absolute biomass estimate. This requires making assumptions about target strength, absolute levels of retention time and proportion spawning, which are essentially assumed invariant and are therefore excluded from relative estimates., The large year-to-year variability observed in biomass estimates does raise questions about the ability of acoustic estimates to distinguish, in the short term, fishery induced changes from natural variability (Ryan 2006).

Three biomass estimates are used in the assessment – all other data remain constant. The base case assumes that any overestimates in acoustic biomass (eg. due to incorrect target strength) are balanced by assuming the largest observed bomass on one night represents the entire mature population. Alternative biomass estimates assume that acoustic biomass estimates are high by a factor of two, or that only 50% of the mature population is present on any one night. For the base case, current female spawning biomass is estimated to be 73 % of average unfished biomass, for the lowest biomass index this proportion is 62 %, and for the largest biomass index it is 82 %.

[17] Paper presented to the Deepwater Resource Assessment Group on 28 August, 2006

The recommended biological catches under three versions of the Tier 2 rule of the SESSF harvest strategy framework are calculated.The recommended biological catch for 2007 ranges from 283 t to 1,307 t for the three scenarios, and the three versions of the Tier 2 harvest control rule. We note that under the base case fishing at 50:50:20 results in 60% of spawning biomass being reached in 18 years, suggesting that a phased approach to the 60:60:20 rule may be possible for this fishery.

A comparison of the 2006 assessment results using the old software and using SS2 was performed. This comparison is reported in detail in Section 25.9, Appendix. The two assessments are extremely similar.

25.2 Introduction

25.2.1 The Fishery

Orange roughy inhabit deep, cold waters over steep continental slopes and oceanic ridges. In Australia, they occur in depths of 700 m to 1400 m, on the continental slope between Port Stephens in NSW and Cape Naturaliste in WA, and on the South Tasman Rise, the Cascade Plateau and the Lord Howe Rise (Kailola et al., 1993). Adult fish form dense winter spawning aggregations, commonly associated with submerged hills or pinnacles. They also form non-spawning aggregations. Orange roughy are slow-growing, long-lived and have low fecundity.

Orange roughy fisheries are generally high-value, targeted fisheries. Most of the Australian catches of orange roughy have occurred off southern and eastern Tasmania, at reliable spawning locations. Each spawning stock fishery appears to be based on a separate stock, and is thus managed separately.

The Cascade Plateau is a rocky seamount approximately 125 nautical miles ESE of Hobart, Tasmania. With a current total allowable catch (TAC) of 700 t, it is Australia's largest domestic orange roughy fishery. Initial fishing on the Plateau was in 1990 by foreign vessels that caught approximately 2,000 t of roughy. Substantial fishing did not occur again until 1996, when almost 1,000 t of orange roughy were caught. Since then, the Plateau has been fished consistently, subject to a TAC.

The Cascade Plateau fishery has been monitored since 1998 using funding from a voluntary industry levy – initially when a competitive TAC operated through a levy/kilo; subsequent to ITQs being introduced through 100 t of the TAC being set aside for research surveys. Biospherics Pty. Ltd. collected and analysed data on catches, length, weight, gonad staging, acoustic observations and environmental variables on industry-led surveys from 1999-2004. In 2003, Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau, using acoustic equipment on industry vessels that could be directly compared to standardised scientific equipment using standard CSIRO school identification and biomass estimation approaches. This survey was repeated in 2004, 2005, and 2006. From 2006, biomass estimates will only be worked up as they are informative to the assessment – ie. they are thought to either provide a larger absolute biomass estimate or start to show a consistent trend.

25.2.2 Previous Assessments

An analysis of catch per shot data from 1997 to April 2001 showed no trend, due in part to high intervessel variability and variability for individual vessels between years (Wayte, 2001). Catch per shot data for the remainder of 2001 are not directly comparable with earlier years' data as fishing practices changed following the loss of quarterly TACs.

Industry-led surveys in 1999, 2000, 2001 and 2002 described the dynamics of the spawning aggregation and the fishery (e.g. Prince, 2002). Preliminary acoustic biomass estimates for 2000 suggested a spawning biomass in the range of 5,000 – 15,000 t. The volume of the 2001 spawning biomass was more than double that recorded in 2000 and 5 times that recorded in 1999. While there is no direct link between volume and biomass (packing density has been shown to be variable), these results suggest that the biomass of fish spawning on the Plateau is variable and may have increased in recent years.

Simple deterministic population modeling indicated that the prefishery biomass would have to have been about 30,000 t or larger and the biomass in 2002 about 20,000 t or larger for the current catch of 1,600 t to be within the preliminary management target for this fishery (ie. B2010 > 0.30 B1988) (Wayte, 2003). Note that the biological parameters and management target used for this analysis were different from those used in the current analysis, so these analyses are not comparable.

There has been no indication of a declining trend in catch or catch rate in this fishery, but any decline would be disguised by the high variability in catch rate data. Given the lack of a clear signal in the data, and the changed fishing practices, the Orange Roughy Assessment Group (ORAG) recommended that annual acoustic and biological surveys of the spawning aggregation continue until such a time that current biomass estimates are refined and a formal stock assessment is completed. Industry members indicated their support for continuing surveys and continuing support for a voluntary closure of the spawning area during spawning in 2003, 2004 and 2005 to facilitate these surveys.

Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau in 2003, using acoustic equipment on industry vessels that could be directly compared to standardized scientific equipment (Honkalehto and Ryan, 2003). The survey was supported by industry through the 100 t research quota. ORAG provided funds for the acoustic biomass estimate.

The first formal quantitative assessment of the Cascade Plateau population of orange roughy was performed in 2004 (Wayte, 2004). An integrated assessment model, with an age- and sex- structured population dynamics model was applied. This assessment concluded that it is likely that a sustainable long-term annual catch level for the Cascade Plateau could be between 200 and 400 t. The pre-fishery population size was estimated to be much less than half those estimated in the Eastern or Southern zones, and the stock productivity was estimated to be half that of other stocks.

In 2005 the assessment was updated with the 2004 acoustic biomass estimate, which was slightly lower than the 2003 estimate (Wayte, 2005). Assessment results were similar to the previous year. The recommended biological catch was estimated to be less than 500 t for all scenarios considered. However the 2005 survey estimated a larger absolute biomass present than in previous years, leading DeepRAG to send a letter out of session to AFMA updating the 2005 assessment. This 2006 assessment is the first formal assessment to use the higher 2005 survey estimate.

25.3 Methods

25.3.1 The Data and Model Inputs

25.3.1.1 Catches

The Cascade Plateau was first fished in 1989/90 when 2,000 t of roughy were caught by mostly foreign vessels. Smaller catches were reported by domestic vessels from the Cascade Plateau between 1991 and 1994, but these data are believed to be misreported. Substantial fishing did not occur again until 1996, when 863 t were caught. In April 1997 a precautionary trigger limit of 1,000 t set by the South East Trawl Management Advisory Committee (SETMAC) was reached. An ORAG proposal to increase fishing to a 1,600 t competitive TAC (400 t per quarter with no carryover of uncaught quota between quarters or years) based on a strategic fishing and research program, was accepted by SETMAC for 1998 and subsequently approved by the Australian Fisheries Management Authority (AFMA). Individual Transferable Quotas (ITQs) replaced the competitive TAC from 1 April 2001, and the quarterly distribution of quota was lost, increasing effective fishing effort in the fishery.

Information on catches reported here (Table 25.1) has been obtained from the AFMA catch landings database (SEF2). These figures include the 100 t research quota. Total reported catches to the end of 2005 are 16,647 t.

Table 25.1. Cascade Plateau catches and quota (the catches include the 100 t research quota)

Year	Agreed TAC (t) (before adjustment)	Research quota	Management method	landed catch (t)
1989	None		none	260
1990	None		none	1,858
1991	None		none	0
1992	None		none	0
1993	None		none	0
1994	1,000		trigger limit	0
1995	1,000		trigger limit	0
1996	1,000		trigger limit	972
1997	1,000		trigger limit	1,178
1998	1,600		4 openings	1,560
1999	1,600		4 openings	1,689
2000	1,600		4 openings	1,639
2001 (first quarter)	400		1 opening	310
2001 (after April 1)	1,165		ITQs	1,156
2002	1,500	100	ITQs	1,592
2003	1,500	100	ITQs	1,638
2004	1,500	100	ITQs	1,520
2005	1,200	100	ITQs	1,275
2006	700	100	ITQs	-
			Total catch	16,647

25.3.1.2 Length frequencies

Length frequency data (Figure 25.1) have been collected from the industry surveys run by Biospherics Pty. Ltd. from 1998-2004 (eg. Prince, 2002). Sub-samples of 100-200 fish were taken from large catches; all fish were measured in smaller samples. The data from each shot are considered to be uniform and representative of the population, thus no weighting by proportion of catch sampled has been performed (J.Prince, pers.comm.).

In stock assessments of orange roughy in New Zealand (Smith et al, 2002), effective sample sizes calculated from bootstrap resampling of the length frequency samples were used in place of the actual sample sizes in the likelihood. This was done in an attempt to take sampling error into account. Due to time constraints the bootstrap re-sampling procedure has not yet been done for the Cascade Plateau dataset. Instead, the effective sample sizes are approximated by multiplying the actual sample sizes by 0.01 (the average of the ratios of effective to actual sample sizes calculated in New Zealand orange roughy length-frequency samples). Sensitivity to this weighting was investigated in the 2004 assessment.

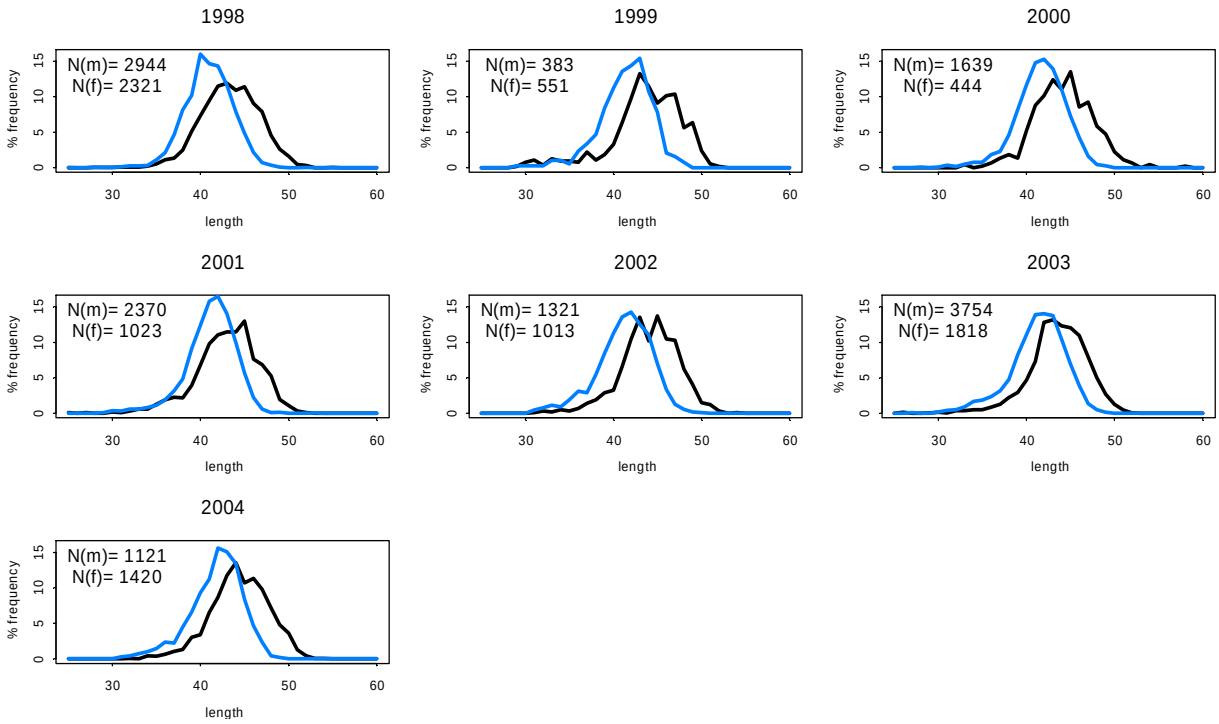


Figure 25.1. Female (black) and male (grey) length frequencies, with sample sizes.

25.3.1.3 Age frequency

Two age frequency samples from the Cascade Plateau have been aged by the Central Ageing Facility in Queenscliff. 816 otoliths (529 female and 287 male) were taken in 1999, and 540 otoliths (383 female and 157 male) in 2004 (
Figure 25.2). The sexes have been combined when input to the model, as there are too few observations for the sexes separately to produce a sensible age-frequency distribution (too many ages have no observations).

If a sample of otoliths has been re-aged it is possible to estimate imprecision in ageing using an ageing error matrix. However, only 250 of the 1999 otoliths have been re-aged. This is not enough to estimate a useful ageing error matrix for such a long-lived species. Actual sample sizes are multiplied by 0.1 to approximate effective sample sizes, based on the same reasoning described for the adjustment of length frequency sample size, but retaining greater emphasis on the age data, as the age data are considered to contain more information than the length frequency data. Sensitivity to this weighting was investigated in the 2004 assessment.

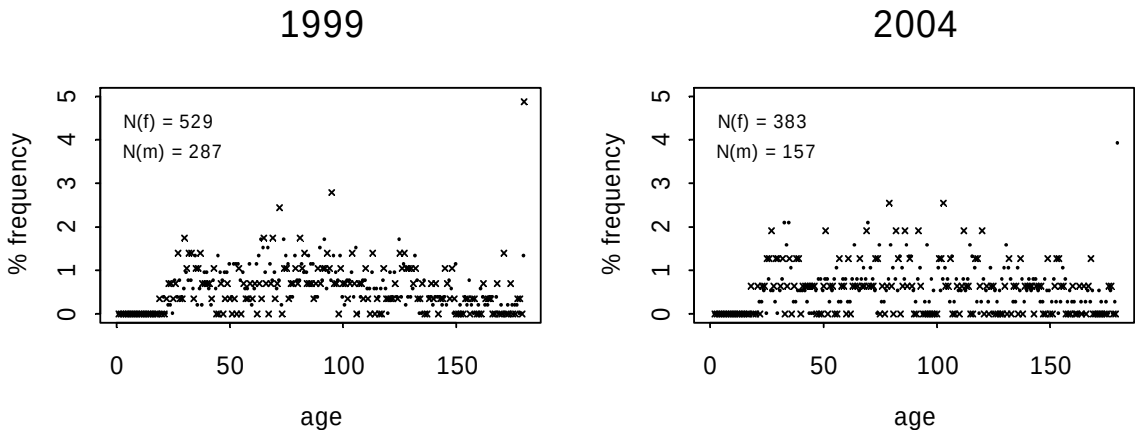


Figure 25.2. 1999 and 2004 female (dots) and male (crosses) age frequencies, with sample sizes.

25.3.1.4 Acoustic biomass estimate

Biospherics Pty. Ltd. and industry members conducted the first quantitative survey of the Cascade Plateau in 2003, using acoustic equipment on industry vessels that could be directly compared to standardized scientific equipment (Honkalehto and Ryan, 2003). This survey was repeated in 2004 (Honkalehto and Ryan, 2005) and 2005 (Ryan, 2006). A number of absolute biomass estimates were obtained, depending on the value of target strength (TS) used, and the method used to classify orange roughy schools.

Orange roughy target strength (TS) is not well understood especially for the larger fish found on the Cascade Plateau, and thus two alternative published values were used in the acoustic biomass estimation calculations: "Hampton" and "Doonan". Acoustic data were echo integrated for biomass estimation using a classification scheme based on a 3-tiered ranking of confidence of orange roughy echosign. The estimates from scheme OR1, obvious roughy schools, are used in the stock assessment, as these are the most defendable biomass estimates. An acoustic deadzone correction was applied to the data.

The 2005 acoustic biomass estimate is approximately a factor of three higher than the 2003 and 2004 estimates, so clearly does not form a consistent series with the previous estimates. It had been hoped that a third biomass estimate would allow the series to be used as a relative index, but this is not possible. In this assessment the 2005 estimate has been used on its own as an absolute biomass estimate. The difference between the three biomass estimates is in keeping with qualitative observations from earlier surveys that have observed a substantial variability between seasons (Prince, 2004). However, the large variability observed does raise questions about the ability of acoustic estimates to distinguish, in the short term, fishery induced changes from natural variability (Ryan 2006).

The acoustic biomass estimate of orange roughy in schools at the time of the survey is a snapshot biomass estimate. To convert the snapshot acoustic biomass estimates into a Cascade population estimate requires accounting for the proportion of adult fish that do not come to spawn and the turnover of adult fish in the schools. Quantitative measures of the proportion of fish that do not spawn each year are not available for the Cascade fishery but it is estimated to be between 0 to 30%. The Eastern Zone assessment

assumed 20-30% of fish do not spawn each year. The turnover of fish on the spawning grounds based on limited information from the Eastern Zone and New Zealand fisheries is estimated to be in the range of 0 to 50%. In this assessment the snapshot acoustic surveys are doubled (100%) to provide an upper bound taking into account the proportion of adult fish that do not come to the spawning grounds and the turnover of fish in the schools. Future surveys should look at testable hypotheses to quantify and narrow the bound of this range.

25.3.1.5 Biological parameters

Orange roughy from the Cascade Plateau are noticeably larger than those from the Eastern Zone so it was necessary to calculate values for biological parameters from fish collected from the Plateau, rather than use values used in the Eastern Zone stock assessments.

Natural mortality

In previous Cascade stock assessments natural mortality has been estimated to be 0.02. This is used in this assessment.

Length-weight relationship

The length-weight relationship was calculated by Honkalehto and Ryan (2003) from length-weight data from 1,003 female roughy collected during the 2000 spawning survey of the Cascade Plateau:

$$\text{weight(g)} = 0.382*\text{length(cm)}^{2.3409}$$

Growth

The Von Bertalanffy growth curve was fitted separately for males and females using the age and length data from the 2004 age composition sample (Figure 25.3). Due to the lack of data for younger ages it was not possible to estimate a sensible value for t_0 which was therefore fixed at 0. Sensitivity to fixing t_0 at –10 (and altering the other growth parameters accordingly) was investigated in the previous assessment.

Males: $l_t = 42.98(1 - e^{-0.062t})$ 157 observations

Females: $l_t = 45.98(1 - e^{-0.059t})$ 383 observations

The 2004 stock assessment used Von Bertalanffy parameters estimated from the 1999 age composition sample. However, in 1999 the fish aged were larger than those in the length frequency sample, leading to doubts over whether the aged sample was representative of the population. In 2004 the length frequency distribution of the aged fish was the same as the fish measured for length only.

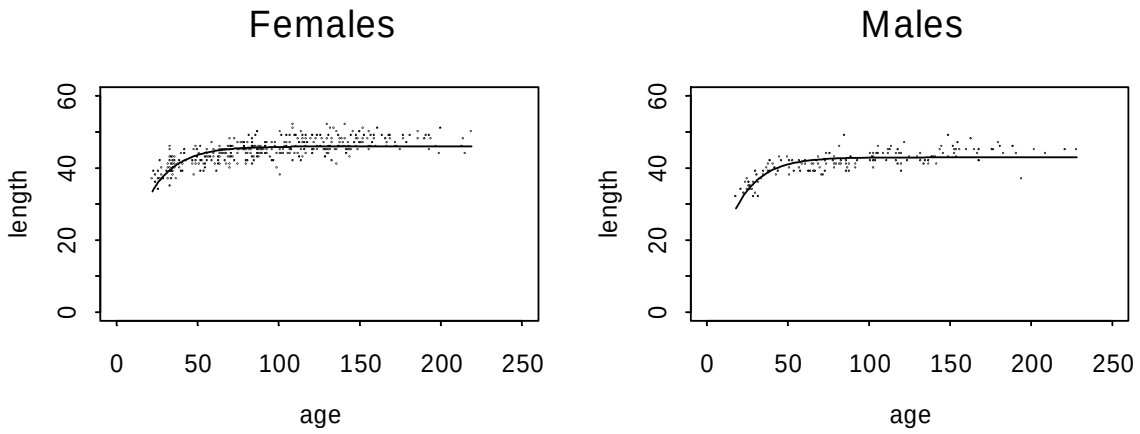


Figure 25.3. Female and male growth curves

Other biological parameters

The fixed biological parameters used in the stock assessment are summarised in Table 25.2. Values for stock-recruit steepness and recruitment variability parameters are the same as those used in other Australian orange roughy assessments. Selectivity was modelled using a logistic ogive, and the maturity ogive was set to be equal to this. σ_R is set to the empirical variability of estimated recruitments.

Table 25.2. Fixed biological parameters used in the assessmnent

Parameter	**symbol**	**male**	**female**	**both sexes**
natural mortality	M			0.02
von Bertalanffy growth	L_∞	42.98 cm	45.98 cm	-
	k	0.062 yr^{-1}	0.059 yr^{-1}	-
	t_0	0 yr	0 yr	-
length -weight	a			0.382 g/cm^3
	b			2.3409
stock-recruit steepness	d			0.75
recruitment variability	σ_R			0.25
length-at-age cv	σ_l			0.05
plus-group age	z			180

25.4 The Assessment Model

25.4.1 Model Structure

The 2006 assessment is based on the Stock Synthesis model of Methot (2005). The software used to estimate the parameters of the model, SS2, is a generalised assessment package based on the integrated analysis paradigm. This means that all relevant processes are built into the model, and goodness-of-fit is estimated in terms of the original data. This model differs from that used previously for stock assessment of Cascade orange roughy in only a few technical details. The appendix (Section 25.9) compares SS2 and the previous assessment method.

25.4.2 Parameter estimation

The base case analysis estimates 182 parameters (R_0, 2 selectivity parameters and 179 recruitment deviations). Selectivity is based on length rather than age, and is modeled using a logistic curve.

Due to time constraints a smaller set of sensitivity tests were performed in this assessment than in the 2004 assessment. The sensitivity tests performed in the 2004 assessment did not produce any surprises or anomalous results, and are not all worth repeating. The only sensitivity tests performed this year were using different biomass estimates.

25.5 Results

25.5.1 Base case analysis

The base case analysis includes all the data, and estimates all 182 free parameters. It uses the acoustic estimate calculated using the Hampton TS estimate. Length where 50% of the population is selected is estimated to be 41.5 cm, with the width for 95% selection estimated to be 8.42 cm.

The fit to the acoustic estimate and the estimated recruitment multipliers are shown in Figure 25.4.

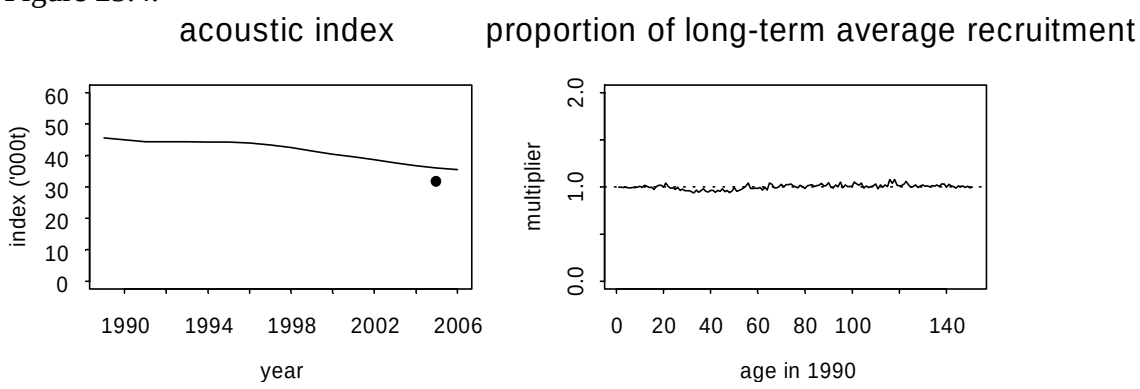


Figure 25.4. MPD fits for the base case

The base case MPD fits to the age frequency data are shown in Figure 25.5. The fits to the age data appear reasonable given the large amount of variability in the data. The variability in the data occurs partly because there are relatively few observations (885 in 1999 and 540 in 2004) compared to the number of age classes (180), which leads to few (and occasionally no) observations in each age class. The sexes have been combined when input to the model, as there are too few observations for the sexes separately to produce a sensible age-frequency distribution (too many ages have no observations). The standard deviation of the recruitment deviations has been set to 0.25, based on the empirical variability of estimated recruitments. If this value is set too high, the biomass will be estimated to decline even without fishing, due to bias arising from the log-normal distribution of the recruitment deviations (Punt, 2006).

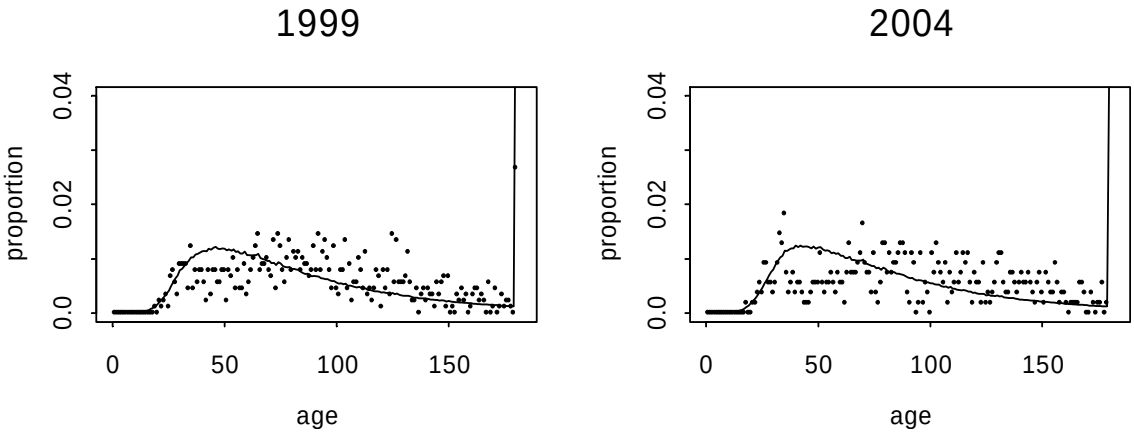


Figure 25.5. MPD fits (solid lines) to the age frequency data (dots) for the base-case analysis.

The fits to the length frequency compositions are generally good (Figure 25.6). The contradiction between the fits to the age and length frequency data observed in the 2004 assessment is no longer evident. This is because the lengths of the fish in the 2004 age frequency sample are consistent with those in the length frequency sample (and therefore hopefully representative of the population).

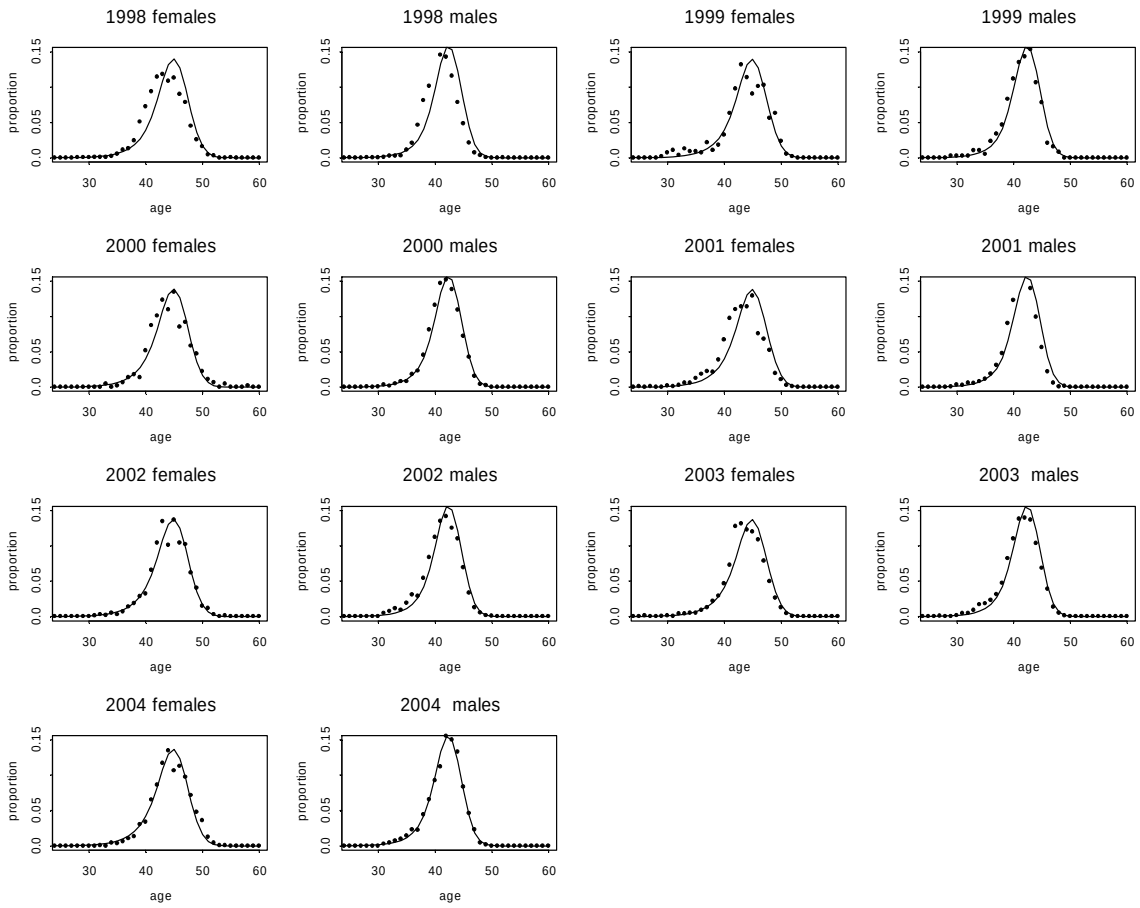


Figure 25.6. MPD fits (solid lines) to the length frequency data (dots) for the base-case analysis.

25.5.2 RBC calculation

Tier 2 of the SESSF harvest strategy framework (Smith and Smith, 2005; Smith, 2006) is recommended for Cascade orange roughy. This rule has been modified from last year, and three versions of it are applied this year. The SESSF harvest strategy framework is still under development, and will be tested via a management strategy evaluation (MSE) project due to start later this year.

The general formula for calculating the fishing mortality F_{ADJ} is :

$$F_{ADJ} = F_{TARG} \qquad \text{where } B_{CUR} > B_{break}$$

$$F_{ADJ} = F_{TARG}\left(\frac{B_{CURR} - B_{20}}{B_{break} - B_{20}}\right) \qquad \text{where } B_{break} > B_{CUR} > B_{20}$$

$$F_{ADJ} = 0 \qquad \text{where } B_{CUR} < B_{20}$$

The three versions of the harvest control rule (HCR) used this year are:

$F_{TARG}=F_{50}$ and $B_{break}=B_{50}$ (50:50:20)

$F_{TARG}=F_{60}$ and $B_{break}=B_{50}$ (60:50:20)

$F_{TARG}=F_{60}$ and $B_{break}=B_{60}$ (60:60:20)

The recommended biological catch (RBC) is calculated by applying F_{ADJ} to the current biomass as estimated by the agreed base case assessment model.

F_X represents the fishing mortality rate that would cause the spawning biomass to decline to X% of its unfished levels.

B_X represents the biomass at X% of unfished levels.

B_{CUR} is the current estimated biomass from the base case assessment model.

The tier 2 rules are shown graphically in Figure 25.7, and the projected catches under each rule are shown in Figure 25.8.

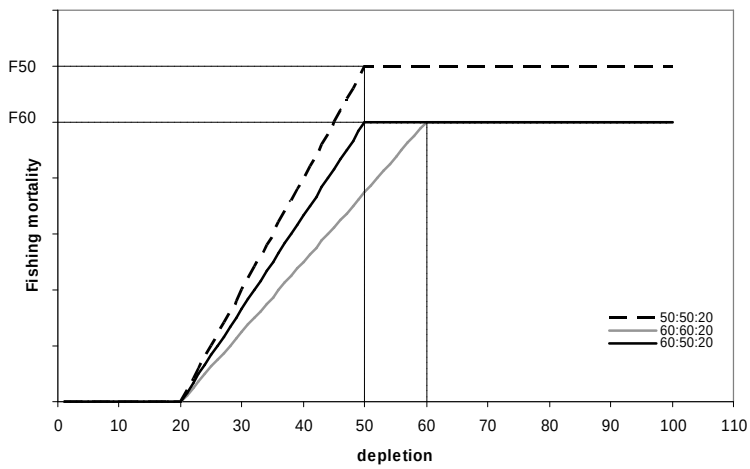


Figure 25.7. Tier 2 harvest control rules

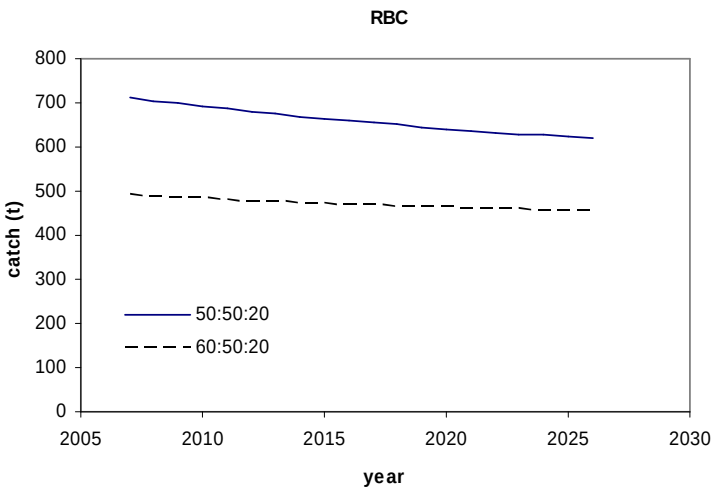


Figure 25.8. Projected RBCs under three versions of the Tier 2 rule for the base case analysis (the 60:50:20 and the 60:60:20 rules are the same in this case)

25.5.3 Projections

Figure 25.9 shows fishing mortality vs depletion over time for the base case. The first graph projects into the future using a fixed catch of 800 t (the current TAC). The second graph projects 50 years into the future using the tier 2 harvest control rule 50:50:20. The straight line on the plots shows the 50:50:20 HCR.This shows that under the base case scenario with a continuing catch of 800 t, the proportion of unfished biomass remaining will continue to decline as fishing mortality increases. Using the 50:50:20 HCR, biomass will eventually stabilise at 50 % of unfished biomass, and F50 immediately brings down fishing effort so that 60% of unfished biomass is not reached for 18 years.

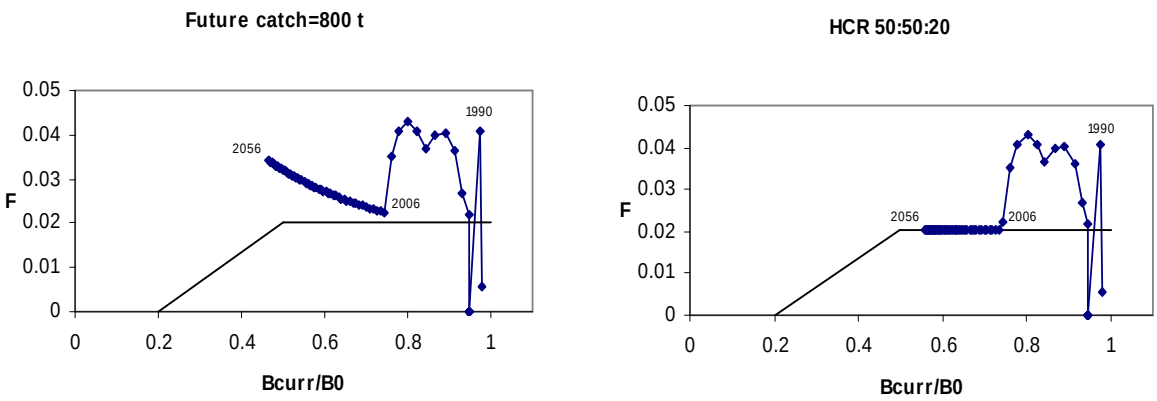


Figure 25.9. Projections for the base case using 800 t (left) and harvest control rule 50:50:20 (right)

25.5.4 Sensitivity tests

Other than the base case, the only models run were that using half the estimated acoustic biomass estimate (to take into account a different target strength value), and that using double the estimated biomass estimate (to take into account proportion spawning and turnover). Thus it can be seen that the base case effectively assumes that any overestimates caused by inaccuracy in the absolute acoustic biomass estimate are

balanced by underestimates from assuming that a snapshot biomass estimate (the largest observed school in one night) represents all mature fish in the population. Table 25.3 summarises the results of the sensitivity tests. The results reported for each analysis are the estimates of average unfished female spawning biomass (SB_0), current (2007) female spawning biomass, and the ratio of the 2007 biomass to SB_0.

All of these results are based on the MPD (mode of the posterior distribution) estimates rather than the more accurate MCMC (Markov chain Monte Carlo) estimates, and should be interpreted with caution. There was not enough time available for calculation of the MCMC estimates.

Table 25.3. Results for the sensitivity tests (MPD)

	Female spawning biomass			**RBCs using the 3 harvest control rules**		
Acoustic estimate	Female SB_0	Female SB_{2007}	SB_{2007}/ SB_0	50:50:20	60:50:20	60:60:20
31,600	28,581	20,986	0.73	711	490	490
63,200	47,206	39,092	0.82	1,307	902	902
15,800	19,247	11,915	0.62	411	283	283

25.6 Discussion and conclusions

Different absolute acoustic biomass indices have virtually no effect on the fit to the age or length composition data, but do give rise to different biomass estimates and levels of depletion. For the base case, current female spawning biomass is estimated to be 73 % of average unfished biomass, for the lowest biomass index this proportion is 62 %, and for the largest biomass index it is 82 %.

The recommended biological catch for 2007 ranges from 283 t to 1,307 t for the three scenarios, and the three versions of the harvest control rule.

The Cascade biomass estimate is based on the maximum observed biomass on the spawning ground. On the one hand this could be an overestimate (target strength too low) , on the other it could be an underestimate (maximum biomasss was only a fraction of the total spawning biomass). Variability between years in size of the spawning aggregation complicates intepretation – when smaller biomasses are estimated in future years it will be difficult to distinguish an overall reduction from natural variability. It is recommended that this fishery continues to be monitored annually, through the industry program and data stored so that they can analysed in the future if needed. An MSE for management of this fishery (where biomass is based on the single largest biomass estimate) is recommended. Continued industry support for annual monitoring should be taken into account when determining the level of risk for this fishery.

25.7 Acknowledgements

André Punt and Tony Smith are thanked for their advice and useful discussions. Members of the Deepwater Assessment Group made useful comments on an earlier version of this document.

25.8 References

Honkalehto, T. and Ryan, T. (2003) Analysis of industry acoustic observations of orange roughy (*Hoplostethus atlanticus*) spawning aggregations on the Cascade Plateau off southeastern Tasmania in June and July 2003. Unpublished report to DAG.

Honkalehto, T. and Ryan, T. (2005) Biomass estimation of Cascade Plateau orange roughy (*Hoplostethus atlanticus*) based on winter 2004 industry vessel acoustic surveys. Unpublished report to DAG.

Kailola, P.J.; Williams, M.J.; Stewart, P.C.; Reichelt, R.E.; McNee, A.; Grieve, C. (1993) Australian Fisheries Resources. BRS, Canberra.

Methot, R. (2005) Technical Description of the Stock Synthesis II Assessment Progra,. NOAA Fisheries, Seattle, WA.

Prince, J. (2002) Orange roughy spawning at the Cascade Plateau : 2002 Cruise Report. Biospherics Pty. Ltd. (unpublished report to ORAG)

Prince, J. (2004) Orange roughy spawning at the Cascade Plateau : 2004 Data Report. Biospherics Pty. Ltd. (unpublished report to ORAG)

Punt, A.E. (2006) B_0, B_{ref} and bias-correction (in prep.)

Ryan, T (2006) Biomass estimation of Cascade Plateau orange roughy (*Hoplostethus atlanticus*) based on winter 2005 industry vessel acoustic surveys. Unpublished report to DAG.

Smith, A.D.M.; Punt, A.E.; Wayte, S.E.; Starr P.J.; Francis, R.I.C.C.; Stokes, T.K.; Hilborn, R.; Langley, A. (2002) Stock assessment of the northeast Chatham Rise orange roughy for 2001. *New Zealand Fisheries Assessment Report 2002/25.*

Smith, A.D.M. and Smith, D. (2002) Towards an improved basis for setting TACs in the South East Fishery. Unpublished report of the SEFAG Harvest Strategies Working Group to the AFMA Board.

Smith, A. and D.Smith (2005) A harvest strategy framework for the SESSF. Report to AFMA, June 2005

Smith, A. (2006) Guidelines regarding implementation of the SESSF Harvest Strategy Framework for 2006. July 2006

Wayte, S.E. (2001) Preliminary analysis of orange roughy catches on the Cascade Plateau, 1996-2001. Unpublished report to ORAG.

Wayte, S.E. and Bax. N. (2002) Stock Assessment Report 2002 : Orange roughy (*Hoplostethus atlanticus*). Unpublished report to SEFAG.

Wayte, S.E. (2003) Deterministic population modelling of the orange roughy population on the Cascade Plateau . Unpublished report to ORAG.

Wayte, S.E. (2004) Stock assessment of the Cascade Plateau orange roughy. In Tuck, G.N. (ed.) 2006. Stock Assessment for the Southern and Eastern Scalefish and Shark Fishery 2004-2005. Australian Fisheries Management Authority and CSIRO Marine and Atmospheric Research, Hobart. 222 p.

Wayte, S.E. (2005) Stock assessment of the Cascade Plateau orange roughy 2005. Unpublished report to DAG.

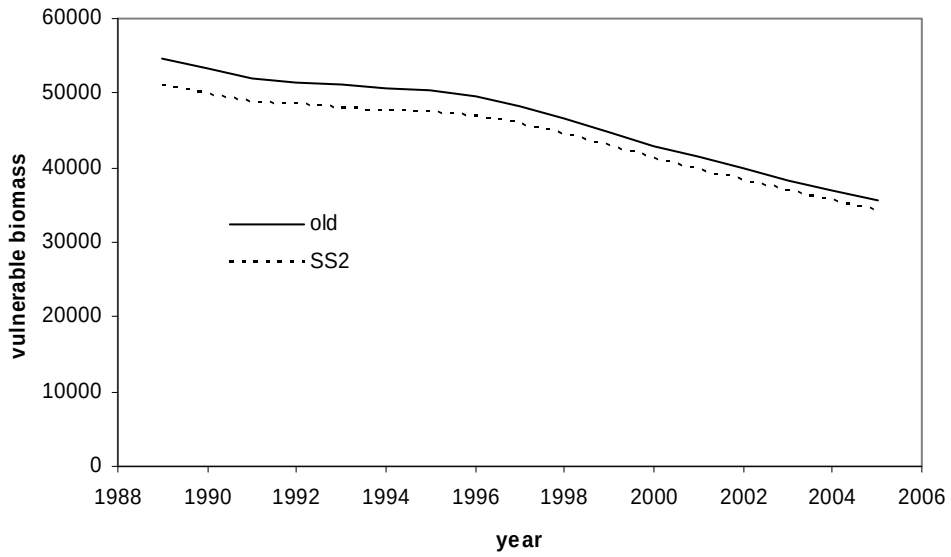
25.9 Appendix: Comparison of previous model with SS2

The previous assessments of Cascade orange roughy were based on an age- and sex-structured model with gradual recruitment according to age. It was fitted to data on catches, age compositions, length compositions and an acoustic abundance index. The 2006 assessment uses the stock assessment package Stock Synthesis 2 (SS2), developed by Rick Methot of NOAA Fisheries (Methot, 2005). The reasons for changing to SS2 are :

1. Well-tested and flexible software
2. Excellent output software allows rapid model testing and development
3. Calculation of RBCs is incorporated into the software
4. Provides a uniform approach to stock assessment for all SEF species
5. Allows stock assessment scientists to more easily understand (and therefore assist with) other assessments
6. Standard outputs will allow RAG members to more easily understand assessments

The model in SS2 is philosophically the same as that used in 2002, however there are some technical differences. The most important of these is that SS2 uses length- rather than age-based selectivity.

The two versions of the assessment are almost identical, so it has been concluded that the change to SS2 will produce results consistent with previous analyses.



26. Eastern Zone Orange Roughy[18]

Sally Wayte[1]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

26.1 Introduction

The last formal stock assessment of Eastern zone roughy in May 2002 incorporated the 1999 synoptic acoustic assessment of Eastern zone orange roughy and age data from 1993 to 2001 (in Smith and Wayte 2002). While there have been annual surveys since that time (designed to detect drastic biomass changes), the dispersed nature of the acoustic targets precluded precise species identification. The 2004 age composition and the 2006 towed-body acoustic survey of St Helens Hill and St Patricks Head provides the opportunity to update the 2002 assessment.

This assessment differs from that in 2002 in the following ways:

- catch data for 2002, 2003, 2004, 2005 and 2006 (estimated) have been added;
- 2004 age composition data from St Helens Hill and St Patricks Head have been added;
- towed-body acoustic abundance estimates for 1999 and 2006 have been added;
- the software for conducting the assessment has been updated to Stock Synthesis 2 (SS2).

A comparison of 2002 assessment results using the old software and using SS2 was performed and reported on in the 2006 preliminary Eastern Zone assessment presented to the Deepwater Assessment Group on August 3-4 (Wayte 2006). It was concluded that the change to SS2 will produce results consistent with previous analyses.

Preliminary assessments and possible scenarios with this model were presented at two meetings of DeepRAG in 2006. Issues surrounding stock structure hypotheses, survey precision and age data were reviewed. How best to include the 2006 acoustic data was also discussed. It was decided that the St Helens hull-mounted acoustic survey series from 1990 to 1999 would be included as a separate series from the combined St Patricks and St Helens towed body 1999 and 2006 series. This maintains the power of the hull-mounted data series in monitoring the early decline of the fishery when orange roughy schools were clearly identifiable, but switches to the increased precision and species identification of the towed body series to monitor the recovery. Based on these meetings there was agreement about how to explore the sensitivity of the model to various acoustic survey and stock structure scenarios (Wayte 2006).

[18] Paper presented to the Deepwater Resource Assessment Group on 20 March, 2008

26.2 Methods

26.2.1 Data and model inputs

26.2.1.1 Stock structure

Early analysis of otolith shape data by the Central Ageing Facility indicated that roughy caught in the spawning aggregation at St. Helens in the winter were not distinguishable from roughy caught in the Southern zone for the rest of the year, but were different from roughy caught in the Eastern zone outside the time of the spawning aggregation, and were different from roughy caught in the Southern zone in winter. This implied that spawning eastern zone roughy and Southern zone non-spawning roughy may comprise a common stock, which is distinct from an eastern non-spawning and southern winter-caught 'stock'. A subsequent analysis was less clear and reviewers have raised questioned the statistical approach used.

Observations from fishers and processors suggested that roughy schools from Maatsuyker are part of a west coast Tasmania 'stock', while the Pedra Branca schools are part of the combined stock. Fishers' observed little interchange of pelagic roughy schools between Pedra Branca and Maatsuyker, while processors suggested that fish from the two areas are morphologically distinct. Maatsuyker is on the western slope of the seabed continuation of Tasmania, while Pedra Branca is on the east.

Overall this evidence and earlier studies of stock structure based on parasites, genetics and otolith microchemistry have been inconclusive on whether the orange roughy stocks around Tasmania comprise one or several stocks. Only one substantial winter spawning aggregation (St Patricks and St Helens Hill) has been found and only one large consistent summer aggregation has been fished (Southern Zone main Maatsuyker and Pedra Banca). Low levels of spawning have been detected elsewhere and an analysis of catch data shows elevated winter catches in the Far Western Zone. The hypothesis that includes all roughy stocks in the SEF (with the exception of Cascade) as one stock is included on the recommendation of the 2002 review of the stock assessment.

Five stock structure hypotheses have been used in the assessments of Eastern zone roughy (Table 26.1 and Figure 26.1). Model scenarios corresponding to these stock structure hypotheses were tested and reported on in the 2006 preliminary Eastern Zone assessment (Wayte 2006). The results of these scenarios did not differ greatly from each other (in terms of estimated stock depletion), so they have not been repeated here. This assessment uses the combined stock structure, as this has been the agreed base-case in previous stock assessments. There remains a need to explore these in detail as longer term RBC levels will differ.

Table 26.1. Description of stock structure hypotheses

Stock hypothesis	Description	Catch data required
East	All roughy in Eastern zone, spawning and non-spawning	Total Eastern zone catch (all months)
2002 Combined	Eastern zone spawning roughy and Pedra Branca non-spawning roughy	Eastern zone winter catch (June, July, August) and Pedra Branca[1] non-winter (all months except June-Aug)
*Combined	Eastern zone roughy and Pedra Branca roughy	Total Eastern zone catch (all months) and Pedra Branca catches (all months)
East + South	All roughy in Eastern and Southern zones	Total Eastern zone catch and total Southern zone catch (all months)
East + South + West	All roughy in Eastern, Southern and Western zones	Total Eastern zone catch, total Southern zone catch and total Western zone catch (all months)

[1] Pedra Branca area : 44<=latitude<=44.5; 146.5<=longitude<=147.75

* used in this assessment

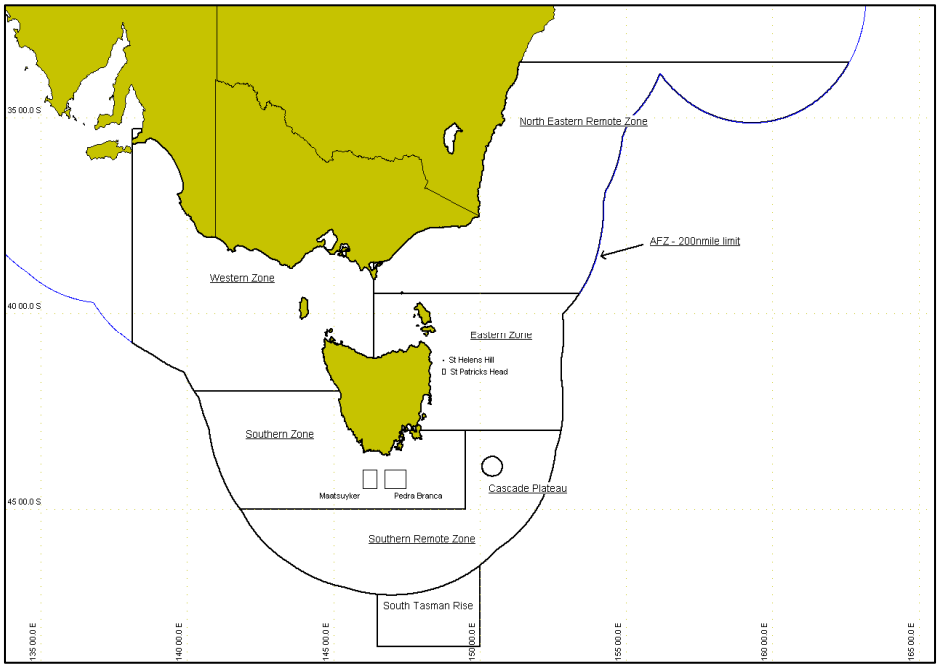


Figure 26.1. Areas of stock hypotheses

26.2.1.2 Fleets

Between 1999 and 2002 (prior to the voluntary closure of St Helens Hill in 2003), a larger proportion of the commercial catch was taken off St Patricks Head than St Helens. St Patricks Head was first acoustically surveyed in 1996 (and again in 1999 and 2006) after a significant portion of the spawning orange roughy biomass was taken there rather than at St Helens. St Helens may not, by itself, provide a consistent index for the Eastern Zone spawning biomass for the fishery. Age distributions in 1999 and 2001

(Figure 26.2) indicated that fish caught at St Patricks Head are younger than those caught at St Helens Hill. Length data also showed that fish at St Patricks were smaller than those at St Helens in 1999. This was previously taken account of in the assessment by using a 2-fleet model, with different selectivity curves for each fleet. This permitted the model to fit to the age compositions from both areas separately. The acoustic abundance indices have been adjusted so that they index the population on both St Helens Hill and St Patricks Head (see section 26.2.1.4 for description). The age composition data in 2004 (Figure 26.2) did not show a difference between St Helens Hill and St Patricks Head, providing support for using a single fleet model. Length data also shows similar mean lengths of fish at both grounds from 2004 to 2006.

26.2.1.3 Catch data

The corrected catch series corresponding to each stock hypothesis are shown in Table 26.2. The following sections describe how logbook and landings data were adjusted to produce the catch series. Some of the catches shown here differ slightly from previous reported catches. This is due to corrections to the logbook database. The differences are not large enough to affect the conclusions from stock assessments.

Eastern stock

The Eastern stock hypothesis uses catches reported in the Eastern zone. Catches for 1985 to 1991 are from logbook records, and catches from 1992 onwards are from landings records. The Eastern zone catches have been adjusted for under-reporting in 1992, mis-reporting in 1993, and general losses in 1989-1994.

It is believed that reported catches in 1992 were 55% of actual catches, so catches in this year were increased accordingly. In 1993, Eastern zone catches were misreported as Southern zone catches. To estimate the level of this misreporting, reported Southern Zone winter (June –August) catches for each of the years 1989-1992 and 1994 were calculated as the proportion of total reported Eastern and Southern zone catches in those years. The total Southern and Eastern zone catch in 1993 was multiplied by the mean of these proportions to estimate actual Southern Zone winter catch. Reported 1993 Southern Zone catch above this estimate was assumed to have been caught in the Eastern zone. These calculations resulted in 2,665 t being transferred from the Southern zone catch total to the Eastern zone catch total in 1993.

Other adjustments were made for burst bags, lost gear and burst panels. It was assumed, based on discussions with operators, that 30% of the total fish caught were lost in 1989 and 1990, 20% lost in 1991, and 10% lost in 1992, 1993 and 1994. The reported catches were increased accordingly. A catch series with half the value of these proportions lost was also calculated (based on different industry participants views). The assessment based on this catch series gave very similar results to the other catch series.

2002 Combined stock

The Combined stock hypothesis uses Eastern zone winter catch (June, July, August) and Pedra Branca non-winter (all months except June-Aug) catch. It represents the earlier stock hypothesis based on otolith shape data of a migratory stock that spawns at St Helens and St Patricks Head and feeds in from the area of Pedra Branca. This hypothesis is kept primarily for comparison with earlier assessments. The area definition for Pedra Branca is shown in Table 26.1.

The same corrections as described in the previous section are applied. The 1993 mis-reported Southern zone catch was caught in winter, so has been added to the 1993 Eastern zone winter catch.

St Patricks Head

The St Patricks Head catches were calculated by multiplying the corrected Eastern zone catch by the ratio of St Patricks Head catches to Eastern zone catches (as recorded in the logbook data). The area definition for St Patricks Head is shown below
Table 26.2.

Table 26.2. Orange roughy corrected catches (t) corresponding to each stock hypothesis

Year	East	2002 Combined (East winter + Pedra Branca non-winter)	Combined East + Pedra Branca (all seasons)	East + South	East + South + West	St Patricks Head[1]
1985	6	0	6	64	193	0
1986	33	57	60	664	4,634	2
1987	310	176	310	663	5,791	20
1988	1,949	1,190	1,949	2,418	7,183	42
1989	26,236	26,387	28,575	37,121	38,507	6
1990	23,200	31,107	34,502	58,630	59,432	4
1991	12,159	16,432	20,436	26,585	27,213	934
1992	15,119	17,309	24,265	31,173	32,314	886
1993	5,151	7,197	8,798	10,637	11,668	255
1994	1,869	3,389	4,140	6,697	7,624	76
1995	1,959	1,965	2,544	4,116	5,171	301
1996	1,998	1,873	2,231	2,800	4,120	624
1997	2,063	1,902	2,250	2,517	2,869	474
1998	1,968	1,868	2,087	2,218	2,578	184
1999	1,952	1,867	2,052	2,126	2,370	899
2000	1,996	1,835	2,109	2,307	2,499	1,111
2001	1,823	1,930	2,027	2,180	2,427	1,150
2002	1,584	1,601	1,674	1,751	2,045	921
2003	772	735	877	982	1,225	636
2004	765	776	797	847	1,168	610
2005	754	634	772	853	1,134	534
total	103,667	120,229	142,460	197,350	222,165	9,667

[1] St Patricks Head area: 41.467<=latitude<=41.567 ; 148.667<=longitude<=148.833

26.2.1.4 Biomass estimates

Hull acoustic index

Acoustic assessments have been made at St. Helens by CSIRO in 1990, 1991, 1992, 1993 and 1996 (Table 26.3). A limited survey of St Patricks Head occurred in 1996. Methods of collection of acoustic data and analysis using echo integration are documented in Kloser *et al*. (2001). A joint CSIRO/Industry survey in 1999 covered St Helens and St Patricks Head. An opportunistic CSIRO/Industry survey in 2001, confirmed earlier distribution patterns and collected biological data, but did not generate an acoustic biomass estimate.

The hull acoustic biomass index was calculated using school-based echo integrations from the vessel-mounted 38kHz transducer. As in previous years, the 1990 estimate was increased by 30 % to account for increased proportion spawning as the fishery developed.

In order to use the combined biomass at St Patricks Head and St Helens as an indicator of the Eastern Zone biomass rather than St Helens by itself, the St Helens hull acoustic biomass index was increased by the proportion of total commercial catch taken off St Patricks Head in the survey year to provide the combined index. This is used as a relative biomass index.

Coefficients of variation (CVs) are set at a nominal 0.4 for hull-mounted acoustic surveys, representing both statistical variability (typically less than 0.2) and other potentially influential factors such as variability in turnover rate that are not explicitly accounted for. CVs were increased in 1990, 1993 and 1999 to account for increased uncertainty in those years' survey resulting from either technological or logistical constraints.

Towed-body acoustic index

In 1999 it was considered that the biomass on St Helens Hill had declined to a level where vessel-mounted acoustics were no longer a viable method for acoustic biomass assessment (Kloser et.al. 2001). This is because the small size of the orange roughy stock (and low target strength of orange roughy) makes vessel-mounted surveys very sensitive to school identification. In 1999 and 2006 the CSIRO-developed multi-frequency towed instrument (MUFTI) acoustic system was used to survey the St Helens Hill and St Patricks Head fishing grounds. The advantage of the deep-towed MUFTI system is its ability to distinguish orange roughy from the bycatch species (Kloser and Ryan, 2001).

The towed-body biomass estimates from a survey on each of the two fishing grounds very close in time (<48 hrs) in each year (18 July 1999, 20 July 1999; and 20 July 2006) have been added together to provide snapshot biomass estimates of Eastern zone roughy for 1999 and 2006 (Table 26.3) .

Egg production biomass estimate

An egg survey was carried out in 1992 to estimate the biomass of the orange roughy stock spawning off St. Helens. Egg production methods are documented in Koslow *et al.* (1995) and have not changed since the last assessment.

The 1992 egg production biomass estimate in Koslow *et al.* (1995) is increased by a nominal 5% to account for possible egg loss (mortality and advection) in stock assessments. The egg production estimate used in the stock assessment is 39,955 t. This is used as an absolute biomass estimate.

Table 26.3. Abundance estimates and their coefficients of variation (cv)

Year	Hull (adjusted for St Patricks Head)	cv	Towed-body	cv	Egg production	cv
1990	50,180*	(0.6)				
1991	31,270	(0.4)				
1992	20,904	(0.4)			39,955	(0.5)
1993	8,829	(0.6)				
1994						
1995						
1996	9,372	(0.4)				
1997						
1998						
1999	9,471	(0.7)	17,335	(0.4)		
2000						
2001						
2002						
2003						
2004						
2005						
2006			13,201	(0.4)		

* adjusted by 1.3 to account for proportion non-spawning

26.2.1.5 Age composition

Age composition samples from winter spawning aggregations at St Helens Hill are available in 1992, 1995, 1999, 2001 and 2004, and from St Patricks Head in 1999, 2001 and 2004 (Figure 26.2). In 1999 and to a lesser extent in 2001, fish caught at St Patricks Head were younger than those caught at St Helens Hill. This led to the development of a two-fleet model, where separate selectivity curves (which combine gear selectivity and availability on the fishing grounds) were fitted to the data from St Helens Hill and St Patricks Head. The 2004 data did not show a difference in age composition between the two areas. Similarly there was no detectable difference in length distributions between the two areas from 2004-2006. This suggests that there is not a consistent difference in availability of fish to the two areas. As the model (and available data) do not allow selectivity curves to be varied annually a single selectivity curve was chosen as the most parsimonious option. Thus the age composition data in each year have now been combined over the two areas, and a single fleet model has been used.

Where possible, the age data from the two areas has been combined in a way that reflects the proportion of stock believed to be present in each area in each year. In 1999,

the towed body acoustics estimated that 85% of the population was at St Patricks Head and 15% at St Helens Hill. St Patricks Head age composition data has been weighted up compared to the St Helens Hill data, taking into account that sample sizes at St Patricks Head were larger in this year. In 2001 there is no information about the proportion of stock in each area, other than that there was approximately twice as much catch taken at St Patricks Head. The age composition sample size at St Patricks Head was 1.65 times that at St Helens Hill. The age compositions in this year have been combined with no weighting. In 2004 St Helens Hill was closed, but in this year the age compositions are very similar in the two areas, so they have been combined with no weighting.

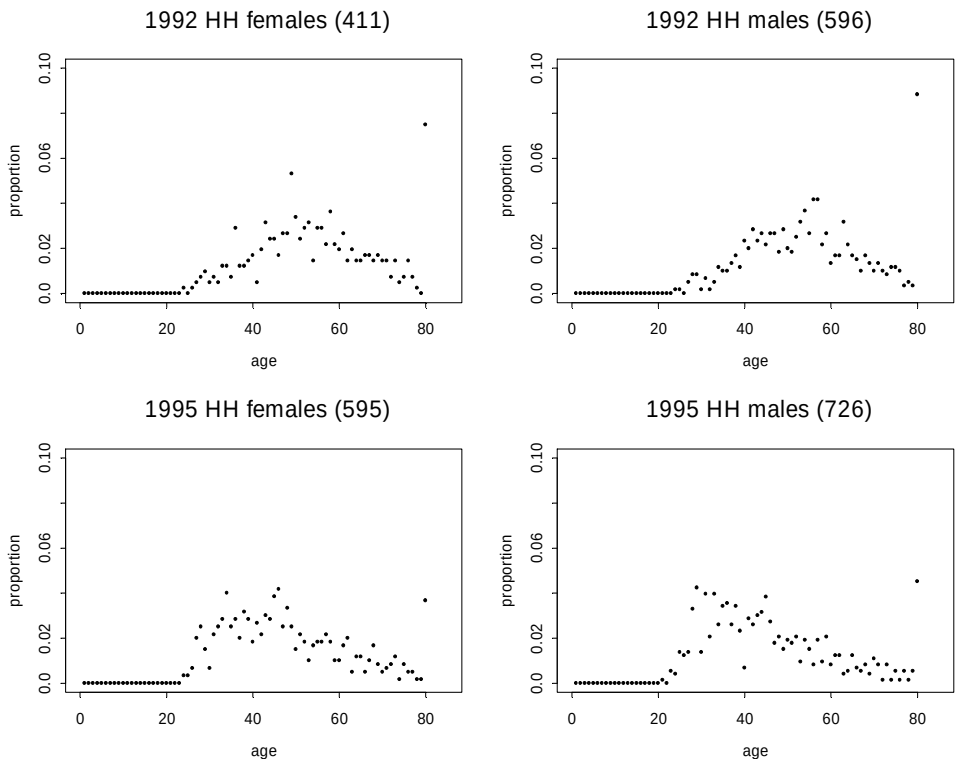


Figure 26.2. Observed age composition data by area and sex. Sample sizes are given in parentheses (Continued on next page).

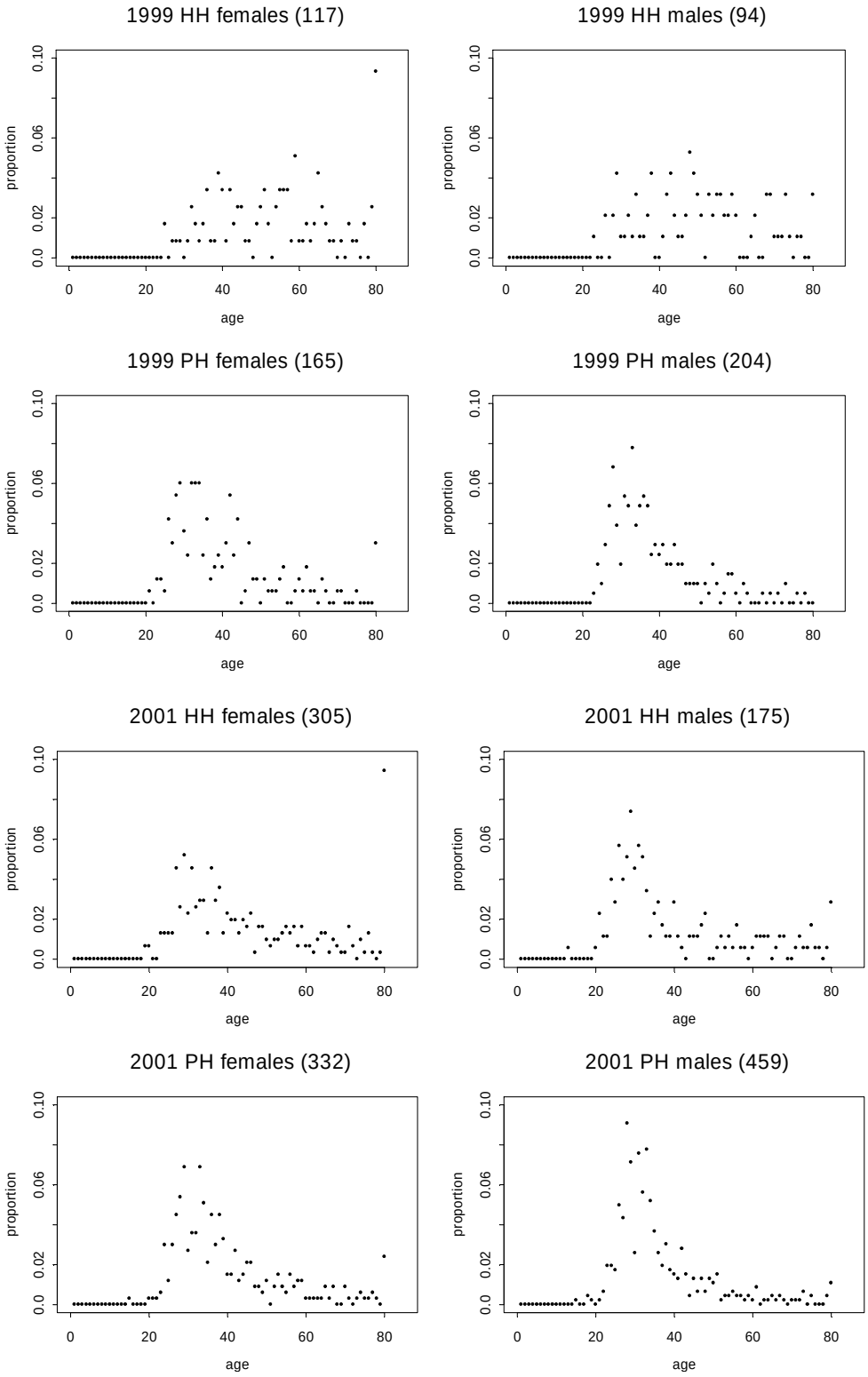


Figure 26.2. Continued. Observed age composition data by area and sex. Sample sizes are given in parentheses.

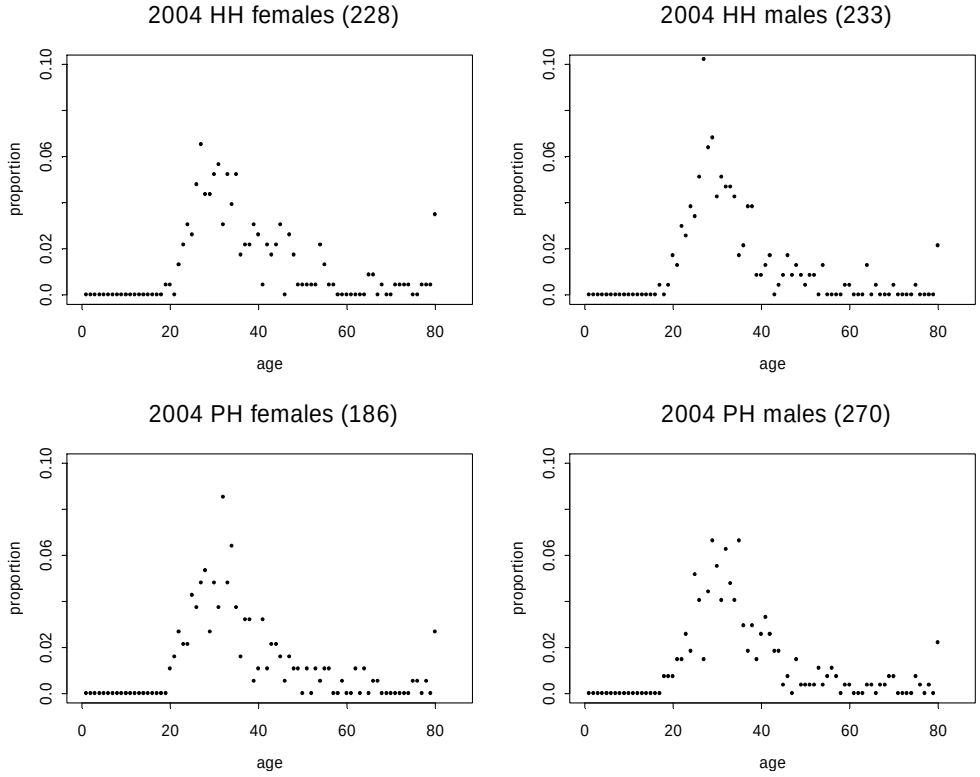


Figure 26.2. Continued. Observed age composition data by area and sex. Sample sizes are given in parentheses.

26.2.1.6 Biological parameters

Biological parameters used in the assessment are given in Table 26.4. They are unchanged from earlier assessments, with the exception of recruitment variability which has been set to 0.58 based on the empirical variability of the estimated recruitment deviations.

Table 26.4. Biological parameters

Biological parameter	Value	Source
Von Bertalanffy growth equation	$l_t = 39.06\ (1 - e^{-0.06(t + 3.18)})$ [l_t is length(cm) at age t(years)]	Smith et al (1995)
Weight-length equation	Males weight(g) = 0.0383 length(cm) $^{2.942}$	Lyle (1991)
	Females weight(g) = 0.0351 length(cm) $^{2.970}$	
Stock-recruit steepness	0.75	Estimated
Recruitment variability	0.58	Estimated

26.2.2 The Assessment Model

26.2.2.1 Overview

The 2006 assessment is based on the Stock Synthesis model of Methot (2005). The software used to estimate the parameters of the model, SS2, is a generalised assessment package based on the integrated analysis paradigm. This means that all relevant processes are built into the model, and goodness-of-fit is estimated in terms of the original data. This model differs from that used previously for stock assessment of Eastern zone orange roughy in only a few technical details. A comparison of the two methods showed no statistical difference in outcome (Wayte, 2006)

26.2.2.2 Parameter estimation

The analysis using all data estimates R_0 (average recruitment in an unfished state), 80 recruitment residuals, 2 selectivity parameters, and natural mortality, M. Selectivity is based on length rather than age, and is modelled using a logistic curve.

26.2.2.3 RBC calculation

Tier 1 of the SESSF harvest strategy framework (Smith 2006) is recommended for Eastern Zone orange roughy. This rule has been modified from last year, and three versions of it are applied this year. The SESSF harvest strategy framework is still under development, and will be tested via a management strategy evaluation (MSE) project due to start later this year.

The general formula for calculating the fishing mortality F_{ADJ} is:

$$F_{ADJ} = F_{TARG} \qquad \text{where } B_{CUR} > B_{break}$$

$$F_{ADJ} = F_{TARG}\left(\frac{B_{CURR} - B_{20}}{B_{break} - B_{20}}\right) \qquad \text{where } B_{break} > B_{CUR} > B_{20}$$

$$F_{ADJ} = 0 \qquad \text{where } B_{CUR} < B_{20}$$

The three versions of the harvest control rule (HCR) to be used this year are:

a. $F_{TARG}=F_{40}$ and $B_{break}=B_{40}$
b. $F_{TARG}=F_{48}$ and $B_{break}=B_{48}$
c. $F_{TARG}=F_{48}$ and $B_{break}=B_{40}$

The recommended biological catch (RBC) is calculated by applying F_{ADJ} to the current biomass as estimated by the agreed base case assessment model.

F_X represents the fishing mortality rate that would cause the spawning biomass to decline to X% of its unfished levels.
B_X represents the biomass at X% of unfished levels.
B_{CUR} is the current estimated biomass from the base case assessment model.
The three versions of the Tier 1 harvest control rule are shown in Figure 26.3.

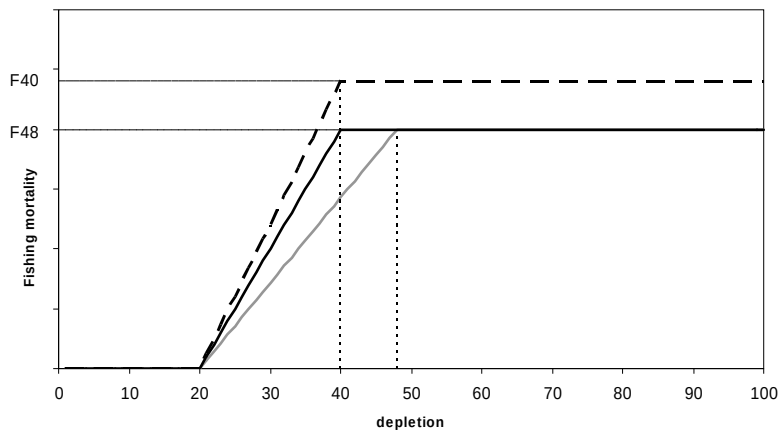


Figure 26.3 The Tier 1 harvest control rules for determining the fishing mortality.

26.3 Results

26.3.1 Scenario using all data

26.3.1.1 Description

The scenario using all data is described in Table 26.5. The 2004 age composition data (Figure 26.2) show little difference between the age compositions at St Helens Hill and St Patricks Head, reducing support for the two-fleet model. Length data from 2004-2006 support the 2004 age composition data. Consequently the age data from both areas have been combined in all years, and the analysis now uses a single fleet model.

Table 26.5. Summary of all data used in the analysis

Catches	All East + Pedra Branca
age compositions	1992, 1995, 1999, 2001, 2004 combined over St Helens Hill and St Patricks Head
Fleets	one
Abundance indices :	
hull acoustic	1990,1991,1992,1993, 1996, 1999 hull-mounted adjusted for St Patricks Head fitted to the whole stock vulnerable biomass
towed-body acoustic	1999 and 2006 towed-body estimate fitted to whole stock vulnerable biomass
egg production	1992 egg production fitted to mature biomass (maturity ogive=estimated selectivity ogive)

26.3.1.2 Fits to data

The fits to all abundance indices are shown in Figure 26.4. The unrealistic recruitment spike for fish aged 20-25 in 2006 from previous assessments has now been removed. The fits to the combined age composition information are shown in Figure 26.5.

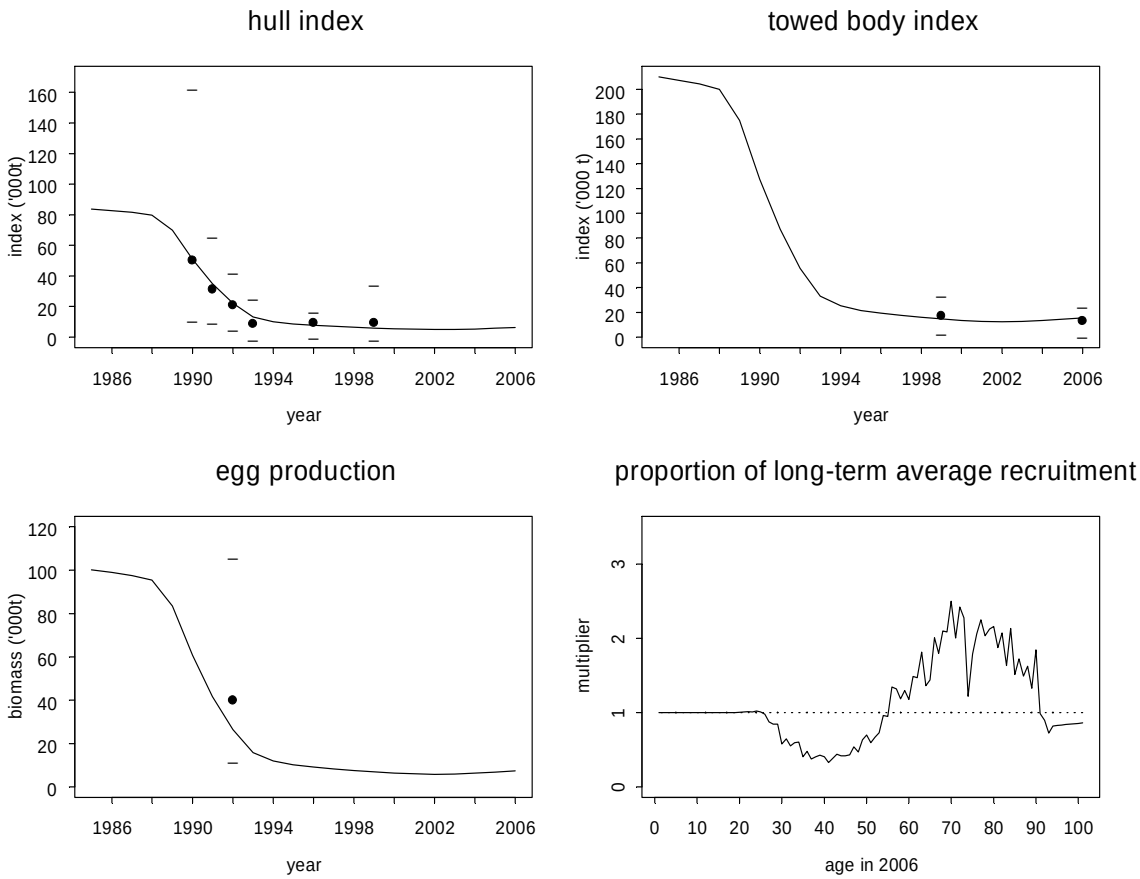


Figure 26.4. Fits to the abundance indices (with 95% confidence limits on observed indices) and recruitment multipliers for the base-case analysis.

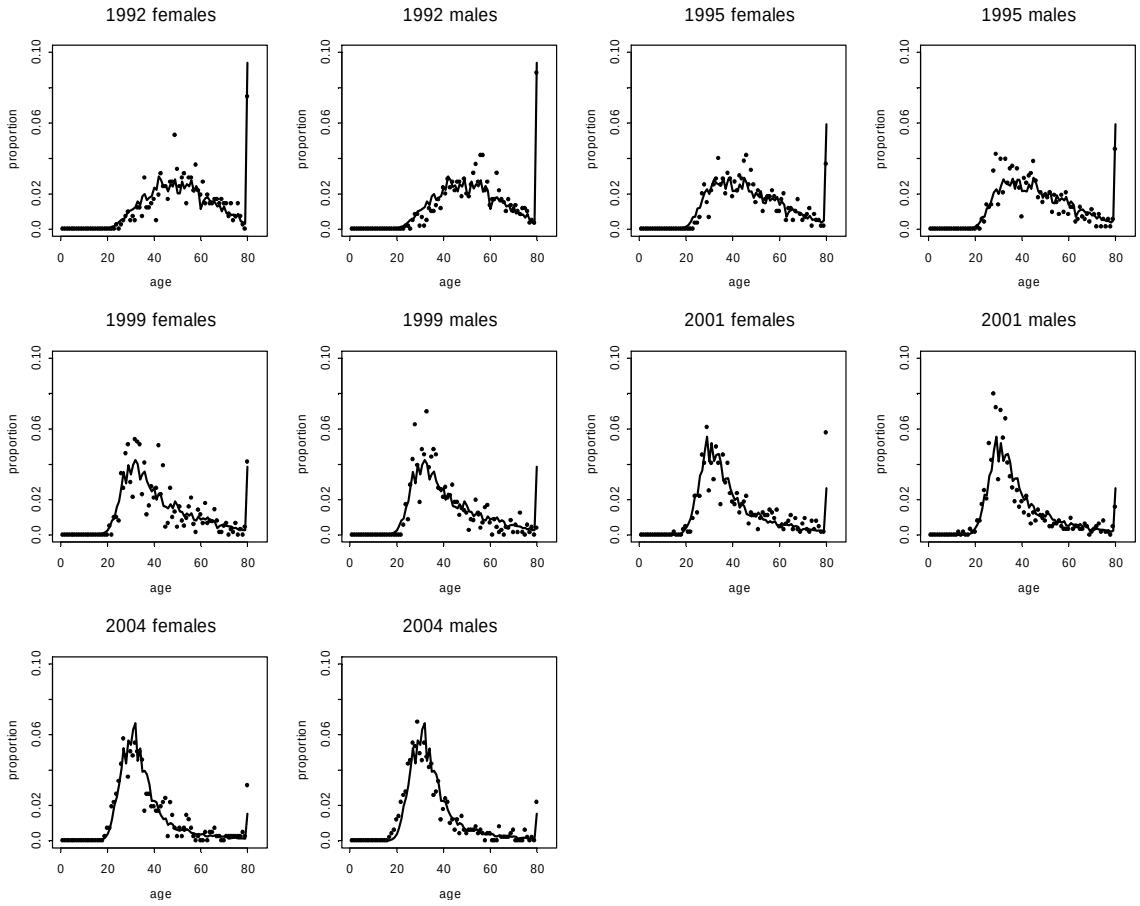


Figure 26.5 Fitted (lines) and observed (points) age distributions

26.3.2 Sensitivity tests

The results for all scenarios tested are summarised in

Table 26.6. Note that female spawning biomass, rather than vulnerable biomass as in previous years, is reported as this is the metric required in the RBC.

Two main scenarios were tested – a single fleet model using all age composition data (‘with age’scenario), and a single fleet model not using age composition data, but using selectivity and mortality estimated from the model using the age data (‘no age’ scenario). While it is preferable to use all the age composition data as this estimates recruitment residuals, it has been questioned whether age composition data are representative of the entire fishery. In the only data set for which length composition data are available from the aged fish and the broader fishery (Bax and Green 2005) aged fish lacked the smaller and larger fish observed in the broader fishery. This suggests that recruitment residuals estimated from age composition data may not be realistic for this fishery. At the same time, the trend in recruitment residuals observed for this fishery (less than average recruitments for fish aged 30-60 years in 2006) has been observed for NZ fisheries, and as there is no obvious environmental correlate, the trend was questioned by the 2002 review. The alternative to estimating recruitment residuals is to

use long-term mean recruitment (ie. no age composition). If recruitment of fish that are 30-60 year old in 2006 is in fact lower than average, this approach will overestimate current stock status and future rate of recovery.

Models using different stock structure hypotheses with age data were not run as they were tested in the preliminary Eastern Zone analysis (Wayte 2006), and found to all produce similar results in terms of estimated stock depletion (below 20% B_0). They will however estimate different levels of current biomass, so the rebuilding RBCs for the scenarios where RBCs are non-zero will be different. The 'no age' scenario has been run for the different stock structure hypotheses.

For the scenario using all data (run 1), the ratio of 2007 female spawning biomass to SB_0 is 10%, and thus the 2007 RBC is 0 t for all versions of the harvest control rules. Spawning biomass is expected to reach 20% SB_0 in 2014.

The comparable 'no age' scenario (run 2) is considerably more optimistic in terms of the stock remaining. This is because when fitting to the age data, recruitment is estimated to have been poor for fish aged 30-60 years in 2006 (Figure 26.4). This age range covers the bulk of the available stock. When age data are not used, the recruitment deviations are not estimated and so recruitment is assumed to be at average levels for all years. For this scenario the percentage of stock remaining is estimated to be 27%, and the 2007 RBC ranges from 672 t to 1,087 t for the three harvest control rules.

The runs using 'no age' and different stock structures estimate depletion ranging from 25 to 29 %, and different absolute stock sizes. However, there is not a great variation in the estimated RBCs – for the 48:48:20 rule the 2007 RBC ranges from 642-807 t; for the 48:40:20 rule from 749-942 t; and for the 40:40:20 rule from 1,039-1,308t.

Table 26.6. MPD (mode of the posterior density) results for all scenarios tested. The scenario label describes the variation of the run from the base-case. For the scenarios where age data is used, natural mortality and selectivity parameters are estimated. For scenarios where no age data is used, natural mortality and selectivity parameters are fixed at the values estimated using the age data.

scenario	**Female SB_0**	**Female SB_{2007}**	**SB_{2007} / SB_0**	**M**	**Size at 50% selection**	**Width for 95% selection**	**2007 RBC**			**Year in which reach 20% SB_0 using 48:48:20**
							40:40:20	**48:40:20**	**48:48:20**	
1 One fleet, 'with age' ; catches east + PB	40,746	4,227	0.10	0.042	35.8	2.25			0	2014
2 One fleet, 'no age' ;catches east+Pedra Branca	60,658	16,434	0.27	0.042	35.8	2.25	1,087	784	672	(2001)
3 'no age'; catches east	45,791	13,266	0.29	0.042	35.8	2.25	1,039	749	642	
4 'no age'; catches east + south	80,625	21,202	0.26	0.042	35.8	2.25	1,308	942	807	
5 'no age'; catches east + south + west	86,097	21,257	0.25	0.042	35.8	2.25	1,063	765	655	

26.3.3 Future projections

The future projections of stock depletion and catches for the 'with age' and 'no age' models are shown in Figure 26.6. The recommended biological catch (RBC) under all versions of the Tier 1 harvest control rule for the 'with age' scenario is 0 t. A projection into the future, applying the 48:48:20 harvest control rule each year indicates that the biomass will reach the limit level of 20% unfished in 2014.

The dip in the catches from 2030 reflects the anticipated effect of the fishery on recruitment. Recruits entering the fishery from 2020 onwards will have been affected by the reduction in spawning biomass due to fishing. To investigate the effect of applying different future catch regimes, another future projection was performed using the scenario with all data, but with the RBC catch series estimated from the no age model (run 2) under the 48:48:20 control rule. The future projection of stock remaining for this run is also shown in Figure 26.6.

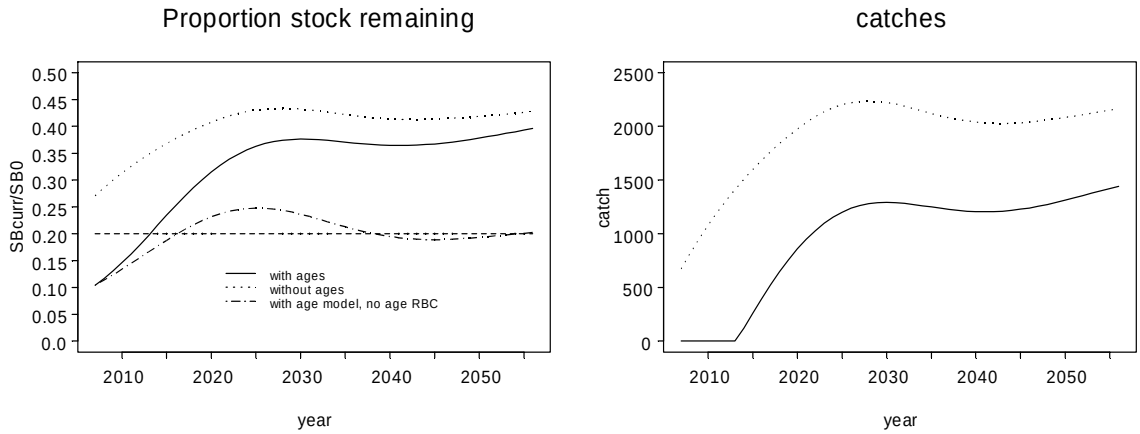


Figure 26.6. RBC calculations for the 48:48:20 HCR for the scenarios with and without fitting to age, and the estimates of proportion of stock remaining if the 'no age' RBCs are applied to the 'with age' scenario.

Table 26.7 shows that if the RBCs calculated from the no age model are applied to the model with all data, then the stock becomes considerably more depleted (0.19) in ten years time than if the age data RBCs are applied (0.25). Under this scenario, the stock reaches the limit level of 20% unfished in 2017.

Table 26.7. Proportion of stock remaining in ten years and catch over ten years using different future catch regimes.

Model	Future catches	Prop. remaining in 2016	Total catch 2007-2016
One fleet with age	RBC 48:48:20	0.25	777
One fleet with age	RBC 48:48:20 from no age model	0.19	12,199
One fleet, no age data	RBC 48:48:20	0.38	12,199

All of these results are based on the MPD estimates rather than the more accurate MCMC estimates, and should be interpreted with caution. There was not enough time available for calculation of the MCMC estimates.

The RBC is only one of two management decision rules that govern catch levels in fishery. Under the second management rule, fishing may not be allowed until there is at least a 90% probability of the biomass being greater than 20% prefishery biomass. This probability cannot be estimated until the MCMC runs are completed.

26.4 Discussion and conclusions

The model results provide essentially two scenarios:

1. When all data are used, a reduced recruitment of fish aged between 30-60 in 2006 leads to a stock biomass below the 20% limit reference point, at which catches should be set at zero. Stock biomass is predicted to rise above 20% in 2013.

2. When age composition data are not used to estimate recruitment residuals, and constant average recruitment is assumed, the stock biomass is estimated at 27% and the RBC indicates a catch of 672 t – 1,087 t (depending on which HCR is used).

A sensitivity analysis assuming that the 'with age' scenario is correct but with the catch of the 'no age' scenario was carried out to explore risk to recovery times for the fishery. Under this scenario, the stock reaches the limit level of 20% unfished in 2017, as compared to 2014 for the scenario using the 'with age' RBCs.

No times for recovery of an overfished stock have been specified for orange roughy. As a guide DeepRAG is using the US west coast specifications of a minimum of 10 years and maximum of 10 years plus one generation. For orange roughy this would make the maximum time for recovery approximately 40 to 45 years. The following additional points can be made:

1. The 2002 reviewers suggested that due to the great age of orange roughy and the possible shallow slope of the stock-recruitment relationship there was little value in unduly reducing catches in the short-term if negative impacts on the fishery outweighed any gains from reaching rebuilding targets earlier. It was more important that catches be set at a rate that permitted measurable recovery within a reasonable time frame.

2. There was no significant difference between the stock biomass estimates in 1999 and 2006, however earlier model projections indicated that a measurable increase in biomass would not be detected until 2025 even under a zero catch regime.

3. An index of recovery abundance will have more value in determining the recovery of the orange roughy stock and be more informative for the assessment model. A repeat of the Eastern Zone monitoring strategy that provides yearly checks on biology and biomass distribution with a more precise multi-frequency survey every 5 years would be of value.

26.5 Acknowledgements

Thanks to Nic Bax and Rudy Kloser (CSIRO) for valuable contributions to this document. Thanks to André Punt (CSIRO) for help with SS2. Thanks to Tim Ryan, Jemery Day and Tony Smith (CSIRO) for useful discussions.

26.6 References

Bax , N. and Green, C. 2005. Orange Roughy Age Compositions Western Zone II Southern Zone I, With Some Notes On Ageing Smooth Oreo Dory. Report to DAG November 2005

Kloser, R.J., T.E. Ryan, A.Williams, M.Lewis 2001. Development and application of a combined industry/scientific acoustic survey of orange roughy in the Eastern Zone. FRDC project 99/111.

Koslow, J.A., C.M. Bulman, J.M. Lyle, and K.A. Haskard. 1995. Biomass assessment of a deep-water fish, the orange roughy (*Hoplostethus atlanticus*), based on an egg survey. Marine and Freshwater Research 46: 819-30.

Kloser, R.J. and Ryan, T.E. 1999. Review of analysis methodologies and data holdings for acoustic assessments of orange roughy on St Helens Hill, 1989-1999. ORAG report.

Methot, R.D. 2005. Technical description of the Stock Synthesis II Assessment Program. Version 1.17

Smith, A.D.M. and S.E. Wayte (eds) (2002) *The South East Fishery 2002*, Fishery Assessment Report compiled by the South East Fishery Assessment Group. Australian Fisheries Management Authority, Canberra.

Smith, A. (2006) Guidelines regarding implementation of the SESSF Harvest Strategy Framework for 2006. July 2006

Wayte, S.E. (2003) Estimating time to detectable increase in the Eastern zone orange roughy stock. Unpublished report to ORAG, June 12-13 2003.

Wayte, S.E. (2006) Eastern Zone Orange Roughy. Preliminary 2006 assessment. Discussion document provided to Deepwater Assesament Group August 2006.

27. Updated Stock Assessment for Deepwater Flathead (*Neoplatycephalus conatus*) and Bight Redfish (*Centroberyx gerrardi*) in the Great Australian Bight Trawl Fishery Using Data to June 2006

Neil L. Klaer[1] and Jemery Day[1]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

27.1 Background

Deepwater flathead (*Neoplatycephalus conatus*) and Bight redfish (*Centroberyx gerrardi*) have been trawled sporadically in the Great Australian Bight (GAB) since the early 1900s (Kailola et al., 1993). The GAB trawl fishery (GABTF) was set up and managed as a developmental fishery in 1988, and since then a permanent fishery has been established with steadily increasing catches of both species. Deepwater flathead are endemic to Australia and inhabit waters from NW Tasmania, west to north of Geraldton in WA in depths from 70m to more than 490m (Kailola et al., 1993). Bight redfish are also endemic to southern Australia, occurring from off Lancelin in WA to Bass Strait in depths from 10m to 500m (www.fishbase.org).

27.1.1 Previous assessments

An initial stock assessment workshop for the GABTF held in 1992 focused on the status of deepwater flathead and Bight redfish. Sources of information for the workshop included historical data, logbook catch data, observer data and biological information. At this time, the short history of the managed fishery precluded any stock assessment based on a time series of catch and effort data. Therefore, logbook data were examined on a shot-by-shot basis to make biomass estimates using an 'area-swept' approach. Catch per unit area (kg/km^2) was calculated for quarter-degree squares and then scaled up by the total area in which the species had been recorded. The approximate exploitable biomass estimates for deepwater flathead and Bight redfish obtained by this crude method were 32000 t and 12000 t respectively (Tilzey and Wise 1999). Large uncertainties in the method prevented calculation of error bounds. Using growth and mortality data together with these biomass estimates, sustainable yields were estimated to be 1500-3000 t for deepwater flathead and 200-400 t for Bight redfish.

Wise and Tilzey (2000) summarised the data for the GABTF focusing on deepwater flathead and Bight redfish, the two principle commercial species in shelf waters. They produced the first attempt to assess the status of these deepwater flathead and Bight redfish populations using age- and sex-structured stock assessment models. The virgin total biomass estimates for the base case model were 53760 tonnes (95% confidence interval is 2488-105032 tonnes) for deepwater flathead and 9095 tonnes (95% confidence interval is 4924-13266 tonnes) for Bight redfish. In 2002 an updated assessment was carried out including data up to 2001. The unexploited biomass

estimates for the base case model were 12876 (95%CI=11928-13824) tonnes and 9563 (95%CI=8368-10759) tonnes for deepwater flathead and Bight redfish, respectively.

GABTF assessments in 2005 (Wise and Klaer, 2005; Klaer, 2005) continued to use a custom-designed integrated assessment model developed using the AD Model Builder software (Otter Research Ltd. 2000). A series of fishery-independent resource surveys was also commenced in 2005, providing a single annual biomass estimate for Bight redfish and deepwater flathead (Knuckey et al., 2005). Although it was recognized that the survey was designed to provide relative abundance estimates after several years of operation, at this early stage preliminary absolute abundance estimates were made using swept area methods from the survey data. The unexploited biomass levels estimated for the base case models were 20,418t and 13,932t for deepwater flathead and Bight redfish, respectively. Current depletion levels were estimated at over 100% for deepwater flathead due to recent large recruitments and 75% for Bight redfish. The absolute biomass estimate from the survey was consistent with other fishery data for deepwater flathead, but was much greater than the biomass modelled without the survey for Bight redfish.

27.1.2 Modifications to the 2006 assessment

The intention for the 2006 assessment was initially to duplicate as far as possible the assessment results from 2005 (Wise and Klaer, 2005; Klaer, 2005). The same biological parameter values and input data were used, but the population dynamics model was Stock Synthesis 2 (SS2) as documented by Methot (2005). The advantage of switching stock assessment models to SS2 are (a) the SS2 model is used for a large number of other fisheries, particularly in NW USA and the Australian SESSF fisheries, so has been well tested (b) there are advantages in standardising stock assessment models so that output can be standardised and become familiar to RAGs (c) stock assessment scientists trained to use SS2 can more easily work on different species (d) a library of existing stock assessments can be used as a reference resource for stock assessments on new species (e) stock assessment input file structures can be standardised and automated.

Although it was possible to replicate 2005 results reasonably well, there are a few differences in the model structure implemented in SS2:

- Recruitment deviations are estimated independently
- Recruitment deviations are allowed to occur for a period prior to commencement of the fishery approximately equal to the maximum age that the species attains

27.2 Data available for assessment purposes

Sources of available data for deepwater flathead and Bight redfish include values for biological parameters, landed catches, catch-rates, age-frequencies and fishery-independent biomass surveys.

27.2.1 Biological parameters

Analyses of biological samples collected during the 2004 GAB reproductive study (1), length and age samples collected between 2000-2003 (2) and length samples collected during the 2001 FRDC project (3) were used to update the biological parameters (Table 27.1).

Table 27.1. Biological parameters.

	Source	Parameter	Parameter values			
			Deepwater flathead		Bight redfish	
			Female	Male	Female	Male
Years		y	1988-2006		1988-2006	
Age classes		a	0-30 years		0-65 years	
Sex ratio		p_s	0.5 (1:1)		0.5 (1:1)	
Natural mortality		M	0.2 per year		0.1 per year	
Female maturity	1		40 cm (TL)		25 cm (LCF)	
Growth	2	L_∞	69.82 cm (TL)	50.56 cm (TL)	38.45 cm (LCF)	
		K	0.195 per year	0.346 per year	0.108 per year	
		t_0	-0.637 years	-0.468 years	0 years	
Length-weight	3	ϕ_1	0.002 cm (TL)/gm	0.002 cm (TL)/gm	0.128 cm (LCF)/gm	0.144 cm (LCF)/gm
		ϕ_2	3.332	3.339	2.559	2.522

27.2.2 Catches

Catches for deepwater flathead and Bight redfish were taken directly from CDR landings data for the GABTF maintained by AFMA. Catch estimates for the period 1988/89 to 2005/06 are given in Table 27.2.

Table 27.2. Financial year catch of deepwater flathead and Bight redfish.

	Catch (kg)	
	Deepwater flathead	Bight redfish
88/89	312491	85651
89/90	394672	170833
90/91	420152	281808
91/92	608128	265612
92/93	508162	120698
93/94	585072	107472
94/95	1254803	157803
95/96	1551593	173922
96/97	1459341	327177
97/98	1010348	372617
98/99	680659	437788
99/00	544992	323641
00/01	776912	387879
01/02	913871	228094
02/03	1607575	363913
03/04	2191417	842280
04/05	2283671	986390
05/06	1545604	789704

27.2.3 Catch rates

Catch rates were previously standardised using Generalised Additive Models (GAMs) (Hobsbawn et al. 2002a, 2002b). Standardisations for a range of SESSF species are carried out each year by the University of Tasmania (see Haddon, 2006). It is expected that next year, standardisations for deepwater flathead and Bight redfish will be added to the list of SESSF species processed in a standard manner. In preparation for this, a standardisation was carried out for GAB species this year that is more comparable to that of Haddon (2006) than Hobsbawn et al. (2002a, 2002b). Data filtering and factors to be examined were chosen to match with the methods of Haddon (2006), although the form of the model was a simple log-linear (LM) one rather than a Gereralised Linear Model (GLM).

Only data that conformed to the following filtering criteria were examined:

- Boats included if median annual catch greater than 4t and have caught the species for 3 or more years;
- Depth<1000m;
- Non-zero species catch;
- Shot length >1.0 hr <10.0 hr.

The following factors were included for examination of their effects on catch rate:

- Year (Financial)
- Month
- Zone: int(Longitude/5.0)
- Depth: int(Depth/50)
- Vessel

The form of the model used in the R statistical package was:

```
sSP.glm <- lm(datSP.CPUE~datSP.year+
           datSP.month+datSP.zone+
           datSP.depth+datSP.vessel, data= datSP)
```

where CPUE for each fishing operation is log(catch/hours trawled).

Table 27.3. Year factor values from GAB log-linear model.

	Standardised CPUE	
	Deepwater flathead	Bight redfish
88/89	8.99	3.21
89/90	8.37	2.28
90/91	9.59	1.95
91/92	7.78	1.91
92/93	9.56	1.43
93/94	12.40	1.41
94/95	16.86	0.93
95/96	16.70	1.14
96/97	11.15	1.34
97/98	7.78	1.39
98/99	5.62	1.67
99/00	6.45	1.47
00/01	7.04	1.27
01/02	8.26	1.02
02/03	11.81	1.14
03/04	11.27	1.72
04/05	8.65	1.56
05/06	5.98	1.51

A comparison of LM model results with those presented previously using GAM is shown in Figure 27.1 and Figure 27.2.

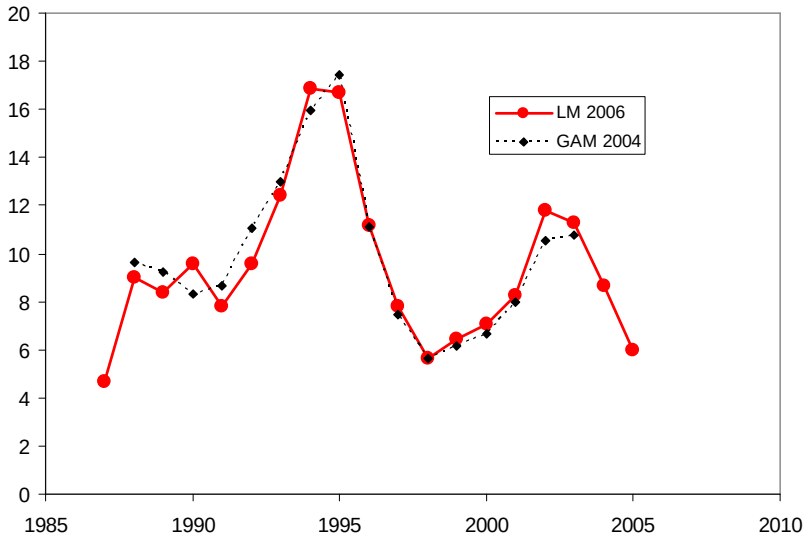


Figure 27.1. Deepwater flathead comparison of LM 2006 results with earlier GAM.

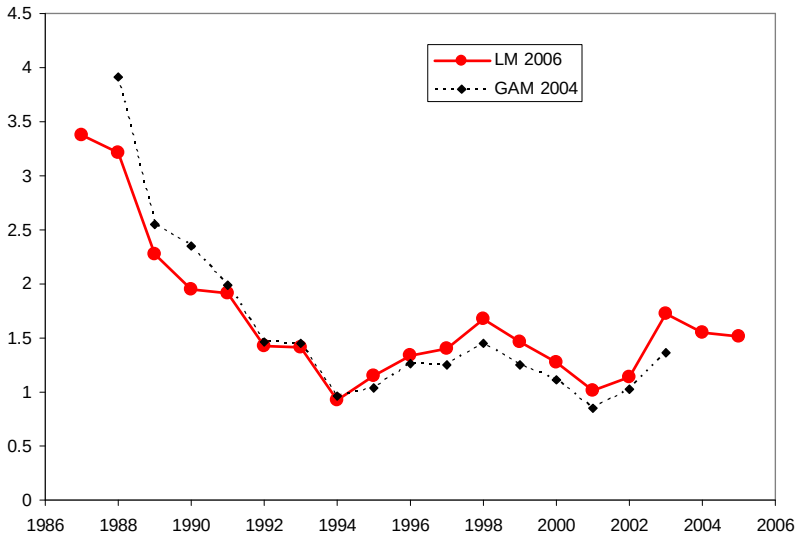


Figure 27.2. Bight redfish comparison of LM 2006 results with earlier GAM.

27.2.4 Fishery-independent survey

Absolute biomass estimates have been taken from Knuckey et. al. (2005), Knuckey (2006).

Table 27.4.Estimated "minimum" exploitable biomass (t) with coefficient of variation (cv) of deepwater flathead and Bight redfish in each stratum and across all strata. Estimates in bold are used in the analyses.

2005	Day and night (hauls=76)				Day time (hauls=37)				Night time (hauls=39)			
Door spread	103.4 m		16.3 m		103.4 m		16.3 m		103.4 m		16.3 m	
Species	t	cv	t	cv	t	cv	t	cv	t	cv	t	cv
deepwater flathead	1,916	0.05	**12,152**	**0.05**	1,903	0.09	12,070	0.09	1,899	0.06	12,046	0.06
Bight redfish	2,128	0.14	13,498	0.14	847	0.36	5,375	0.36	3,293	0.13	**20,887**	**0.13**

2006	Day and night (hauls=75)				Day time (hauls=38)				Night time (hauls=37)			
Assumed swept width	108.0 m		16.3 m		108.0 m		16.3 m		108.0 m		16.3 m	
Species	t	cv	t	cv	t	cv	t	cv	t	cv	t	cv
Deepwater flathead	1,297	0.05	**8,230**	**0.05**	1312	0.08	8322	0.08	1308	0.08	8299	0.08
Bight redfish	2,228	0.16	14,517	0.16	610	0.26	3869	0.26	3902	0.16	**24,753**	**0.16**

27.2.5 Age composition data

Age compositions were compiled from the ISMP by PIRVIC, and the files were then processed using the SESSF automated data processing system. The number of samples per year differs slightly from those presented in previous years because a small number of records were flagged and removed by the processing due to failure of record validity tests.

Table 27.5. Deepwater flathead financial year catch at age samples for females.

	Females									
Age	93/94	94/95	95/96	96/97	97/98	98/99	99/00	02/03	04/05	05/06
0	0	0	0	0	0	0	0	0	0	0
1	0	0	12	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0
3	1	0	0	0	0	0	0	0	6	1
4	3	0	1	0	3	17	13	3	43	8
5	22	0	4	2	20	39	47	26	77	33
6	35	0	17	11	38	50	39	66	44	39
7	33	3	26	22	61	54	36	142	22	19
8	29	4	40	34	52	68	29	63	23	5
9	20	2	24	28	54	36	22	44	20	4
10	13	5	21	18	36	44	19	22	12	7
11	19	2	15	19	18	24	17	21	7	7
12	17	0	10	9	21	16	9	18	4	7
13	7	2	11	8	23	8	11	13	0	2
14	2	4	7	7	18	7	6	9	2	2
15	2	3	14	3	12	6	8	3	2	0
16	1	3	10	1	6	8	4	5	1	2
17	3	0	5	0	5	3	1	2	0	0
18	1	1	2	2	6	2	2	2	0	0
19	0	1	2	0	2	1	0	0	2	0
20	0	0	2	0	3	2	2	0	0	0
21	0	1	0	1	2	2	0	2	0	0
22	0	0	0	0	0	2	0	0	0	0
23	0	0	0	0	2	2	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	2	0	0	0	0
26	0	0	0	0	1	0	0	1	0	0
27	0	0	0	0	1	0	0	0	0	0
28	0	0	0	0	0	1	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
	208	31	224	165	384	394	265	442	265	136

Table 27.6. Deepwater flathead financial year catch at age samples for males.

	Males									
Age	93/94	94/95	95/96	96/97	97/98	98/99	00/01	02/03	04/05	05/06
0	0	0	0	0	0	0	0	0	0	0
1	0	0	5	0	0	0	0	0	0	0
2	0	0	0	0	1	1	0	0	0	0
3	0	0	0	0	6	15	5	1	12	0
4	10	0	3	1	21	83	92	9	63	30
5	27	0	13	4	59	161	129	31	55	48
6	23	3	18	13	75	93	42	17	36	26
7	29	11	34	12	97	81	20	37	22	7
8	15	6	22	11	49	76	5	13	27	12
9	11	5	17	13	50	65	11	12	23	11
10	9	3	17	9	45	37	9	3	14	10
11	5	8	23	16	26	33	7	3	5	6
12	7	9	17	5	22	29	3	2	4	4
13	1	4	4	15	10	19	6	2	2	5
14	3	2	5	4	10	13	2	3	2	1
15	2	1	9	1	12	10	1	2	3	1
16	2	3	6	1	5	12	1	0	5	1
17	0	1	3	6	3	4	1	1	3	1
18	4	1	3	4	4	8	1	1	3	0
19	0	1	2	4	5	5	0	1	2	0
20	0	2	0	0	1	1	0	0	3	1
21	0	0	2	0	1	1	0	0	0	1
22	0	0	2	0	0	2	0	0	0	0
23	0	0	1	2	0	2	0	0	0	1
24	0	0	0	0	1	0	0	0	0	1
25	0	0	0	1	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	1
27	0	0	0	0	0	1	0	0	0	0
28	0	0	0	0	1	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0
	148	60	206	122	504	752	335	138	284	168

Table 27.7. Bight redfish financial year catch at age samples for sexes combined.

Age	89/90	90/91	92/93	93/94	94/95	96/97	97/98	99/00	00/01	01/02	03/04	04/05	05/06
5	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	1	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	4	0
8	0	1	0	1	0	0	3	1	0	0	1	3	0
9	0	0	0	0	0	1	5	0	0	1	3	3	0
10	0	3	0	0	1	0	1	2	0	1	5	6	1
11	0	2	1	0	0	0	9	4	2	5	4	7	2
12	1	5	2	1	1	4	14	11	4	6	6	7	2
13	1	7	4	3	0	2	30	10	20	21	12	14	1
14	4	5	3	9	0	4	35	10	11	35	32	17	3
15	1	7	4	10	0	9	28	14	9	13	37	20	3
16	3	8	6	11	2	8	49	22	19	25	32	23	9
17	1	11	8	12	2	9	55	15	11	22	39	31	6
18	3	9	3	12	1	9	65	15	19	36	30	42	12
19	5	6	8	12	0	5	49	15	12	24	30	27	11
20	0	6	9	15	4	5	41	12	18	15	23	11	8
21	1	8	6	10	7	7	45	20	22	21	13	15	9
22	0	8	3	11	1	4	35	21	22	27	7	26	7
23	1	8	2	6	4	9	49	18	17	23	19	16	7
24	3	5	2	9	5	6	48	13	16	18	19	18	9
25	2	8	2	4	1	3	36	16	17	12	16	16	7
26	0	5	3	6	3	1	31	18	19	17	14	22	6
27	2	1	3	3	3	0	28	10	24	15	13	20	11
28	2	9	4	10	1	2	34	6	26	16	15	16	6
29	4	4	2	7	0	3	23	6	12	8	21	18	7
30	0	3	0	5	0	2	11	2	8	9	18	18	2
31	1	6	2	2	1	1	16	3	6	6	23	22	3
32	0	2	1	6	0	1	20	6	8	5	15	15	12
33	2	0	1	4	3	1	10	4	5	6	19	16	6
34	0	3	0	4	4	1	26	3	7	2	5	7	4
35	3	2	3	4	0	1	15	2	5	5	12	15	0
36	0	1	2	4	1	3	10	2	3	5	11	8	8
37	1	3	0	5	0	2	24	4	4	5	7	10	1
38	1	1	0	2	0	0	7	2	7	5	8	3	8
39	1	2	4	5	1	3	16	4	5	3	10	6	4
40	0	3	0	4	0	0	6	2	11	10	8	6	3
41	0	1	0	7	1	0	12	2	5	7	5	5	1
42	1	1	0	4	0	0	4	3	1	6	8	5	2
43	1	2	0	6	1	4	10	0	8	5	10	7	6
44	0	0	1	0	0	1	11	2	4	2	7	5	4
45	0	1	1	3	0	0	6	1	1	2	5	5	1
46	0	1	1	4	0	0	7	4	3	3	4	2	4
47	1	3	1	1	1	1	8	1	3	5	4	3	2
48	0	2	1	2	1	0	4	3	3	5	3	1	2
49	0	3	0	1	0	0	7	1	2	2	2	3	0
50	1	1	0	1	0	0	6	1	1	2	5	3	2
51	0	0	0	2	0	0	3	0	1	1	4	4	1
52	0	1	0	1	0	1	4	0	1	3	5	1	3
53	0	1	1	4	0	0	2	1	1	0	1	5	1
54	0	1	0	1	0	0	4	0	1	0	2	3	2
55	0	0	0	2	0	0	1	1	2	3	1	1	0
56	1	0	0	1	0	0	3	1	1	1	4	0	0
57	0	0	0	2	0	0	1	0	4	1	0	2	0
58	0	0	0	1	0	0	2	0	1	1	0	1	0
59	0	1	0	0	0	0	1	0	0	0	0	1	0
60	0	0	0	1	0	0	0	0	0	2	4	1	0
61	0	0	0	1	0	0	2	0	1	0	0	2	0
62	0	0	0	1	0	0	0	0	2	1	0	1	0
63	0	0	0	0	0	0	1	0	0	0	0	1	0
64	0	0	1	0	0	0	0	3	0	0	1	1	0
65	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	48	171	95	243	50	113	974	317	415	474	602	571	209

27.3 Analytical framework

27.3.1 Model and parameter estimation

The population dynamics model implemented in SS2 is documented in Methot (2005). Parameters estimated are initial recruitment levels, trawl selectivity and annual recruitment deviations.

27.3.2 Sensitivity tests

A series of sensitivity test is used to examine the sensitivity of the results of the model to some of its assumptions / the data inputs:

Model-related sensitivity tests

3) Vary *M* to values lower and higher than those of the base case.
4) Steepness = 0.65, Steepness =0.75 and Steepness=0.85.

Data-related sensitivity tests

5) Double and halve the residual standard deviations for the catch-rate indices.
6) Double and halve the effective sample sizes for the age-composition data.
7) Exclude the fishery-independent biomass survey.

27.3.3 Projection and calculation of the Recommended Biological Catch

The SS2 model includes the ability to calculate RBC values based on assessment scenario results and the Australian Tier 1 and 2 rule (see Wayte 2006 for details of how the Tier rules are implemented).

27.4 Results

27.4.1 Diagnostic fits to input data for the deepwater flathead base case

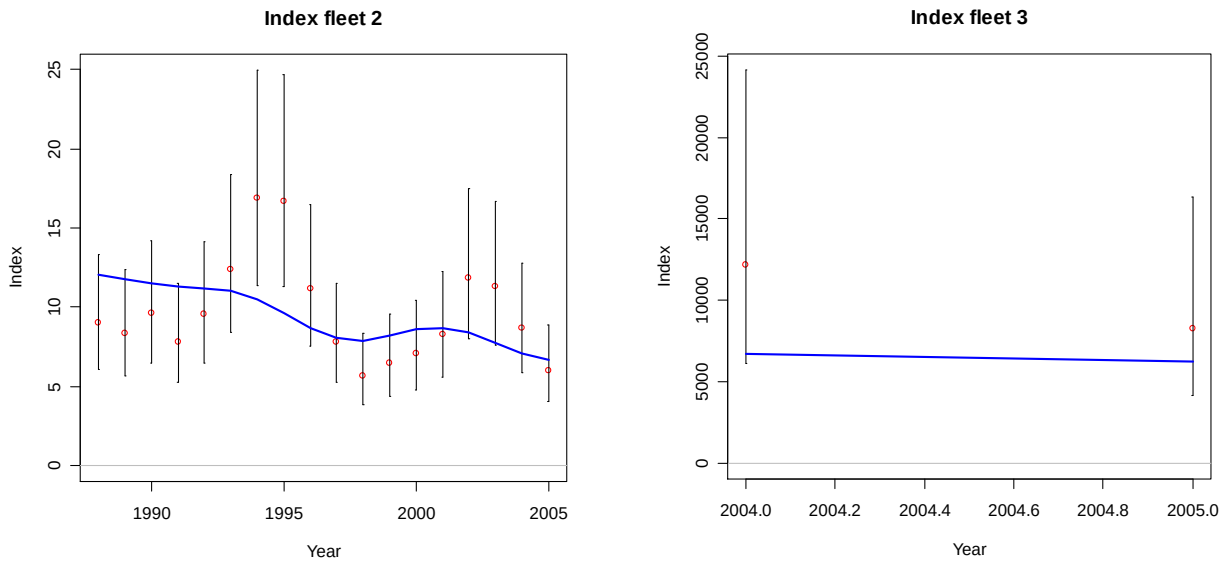


Figure 27.3 Model fits to CPUE and survey.

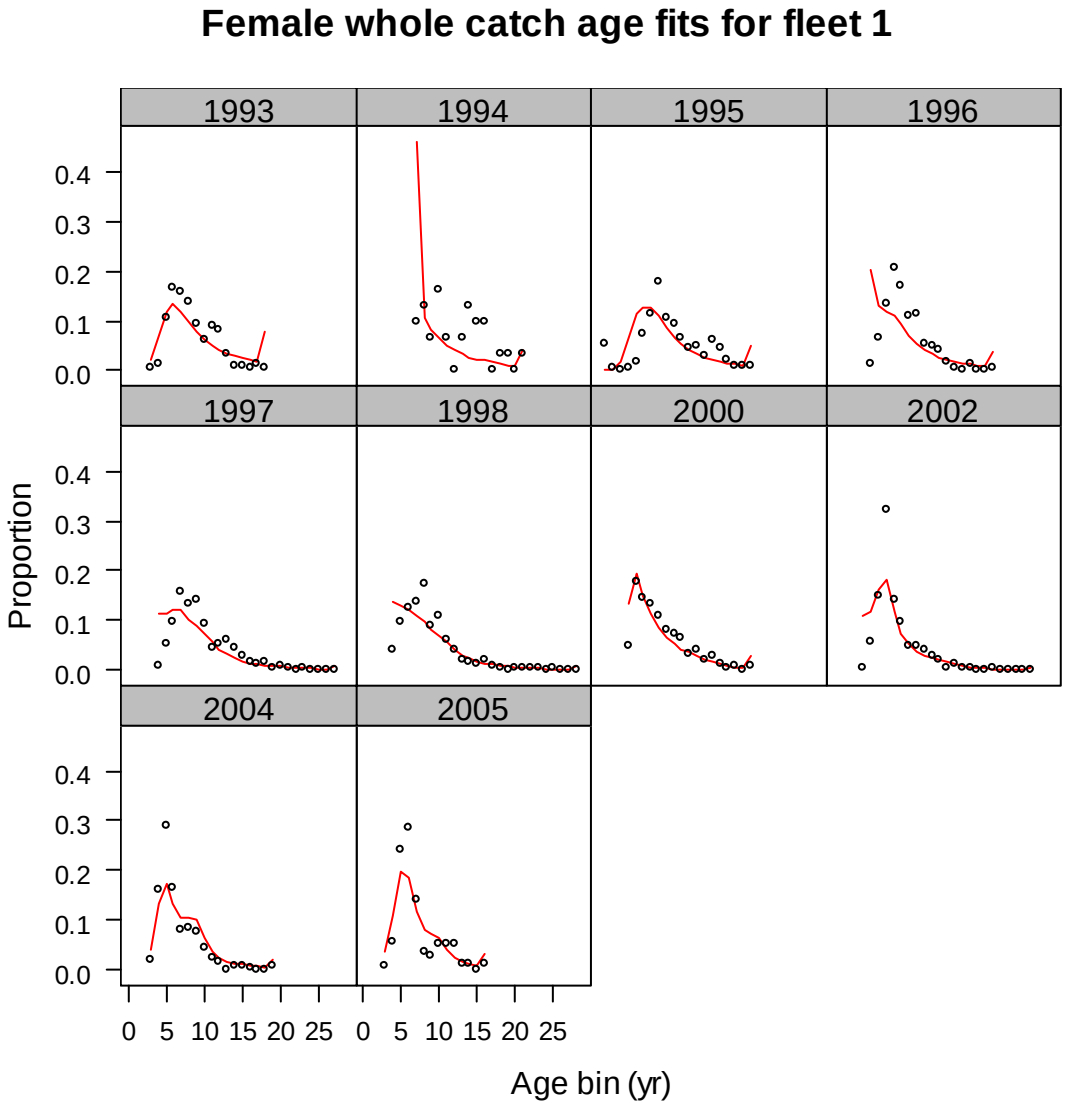


Figure 27.4 Model fits to female age frequency.

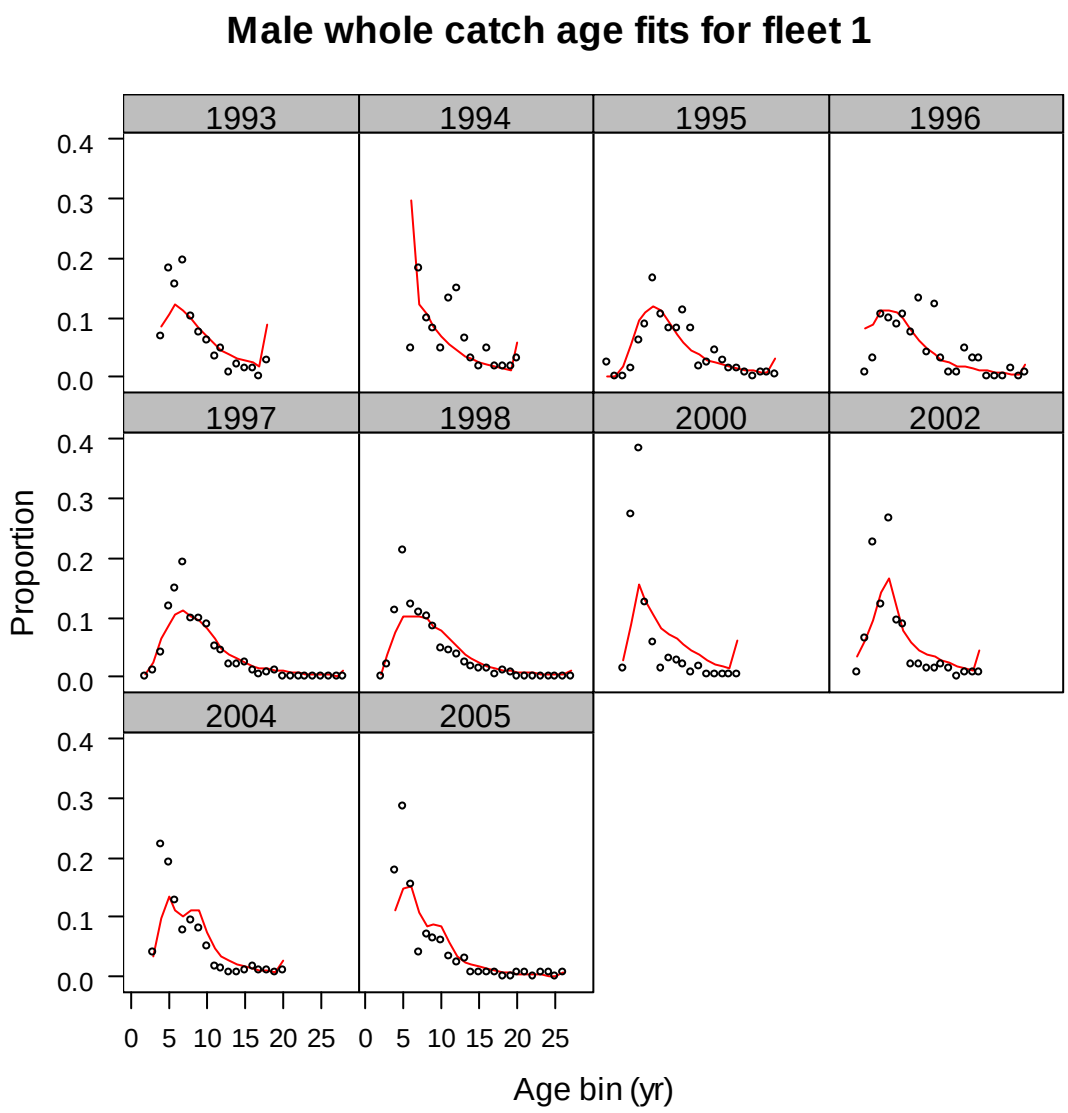


Figure 27.5 Model fits to male age frequency.

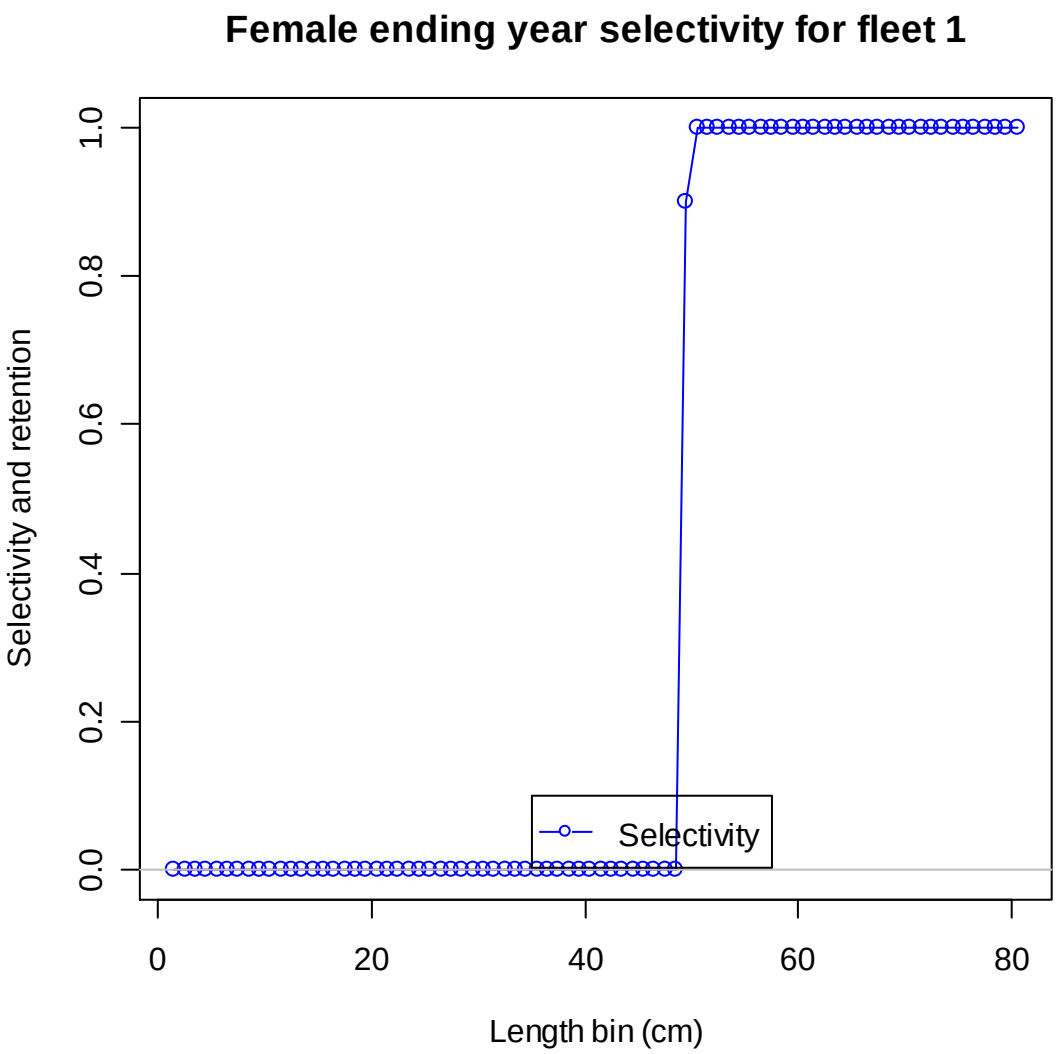


Figure 27.6. Size selectivity fits by fleet (female shown) for trawl.

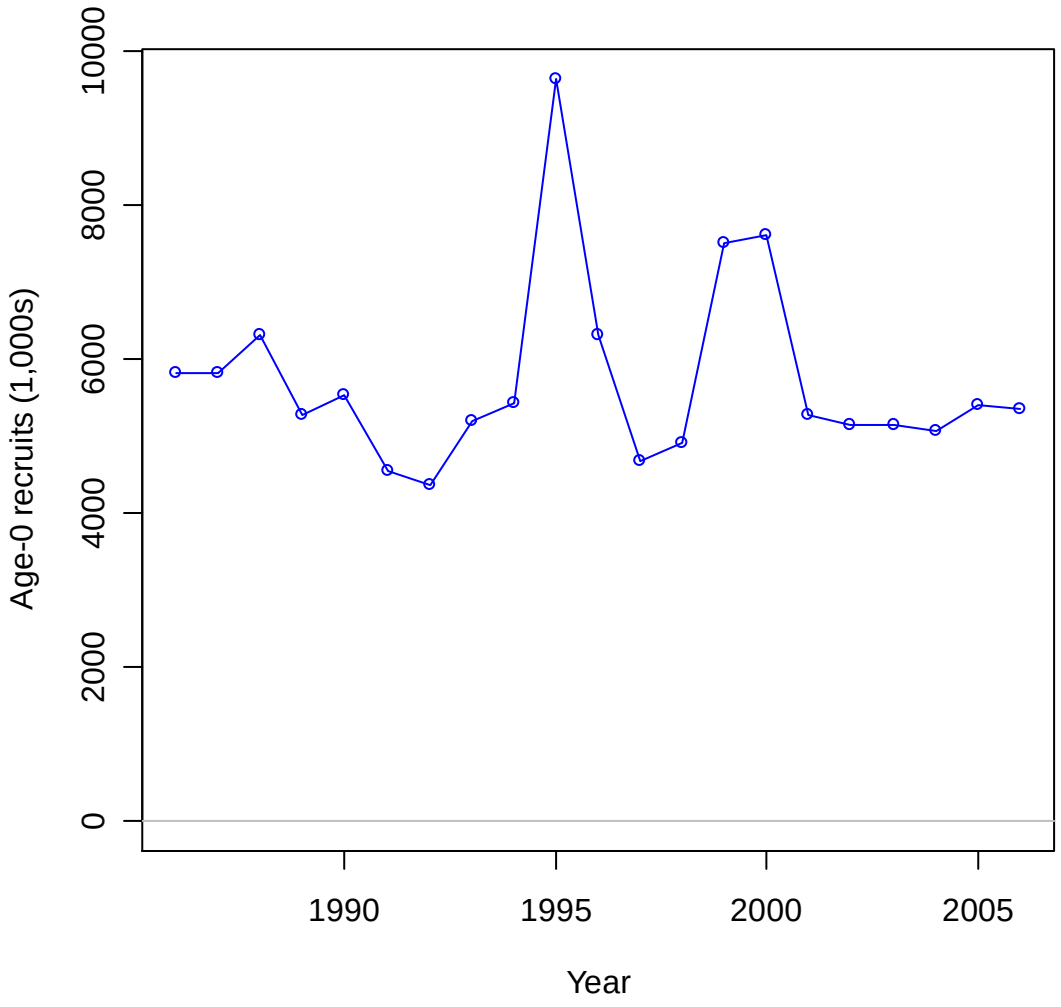


Figure 27.7 Recruitment time series for the base case.

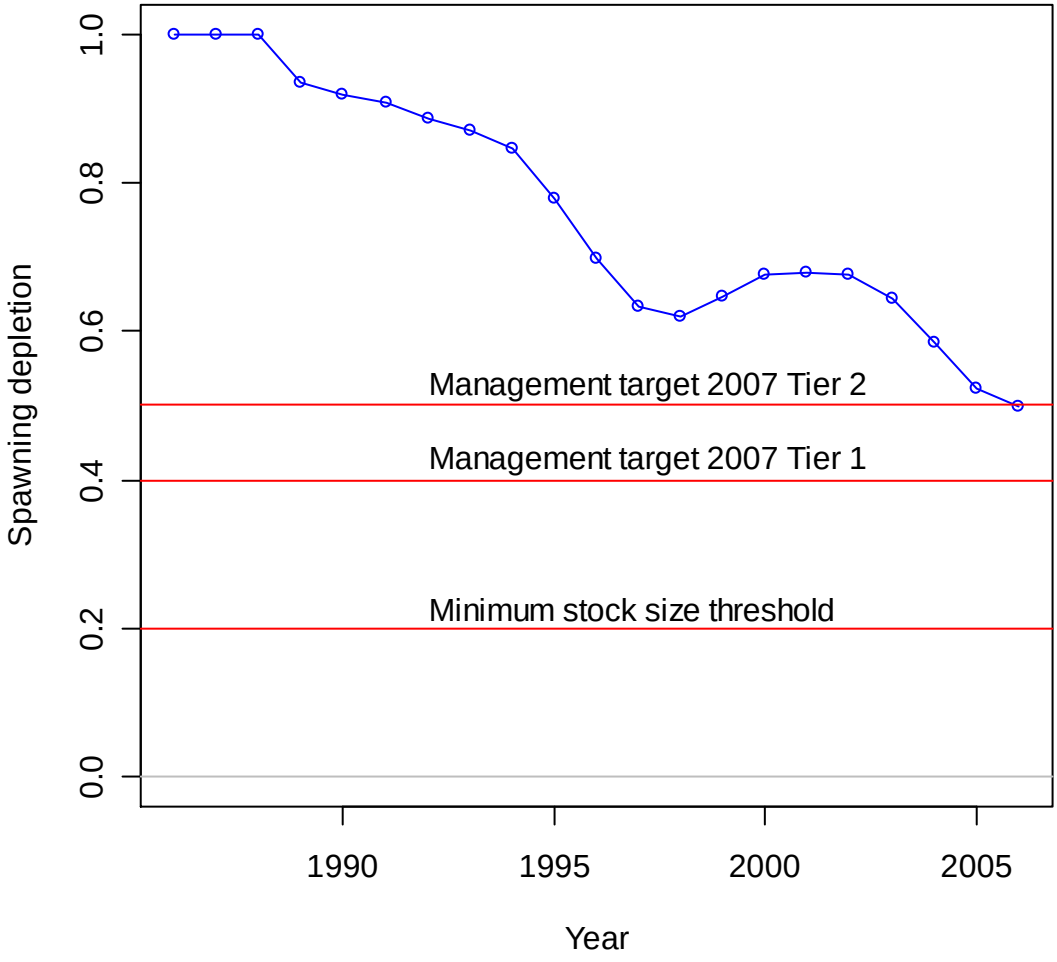


Figure 27.8 Spawning biomass depletion level per year for the base case.

27.4.2 Diagnostic fits to input data for the Bight redfish base case

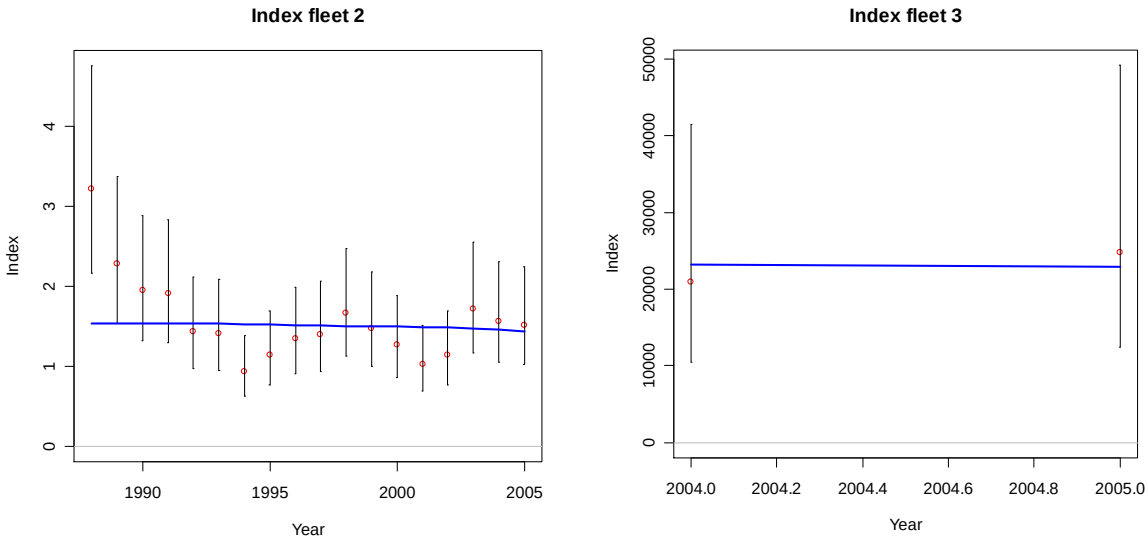


Figure 27.9 Model fits to CPUE and survey.

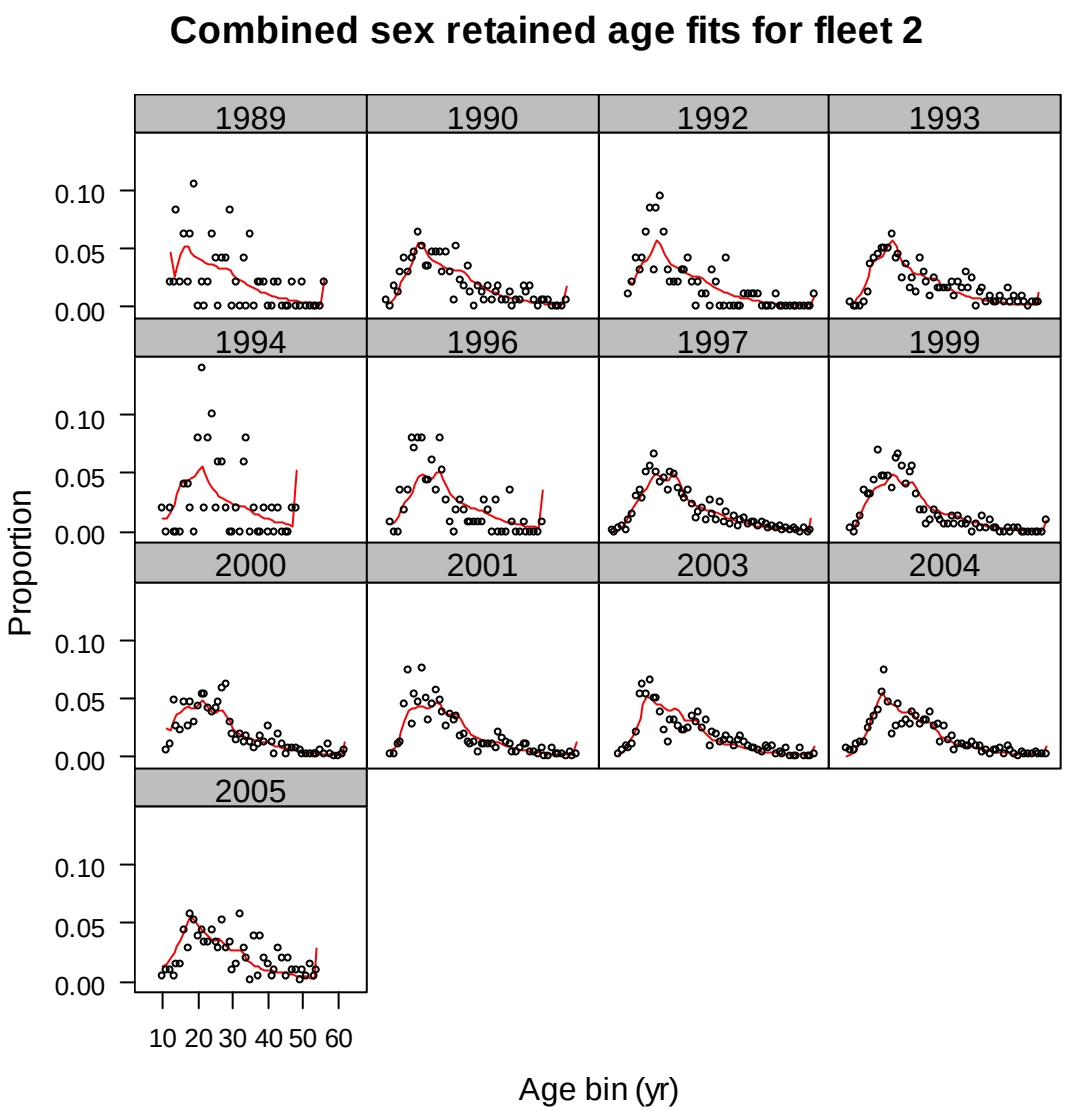


Figure 27.10 Model fits to combined age frequency.

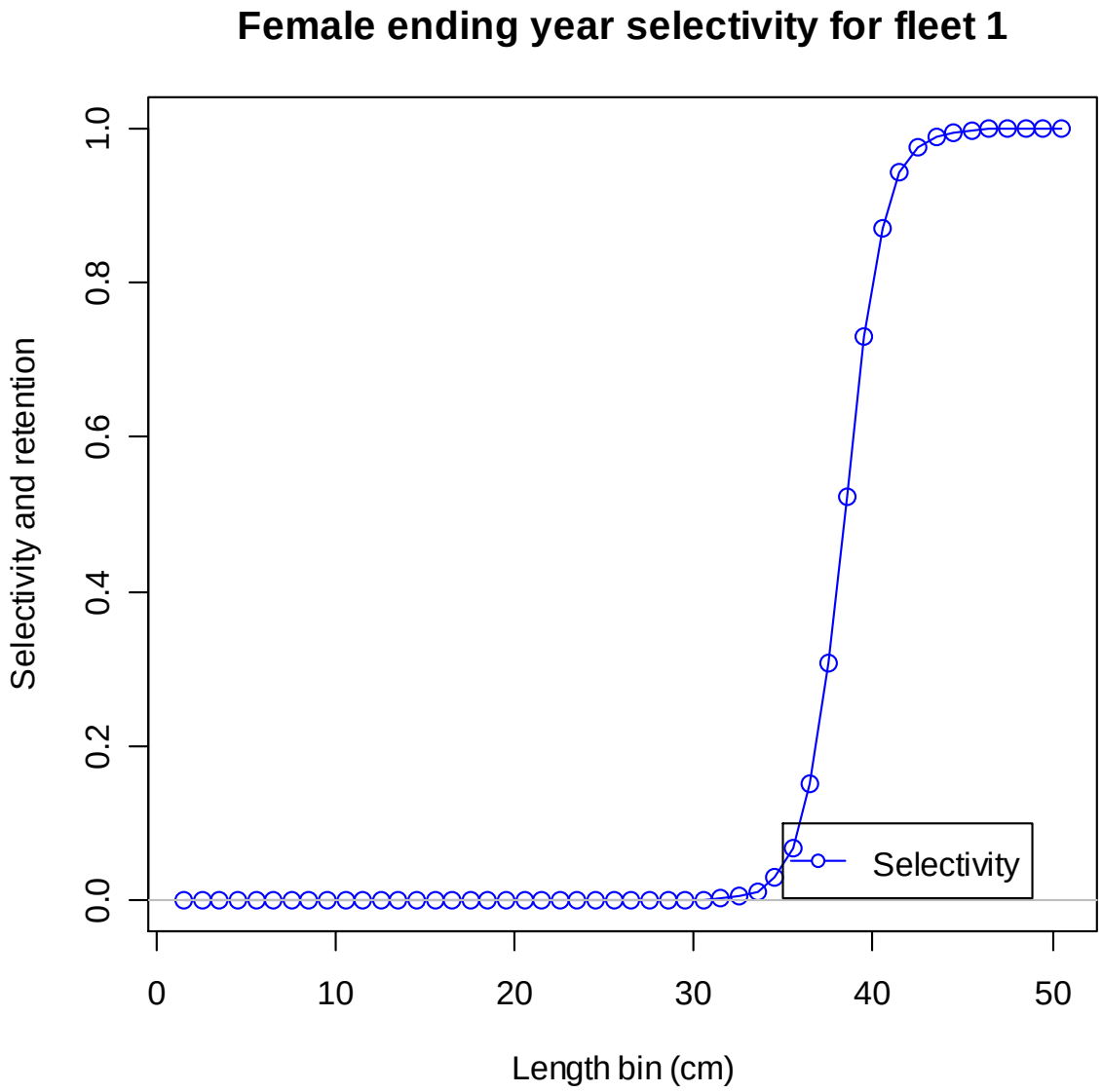


Figure 27.11 Size selectivity fits by fleet (female shown) for trawl.

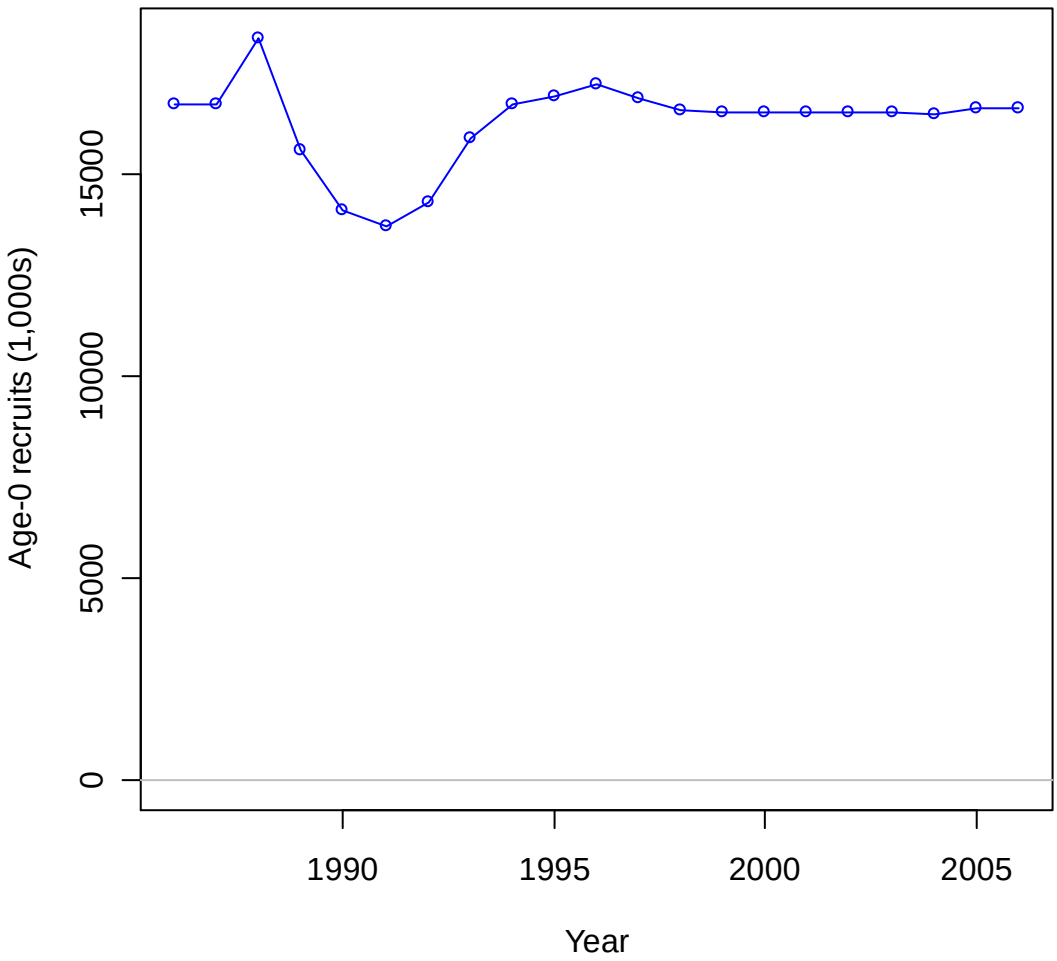


Figure 27.12 Recruitment time series for the base case.

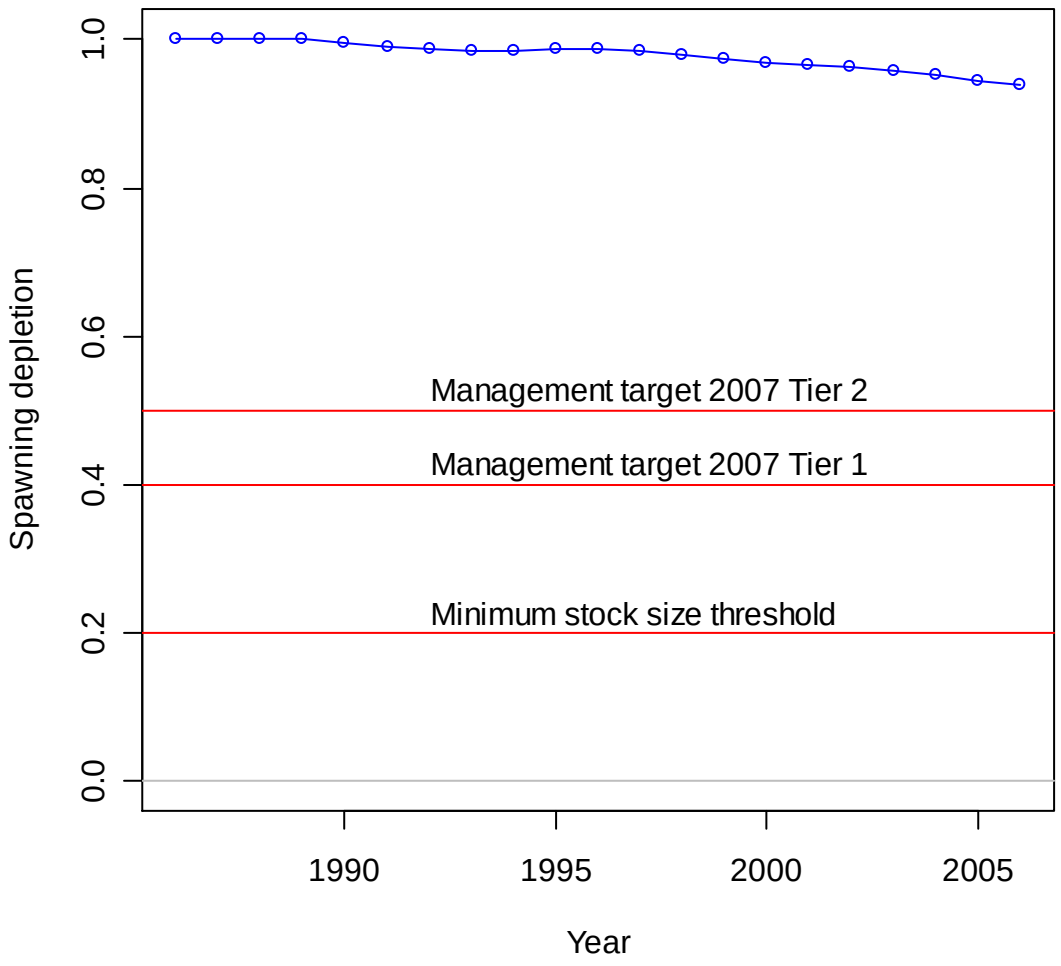


Figure 27.13 Spawning biomass depletion level per year for the base case.

Table 27.8 Summary statistics for the base-case analysis and the sensitivity tests for deepwater flathead. Values for the negative log-likelihood are only listed for those sensitivity tests that are comparable with the base-case analysis.

	Spawning biomass				
Scenario	1986	2006	2006 Depletion	RBC F50B50	$-\ell nL$
Base-case	10,087	5,042	50.0	1,070	176.421
M =0.15yr^{-1}	11,619	4,458	38.4	463	214.475
M =0.25yr^{-1}	11,889	8,102	68.2	2,484	156.267
Steepness = 0.65	10,251	5,043	49.2	954	177.114
Steepness = 0.85	9,931	5,033	50.7	1,161	175.902
Halve CPUE σs	10,629	5,777	54.4	1,225	
Double CPUE σs	9,633	4,455	46.2	893	
Half age sample sizes	11,665	6,189	53.1	1,264	
Double age sample sizes	8,389	4,040	48.2	909	
Ignore biomass survey	5,243	2,332	44.5	898	

Table 27.9 Summary statistics for the base-case analysis and the sensitivity tests for Bight redfish. Values for the negative log-likelihood are only listed for those sensitivity tests that are comparable with the base-case analysis.

	Spawning biomass				
Scenario	1986	2006	2006 Depletion	RBC F50B50	$-\ell nL$
Base-case	31,660	29,763	94.0	>4,040	251.772
M =0.05yr^{-1}	7,809	6,093	78.0	568	479.503
M =0.15yr^{-1}	43,231	42,029	97.2	>4,040	334.378
Steepness = 0.65	31,664	29,763	94.0	>3,700	251.767
Steepness = 0.85	31,657	29,766	94.0	>4,250	251.775
Halve CPUE σs	27,116	24,962	92.1	>3,400	
Double CPUE σs	33,137	31,349	94.6	>3,200	
Half age sample sizes	30,139	28,176	93.5	>3,800	
Double age sample sizes	33,338	31,528	94.6	>4,250	
Ignore biomass survey	86,047	83,162	96.6	>10,000	

Note: RBC values have been limited to the approximate long-term sustainable catch where they are much greater than current catches.

Table 27.10 Detailed assessment results for the base case scenarios.

Species	Tier	SSB_0 (t)	SSB_{cur}/SSB_0	F_{targ}	B_{targ}	RBC 2006/07
D flathead	Tier 1	10,087	0.50	40	40	1,544
	Tier 2	10,087	0.50	50	50	1,070
B redfish	Tier 1	31,660	0.94	40	40	>4,700
	Tier 2	31,660	0.94	50	50	>4,040

27.5 Future work

The following are some ways in which future assessments of tiger flathead could or should be improved.

- Incorporate commercial fishy length data into the model – investigate conditional age at length.
- Include discard values (although small).
- Continue investigation of appropriate ways to weight survey values versus other fishery data.

27.6 Acknowledgements

Matt Koopman, Anne Gason and Kyne Krusic Golub (PIRVic) are thanked for the provision of data. We thank Rick Methot (NOAA) and Andre Punt (CMAR) for their assistance with moving this assessment into SS2, and Andre in particular for reviewing the converted 2005 assessments. We also thank Sally Wayte and Geoff Tuck for our fruitful discussions during our regular SS2 modelling workshops.

27.7 References

Haddon, M. 2006. Standardized commercial catch-effort data for selected Shelf Assessment Group species. Document prepared for SESSF RAGs 2006.

Hobsbawn, P., Wise, B., and Tilzey R. 2002a. Analysis of logbook catch and effort data (1988-2001) for the Great Australian Bight Trawl Fishery (GABTF). (Background paper, GABFAG Canberra, 18 October 2002). BRS, Canberra.

Hobsbawn, P., Wise, B., and Tilzey R. 2002b. Standardisation of deepwater flathead and Bight redfish catch rates in the Great Australian Bight Trawl Fishery (GABTF). (Background paper, GABFAG Canberra, 18 October 2002). BRS, Canberra.

Kailola, P.J., Williams, M.J., Stewart, P.C., Reichelt, R.E., McNee, A and Grieve, C. 1993. Australian Fisheries Resources. Bureau of Resource Sciences, Canberra.

Klaer, N. 2005. Modified base case for Bight redfish (*Centroberyx gerrardi*) in the Great Australian Bight Trawl Fishery (GABTF) September 2005. Paper to GABRAG, September 2005.

Knuckey, I.. 2005. Preliminary Resources survey of the Great Australian Bight Trawl Fishery.

Knuckey, I., 2006. Independent trawl survey of the Great Australian Bight during 2006.

Methot, R.D. 2005. Technical Description of the Stock Synthesis II Assessment Program Version 1.17 – March 2005. NOAA Fisheries Internal Report.

Methot, R. 2006. User Manual for the Assessment Program Stock Synthesis 2 (SS2). NOAA Fisheries, Seattle, WA.

Otter Research Ltd. 2000. An Introduction to AD Model Builder. Otter Research Ltd., Nanaimo.

Thomson, R.B. 2002. South East Fishery data for stock assessment purposes. Draft CSIRO Report.

Tilzey, R. and Wise, B.S. 1999. Great Australian Bight Trawl Fishery. 1998 Fisheries Assessment Report. Australian Fisheries Management Authority, Canberra.

Wayte, S. 2006. Harvest strategy framework for the SESSF - Tier rules 1 and 2.

Wise, B. and Klaer, N. 2005. Updated Stock assessment of deepwater flathead (*Neoplatycephalus conatus*) and Bight redfish (*Centroberyx gerrardi*) in the Great Australian Bight Trawl Fishery (GABTF) September 2005. Paper to GABRAG, September 2005.

Wise, B. and Tilzey, R. 2000. Age structured modelling of deepwater flathead (*Neoplatycephalus conatus*) and Bight redfish (*Centroberyx gerrardi*) in the Great Australian Bight Trawl Fishery (GABTF). Bureau of Rural Sciences, Canberra.

28. Yield and Total Mortality Values and Tier 3 Estimates for Selected Shelf and Slope Species in the South East Fishery

Neil L. Klaer[1] and Robin B. Thomson[1]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

28.1 Introduction

This document updates yield analyses presented in Klaer and Thomson (2005) for major commercial species caught in the South East Fishery (SEF) on the shelf and slope. Much of the data processing and analysis has been automated, following procedures documented particularly in Thomson (2002a).

28.2 Methods

The fishery region and zones referred to here are as shown in Figure 28.1.

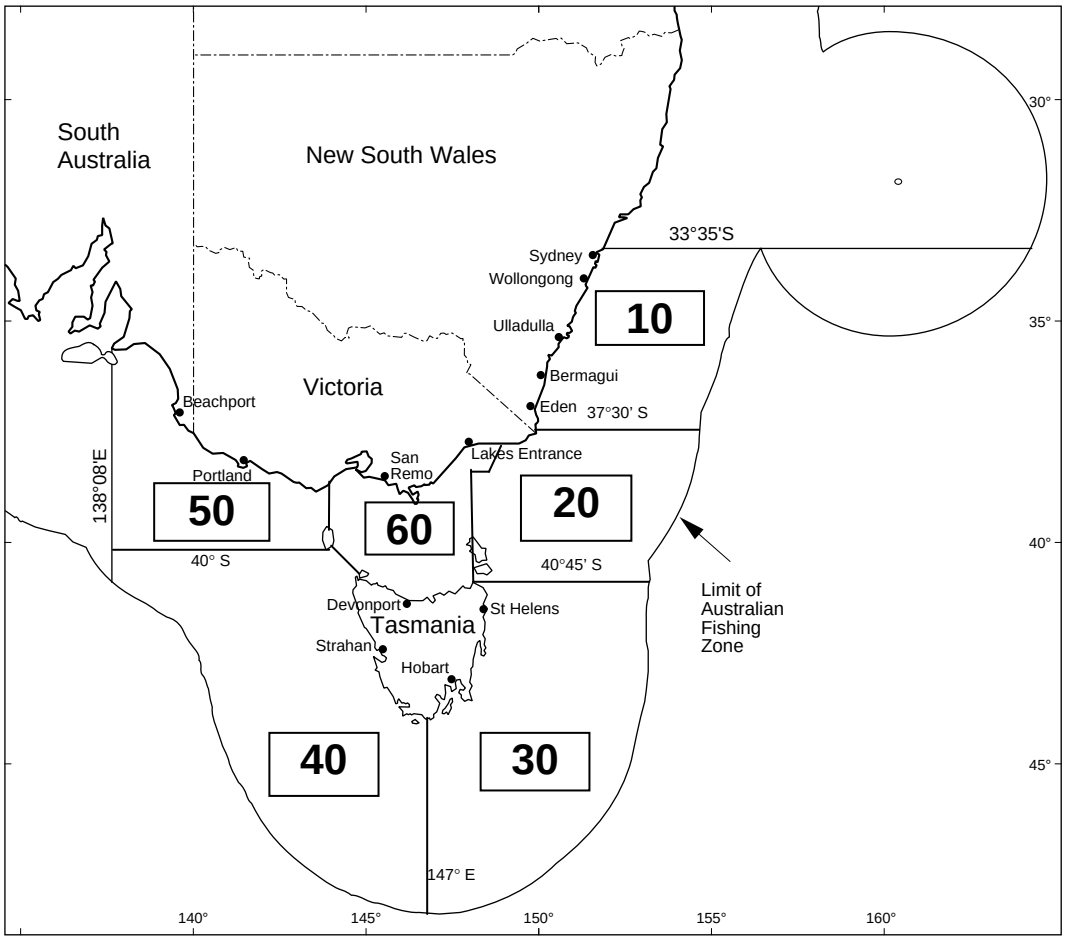


Figure 28.1. Map of the South East Fishery region showing the six zones

28.2.1 Yield Analysis

The information required for this calculation was: selectivity-at-age, length-at-age, weight-at-age; age-at-maturity; and natural mortality. The parameters used are shown in Table 28.1. A mix of shelf and slope quota species have been considered, and results are presented where the automated process appears to have produced sensible results, and where sufficient data were available. The AFMA abbreviations for the names of the quota species are also shown in Table 28.1.

Table 28.1. Population parameters used for yield analysis

	Flathead	Redfish		Morwong	Silver trevally	Spotted warehou	Blue warehou	John dory	School whiting	Mirror dory	Pink ling	Blue grenadier
Code	FLT	RED	RES	MOW	TRE	TRS	TRT	DOJ	WHS	DOM	LIG	GRE
Population	1	1	2	1	1	1	1	1	1	1	1	1
a_{max}	25	40	40	30	20	23	25	20	15	20	30	20
l_{max}	70	60	60	50	70	70	70	70	50	70	140	140
Fleets	2	1	1	2	2		2	2	2	2	2	2
a	0.0249	0.0577	0.0577	0.0429	0.0443	0.0153	0.03	0.046	0.013	0.0164	0.00293	0.00375
b	3.31	2.77	2.77	3	2.7864	3	2.9	2.9	2.93	3	3.139	3.013
l_∞	76.6	25.278	27.37	36.39	44.5	51.25	54.65	53.2	23.9	65.25	103.355	101
k	0.178	0.224	0.2	0.34	0.34	0.464	0.37	0.15	0.513	0.16	0.166	0.18
t_0	-0.65	-0.719	-1.29	-0.45	-1	-0.65	-0.67	-1	-0.3	-0.38	3.139	0.58
M	0.2	0.1	0.1	0.11	0.1	0.25	0.45	0.36	0.5	0.3	0.2	0.2
S_{50}	27.93	15.94	15.94	21.94	22.31	31.05	17.61	15.54	15.29	15.54	39.9	37.8
S_{95}	31.02	17.25	17.25	21.95	22.32	31.06	17.62	15.55	15.3	15.55	43	50.73
l_{mat}	30	19	19	22	28	37	33.4	31.5	16	35	67	70
h	0.85	0.75	0.75	0.75	0.8	0.75	0.75	0.45	0.95	0.75	0.75	0.9

For species for which a recent stock assessment has been performed by the SEF community, the population parameters used in the assessment were used here. Otherwise, the primary source of information on population parameters was Smith and Wayte (2002) or, failing that, the Fishbase website (http://www.fishbase.com). A meta-analysis performed by Koopman et al (2001) was used to provide a value for steepness.

28.2.1.1 Length- and weight-at-age

Length-at-age was calculated using the von Bertalanffy growth equation (parameters are l_∞, K and t_0) and the weight-at-age using the allometric length-weight relationship (parameters are a and b). The von Bertalanffy was calculated using length and age data supplied by the Central Ageing Facility (CAF, John Ackerman pers com). The type of length measurement (e.g. standard length or total length) used was specified in the data. It is assumed the parameters of the length-weight relationship (Smith and Wayte, 2002) use the same measures. The units for these parameters are not specified and do not all appear to use the same units. These were manipulated until the results appeared to be in kg per cm. Parameters that were not available from Smith and Wayte (2002) were obtained from the Fishbase website (http://www.fishbase.org), using values that had been calculated from Australian fish or, if necessary, New Zealand fish.

28.2.1.2 Female length-at-maturity

Length-at-maturity for females (which is converted into a knife-edged function of age using the calculated lengths-at-age) was obtained, where possible, from Wayte and Smith (2002). If separate figures were not available for males and females, that for both sexes combined was used. In some cases several different figures were available and an arbitrary selection was made - when there were three of more figures the median figure was chosen.

28.2.1.3 Natural mortality

Natural mortality figures were obtained from Smith and Wayte (2002) or by calculating the median of the figures presented by Bax and Knuckey (2001). The value of *M* for John dory was updated by the Shelf Research Assessment Group in 2005 based on an additional meta-analysis performed by Matt Koopman.

28.2.1.4 Selectivity

A logistic selectivity curve is assumed for all species. Selectivity parameters were drawn from Bax and Knuckey's calculated selectivity factors. All parameters used in the present investigation apply to a 90mm trawl mesh (except for school whiting where 42mm has been assumed) and non-trawl gear types are not considered. Figures were not available, from Bax and Knuckey, for John dory or silver trevally. Those for mirror dory were applied to John dory because, of all the quota species, mirror dory are most like John dory in shape.

The selectivity parameters used in this study have been estimated from an empirical relationship between fish size and mesh size derived from covered cod end (or trouser haul) experiments on a subset of the species. These pertain purely to gear selectivity, which is not the function often referred to in stock assessments as "selectivity". Fishers are able to target fish of a particular size by fishing in particular areas and in particular different depths -- all SEF quota shelf-associated species show a pattern of larger fish being caught at greater depths. No account is taken in this study of how trawl selectivity changes as a function of gear design or gear deployment (e.g. changing door separation with depth) that have been shown to exert large influences on overall selectivity in other studies.

It has been suggested that practices such as double bagging might reduce the selectivity of commercial trawls below that expected for a 90 mm mesh cod end, however there was no evidence for this, with the possible exception of school whiting and redfish off Eastern Victoria.

The "selectivity" estimated in stock assessment models is a function of both gear selectivity, targeting by the fishery and availability of fish to being caught.

28.2.1.5 Stock-recruit relationship

A Beverton-Holt stock-recruit relationship is assumed using the single-parameter formulation suggested by Francis (1992a). The value of this parameter (steepness) was investigated by Koopman *et al.* (2001) using meta-population analysis. The histograms presented by Koopman *et al.* were examined and likely figures for steepness chosen. The default figure of 0.75 suggested by Francis (1992b) is used when the results of Koopman *et al.* do not suggest a clear pattern.

28.2.2 Catch Curve Analysis

28.2.2.1 Data

This investigation used length frequency data from three sources: the NSW Sydney Fish Market measurement program; the *Kapala* slope cruises of 1976/7 and 1996/7 (Andrew et al, 1997); and the ISMP port measurement data (eg Knuckey et al, 2001). For a given year, fleet and population (see below for further detail) length frequencies from each zone by season cell are catch-weighted and summed to give annual length frequencies. The methodology is described in detail in Thomson (2002).

Age and length data were obtained from the Central Ageing Facility. Some ALK data were available for all species.

These age and length data were used to calculate the parameters of a von Bertalanffy growth curve for each species (again, see Thomson; 2002b for details). Age-length keys (ALKs) were also constructed from these data.

Two methods were used to convert length frequencies data into age frequencies: ALKs and chopping. The ALK method was used, where possible, to generate age frequencies data by multiplying the length frequency for a given year by the ALK for that same year. No allowances were made for inadequate sampling of an ALK so that, if no age samples were taken from a particular length class then all samples from this length class in the length frequency were ignored. This occurs because the ALK has a zero for all ages for that length class so that the length frequency is always multiplied by zero. ‘Chopping’ involves using the von Bertalanffy to chop the length frequency into age classes. Catch curve analysis was applied to all resulting age frequencies. Chopping is a crude methodology, used only because time did not permit greater sophistication. In the future it would be desirable to use a method that allows variance in length-at-age about the von Bertalanffy curve.

28.2.2.2 Fleets and Populations

The difference between a fleet and a population is that although the length frequency data are separated for both, the ALK data are separated into populations but are combined across fleets.

For species except tiger flathead, redfish, spotted warehou and blue grenadier, the length frequency data were separated into trawl and non-trawl (including Danish seine) fleets.

Tiger flathead was separated into trawl and Danish seine. Non-trawl data for redfish was ignored so that there was only one fleet - a trawl fleet. Spotted warehou was divided into trawl and non-trawl fleets but any Danish seine records were ignored. These fleets were numbered in the order in which they are listed above e.g. for most species *Fleet 1* is trawl fleet and *Fleet 2* non-trawl. For blue grenadier the fleets were separated into the summer non-spawning trawl fishery and the winter spawning trawl fishery.

Redfish was divided into two populations – north and south of 36°S. *Population 1* is north and *Population 2* south of this latitude.

28.2.2.3 Automated catch curve analysis

Catch curve analysis involves fitting a straight line to log-transformed data from age classes that are thought to be fully selected by the fishery. The underlying principle is that cohorts diminish in number, over time, through a process that can be described by exponential decay:

$$N_{y+1} = N_y e^{-Z_y} \quad (1)$$

where N_y is the number of animals in a cohort at the start of year y, and

Z_y is the overall instantaneous mortality rate - incorporating natural mortality (M_y), and fishing mortality (F_y) multiplied by selectivity (S which is a function of age and or length):

$$Z_y = M + F_y \; S \quad (2)$$

Log-transforming equation 1 gives:

$$\ln(N_{y+1}) = \ln(N_y) - Z_y \quad (3)$$

Therefore the slope of a straight line fitted to log-transformed age frequency data for a single cohort for consecutive years would be equal to $-Z_y$. However, data are seldom sufficiently accurate to allow the calculation of Z_y for each pair of N_y, N_{y+1} figures. The assumption is usually made that the Z_y (and therefore F_y) has been constant for the lifetime of each cohort. A straight line is fitted to the age data for several cohorts in a single year. The line is confined to ages that are thought to be fully selected (so that S in equation 2 can be taken to be 1 for all ages). This usually involves choosing, by eye, a section of the log-transformed data for which the plotted points seem to lie in a straight line. The youngest ages are assumed to be affected by selectivity and the oldest by a breakdown in the assumption of a constant F_y and possibly also by selectivity.

The method of selecting, by eye, the age classes to be considered was not practicable as roughly 500 catch curves were performed. A computer algorithm was therefore developed for selecting the 'best' of all possible ranges of age classes. It was found that simply selecting the line that gave the greatest value of the squared correlation coefficient (r^2; Zar, 1984) often resulted in the selection of ranges of only 2 or 3 ages because these points happened to be very closely in line (2 consecutive points will always lie exactly in line). Often these points were from a part of the plot that clearly ought not to have been used at all as the resulting slope was positive. After much trial and error, which included attempts to restrict the range of ages that was considered

eligible for consideration, the following simple rules were used. Select the range of ages that gives the greatest value for the quantity ρ, where ρ is given by:

$$\rho = \begin{cases} 0 & \text{for } n <= 2 \\ \sqrt{n}\ r^2 / 100 & \text{for } n > 2;\ \text{slope positive} \\ \sqrt{n}\ r^2 & \text{otherwise} \end{cases} \qquad (4)$$

where n is the number of ages included in the age range, and

r^2 is the squared correlation coefficient (see e.g. Zar, 1984).

"slope positive" indicates that the slope of a line fitted to this age range has a slope that is greater than or equal to zero.

All possible age ranges were considered.

28.3 RESULTS

28.3.1 Yield Analysis

Figure 28.2 – Figure 28.12 show the female spawning biomass (solid curve), relative yield (dotted curve on some plots - yield divided by maximum sustainable yield, MSY) as a function of total mortality, *Z*. The horizontal and vertical lines mark the total mortality values for which female spawning biomass is at 20%, 30% and 40% of its pristine size.

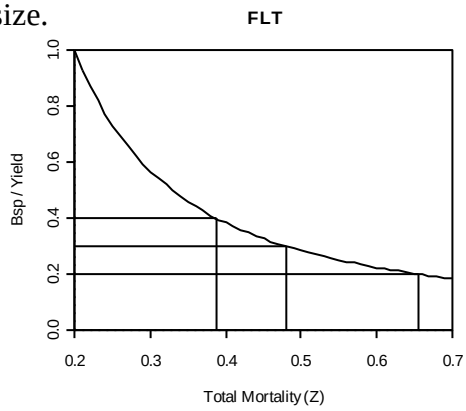


Figure 28.2 Flathead

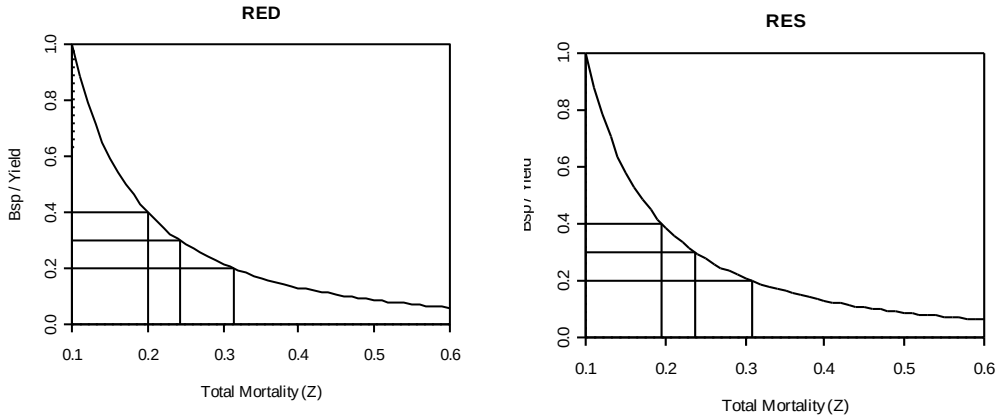


Figure 28.3 Redfish (northern and southern populations)

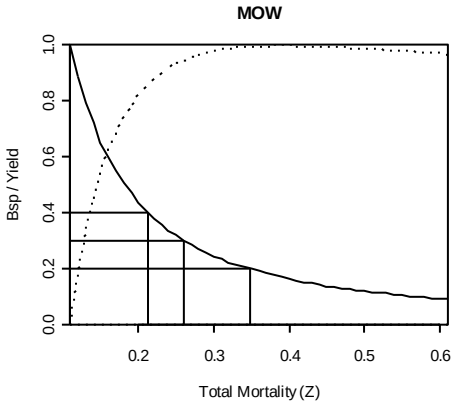


Figure 28.4 Morwong

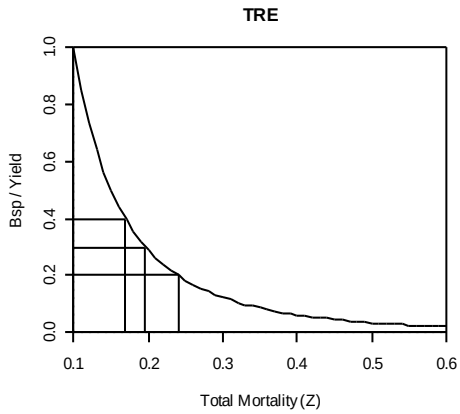


Figure 28.5 Silver trevally

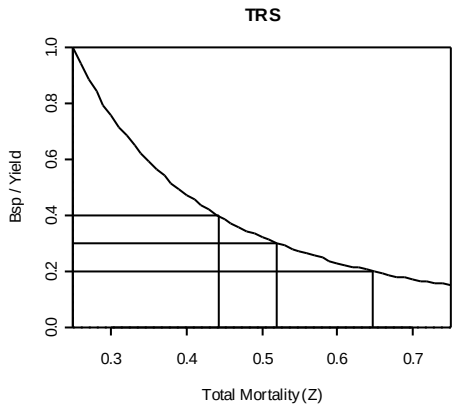


Figure 28.6 Spotted warehou

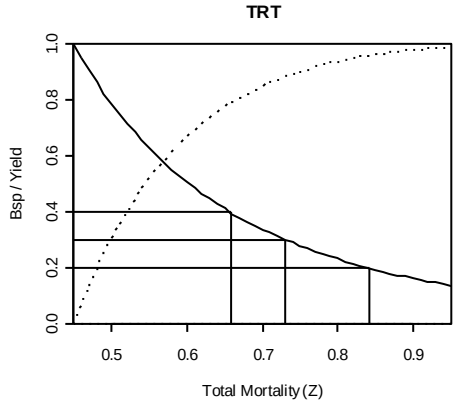


Figure 28.7 Blue warehou

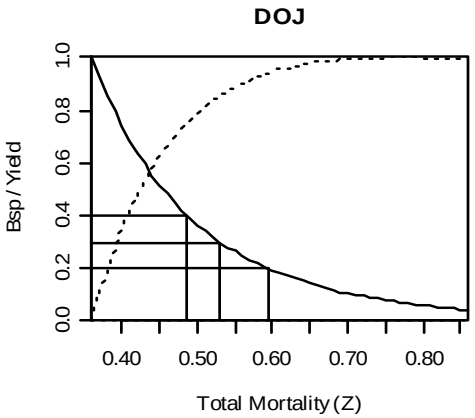


Figure 28.8 John Dory

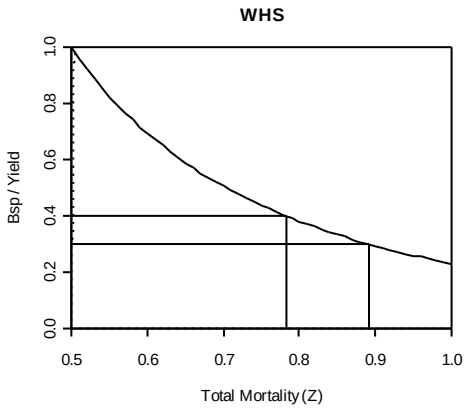


Figure 28.9 School whiting

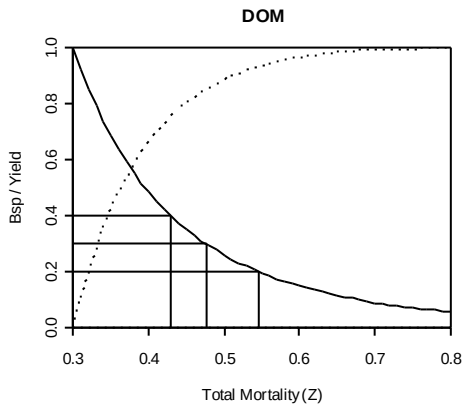


Figure 28.10 Mirror dory

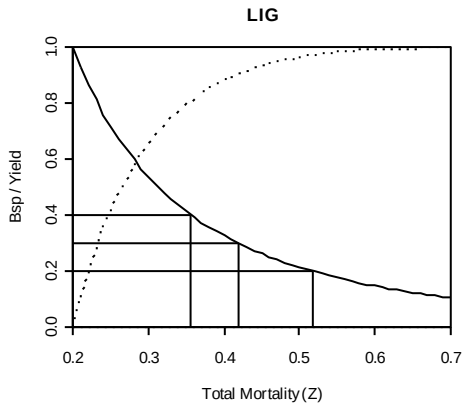


Figure 28.11 Ling

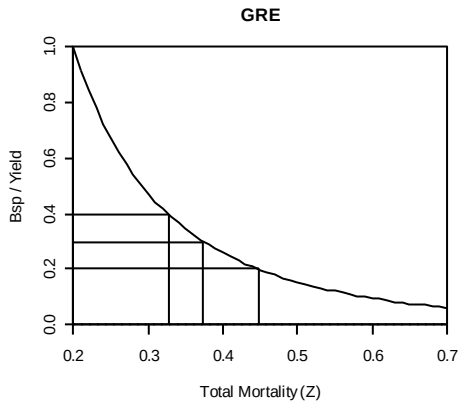


Figure 28.12 Blue Grenadier

28.3.2 Catch Curve Analysis

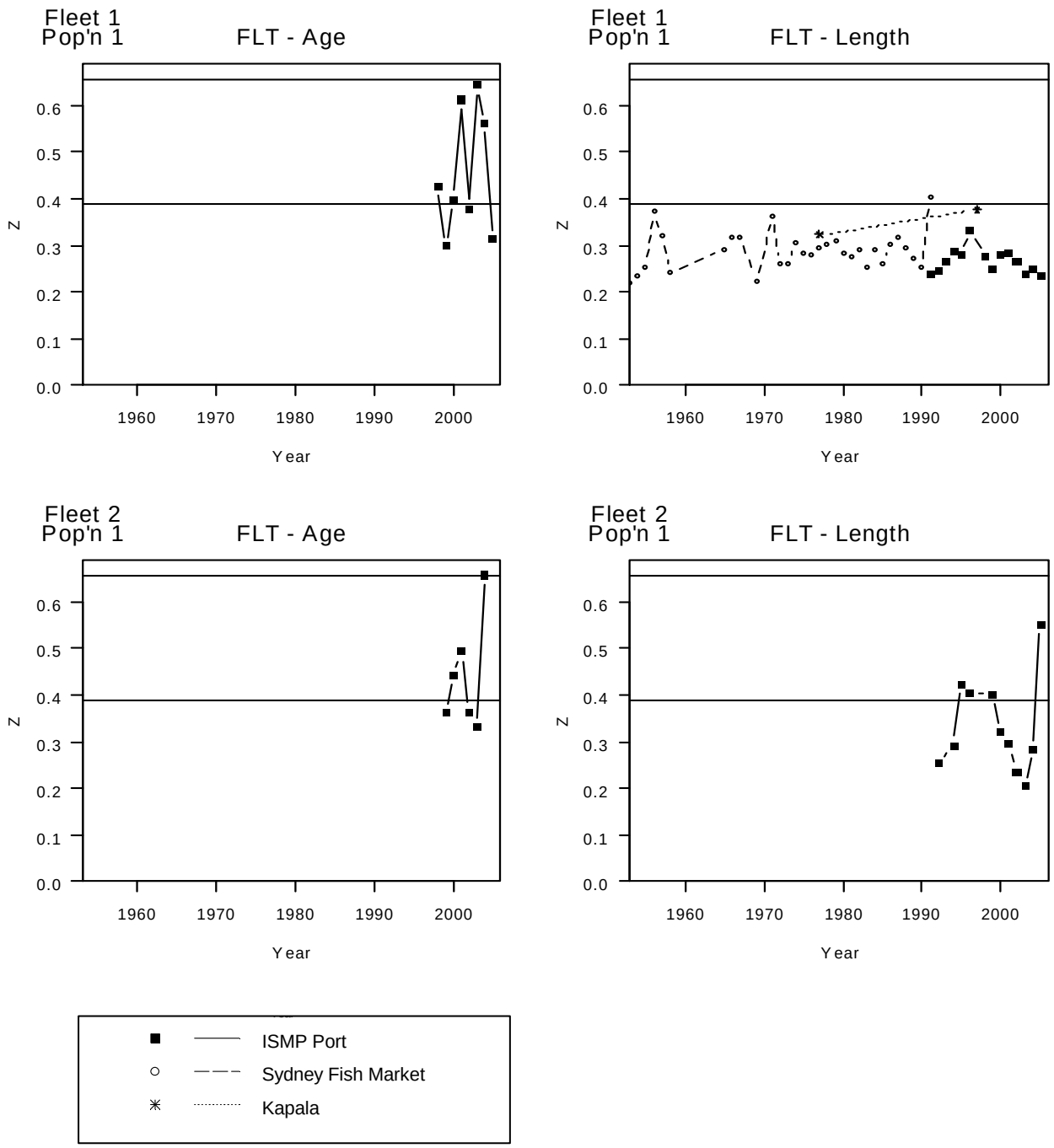
The resulting estimates of *Z* are shown in Figures 28.13 to 28.23. Any positive slopes (which therefore give negative *Z* values) have been excluded, as well as a relatively small number of estimates where the automated fitting procedure appeared to perform badly. AFMA species codes are used to label the plots. An explanation of these codes is given in Table 28.2.

The results of catch curve analysis are shown together with the total mortality figures (*Z*) that resulted in spawning biomasses of 20% and 40% of pristine (solid horizontal lines).

A summary of *Z* estimates from catch curve analysis (given the assumption that *Z* has been unchanged over the lifetime of each cohort, clearly untrue for many species) is given in Table 28.2 and the *Z* values resulting in 20% and 40% depletion from the previous yield analysis are also shown. Recent *Z* estimates are taken from the values in Figures 28.13 to 28.23 by summing the values from estimates from the most recent 5 years, and from age-based estimates rather than length-based where possible. The coefficients of variation (CV) of the recent 5-year averages are also shown. For silver trevally only length-based estimates could be used, and there were only 2 annual estimates available for fleet 2 (see Fig 28.16). For all other species averages were calculated from at least 3 available estimates from the most recent 5 years.

Table 28.2. Yield and most recent 5-year average Z value summary

		Flathead	Redfish	Morwong	Silver trevally	Spotted warehou	Blue warehou	John dory	School whiting	Mirror dory	Ling	Blue grenadier
$Z_{20\%}$		0.66	0.31	0.35	0.24	0.65	0.84	0.59	1.07	0.55	0.52	0.45
$Z_{40\%}$		0.39	0.20	0.21	0.17	0.44	0.66	0.49	0.78	0.43	0.36	0.33
Z_{F1}		0.50		0.17	0.69	0.41	1.02	0.40	1.36	0.43	0.51	
	CV	0.29		0.14	0.18	0.18	0.39	0.18	0.54	0.20	0.34	
Z_{F2}		0.46		0.35	0.11			0.45	1.35		0.42	0.65
	CV	0.32		0.59	0.59			0.17	0.50		0.37	0.34
Z_{P1}			0.24									
	CV		0.22									
Z_{P2}			0.21									
	CV		0.30									



Fleet 1 = Otter trawl and midwater trawl
Fleet 2 = Danish seine and other

Figure 28.13 Flathead

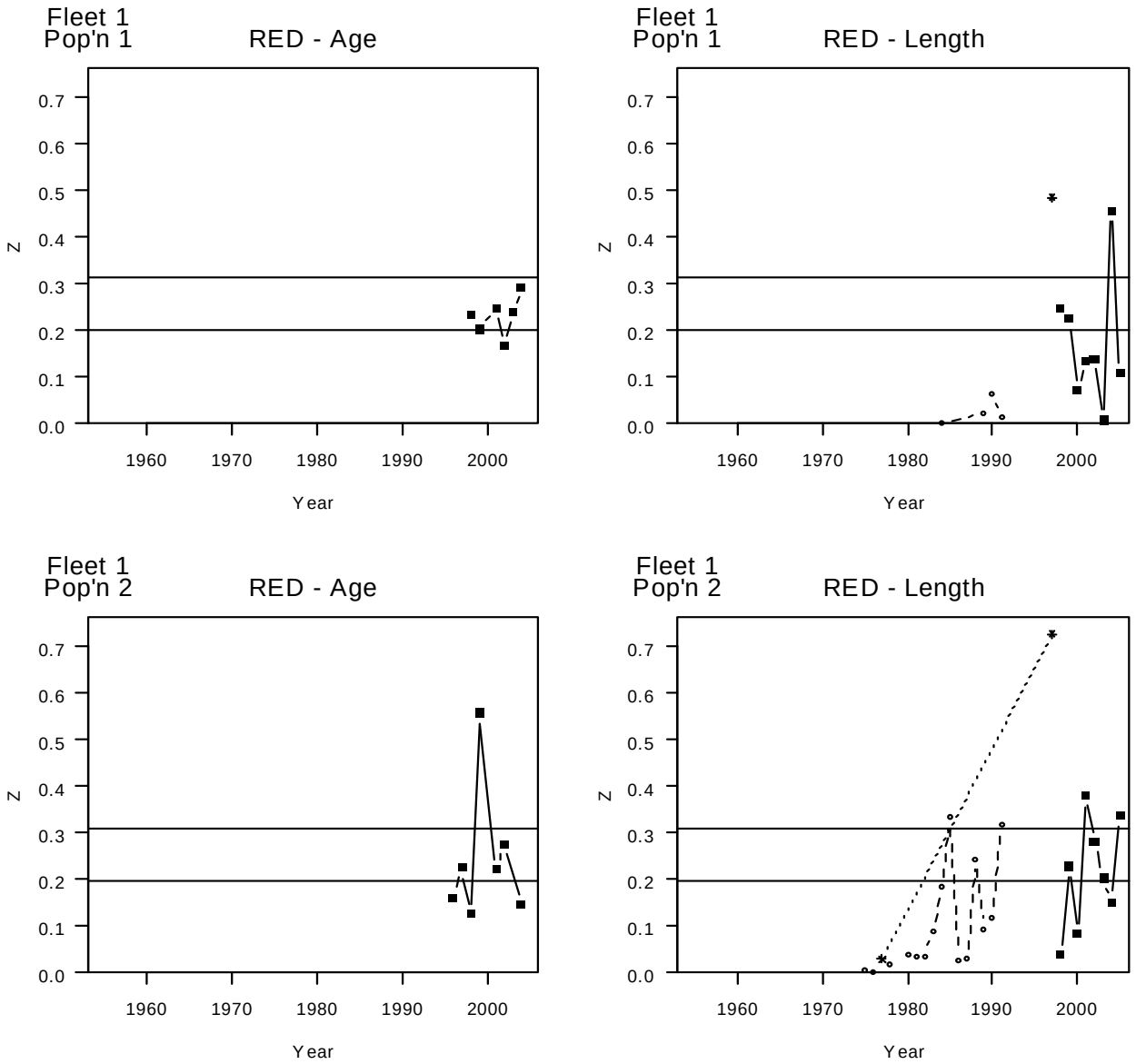


Figure 28.14 Redfish

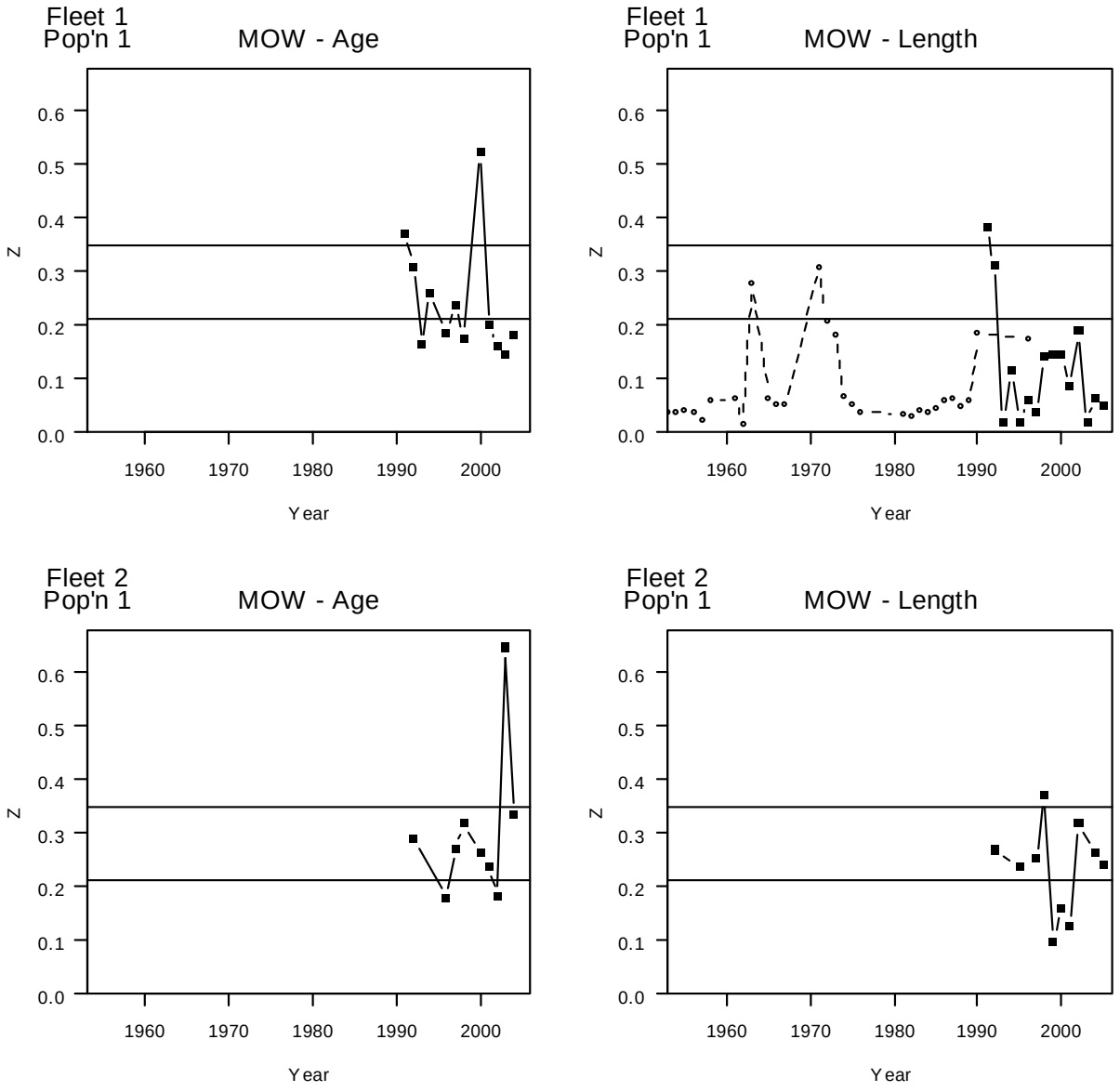


Figure 28.15 Morwong

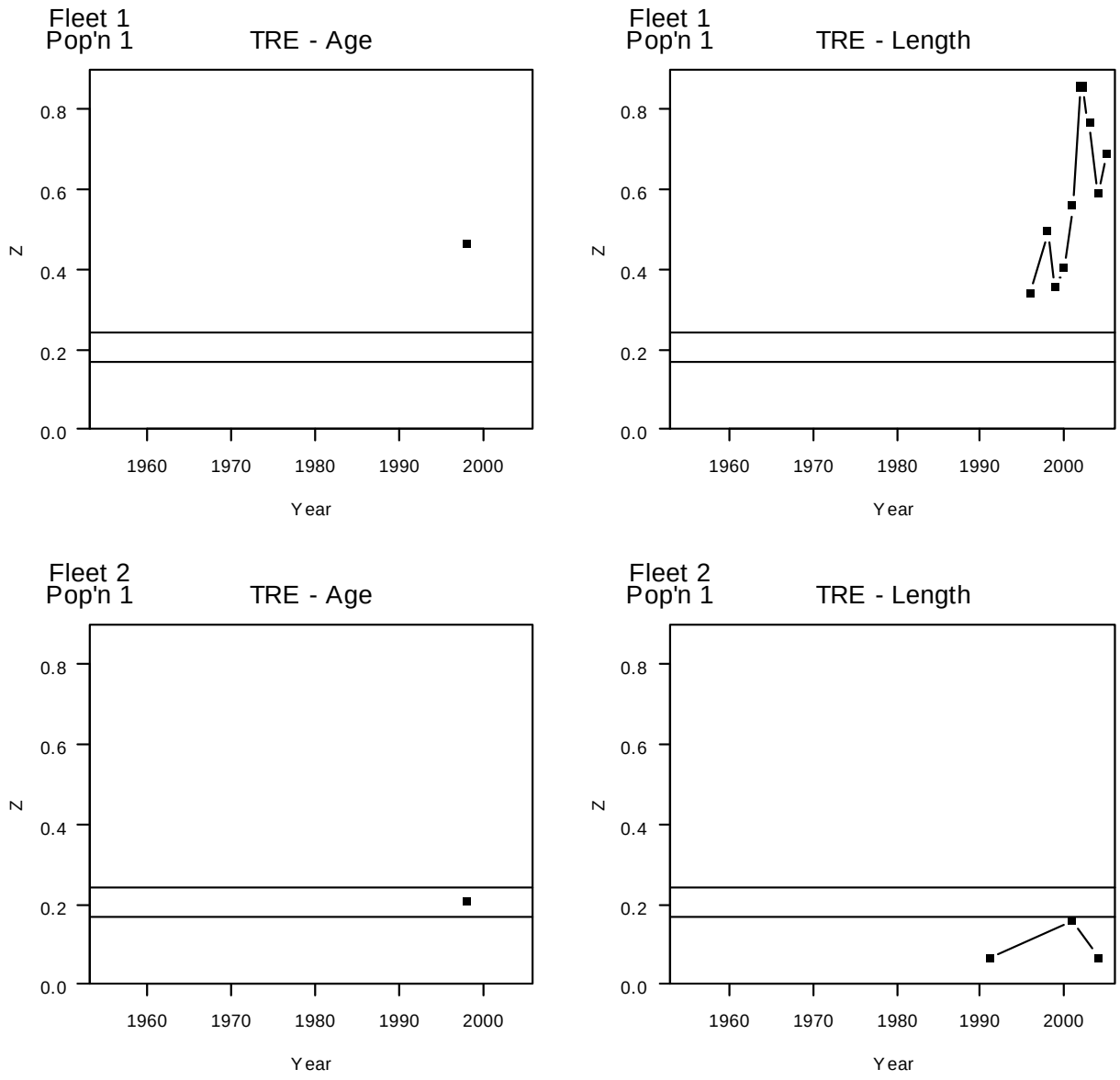


Figure 28.16 Silver trevally

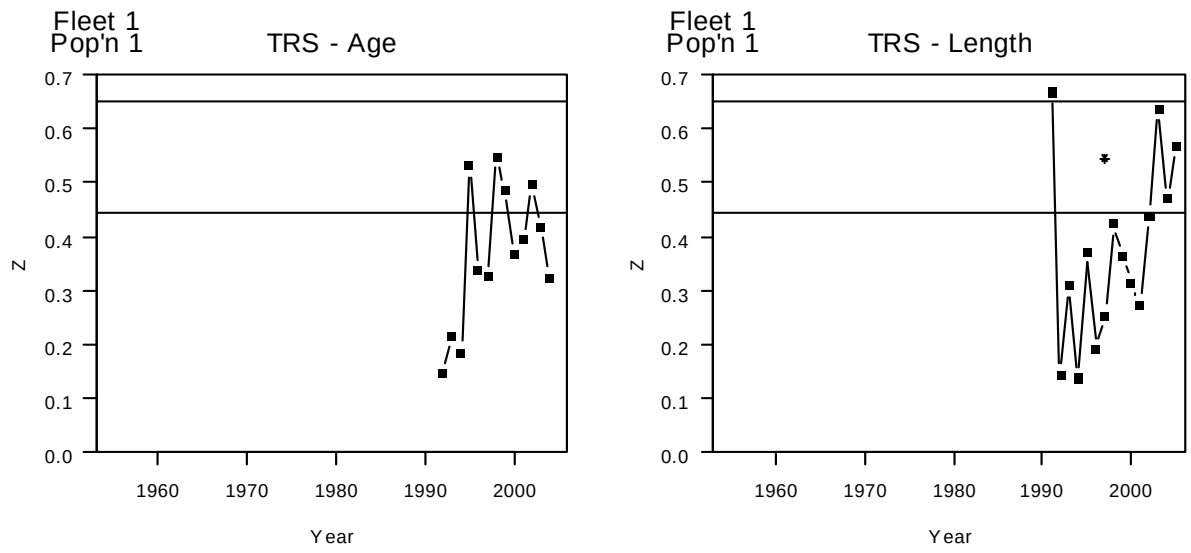


Figure 28.17 Spotted warehou

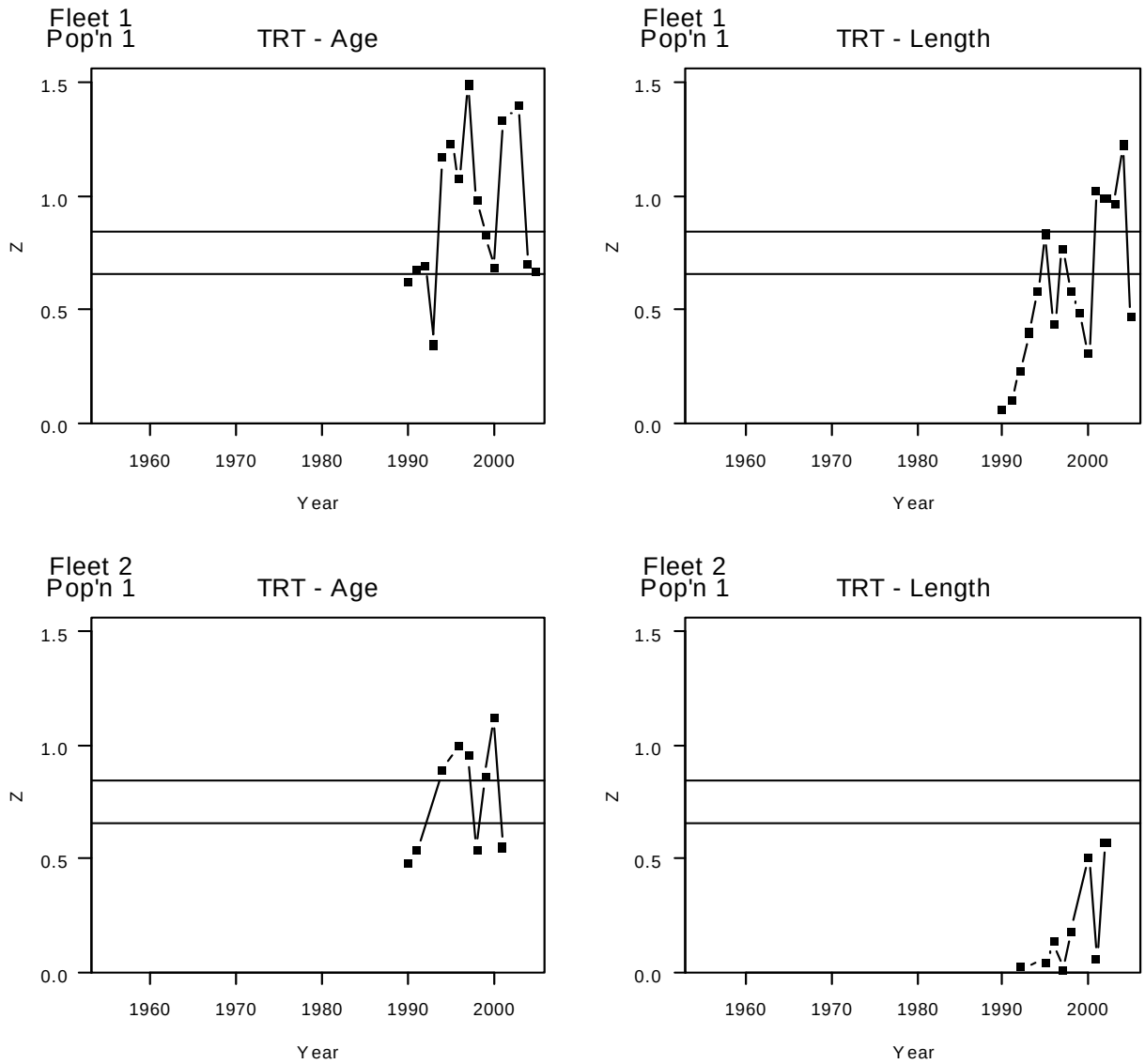


Figure 28.18 Blue warehou

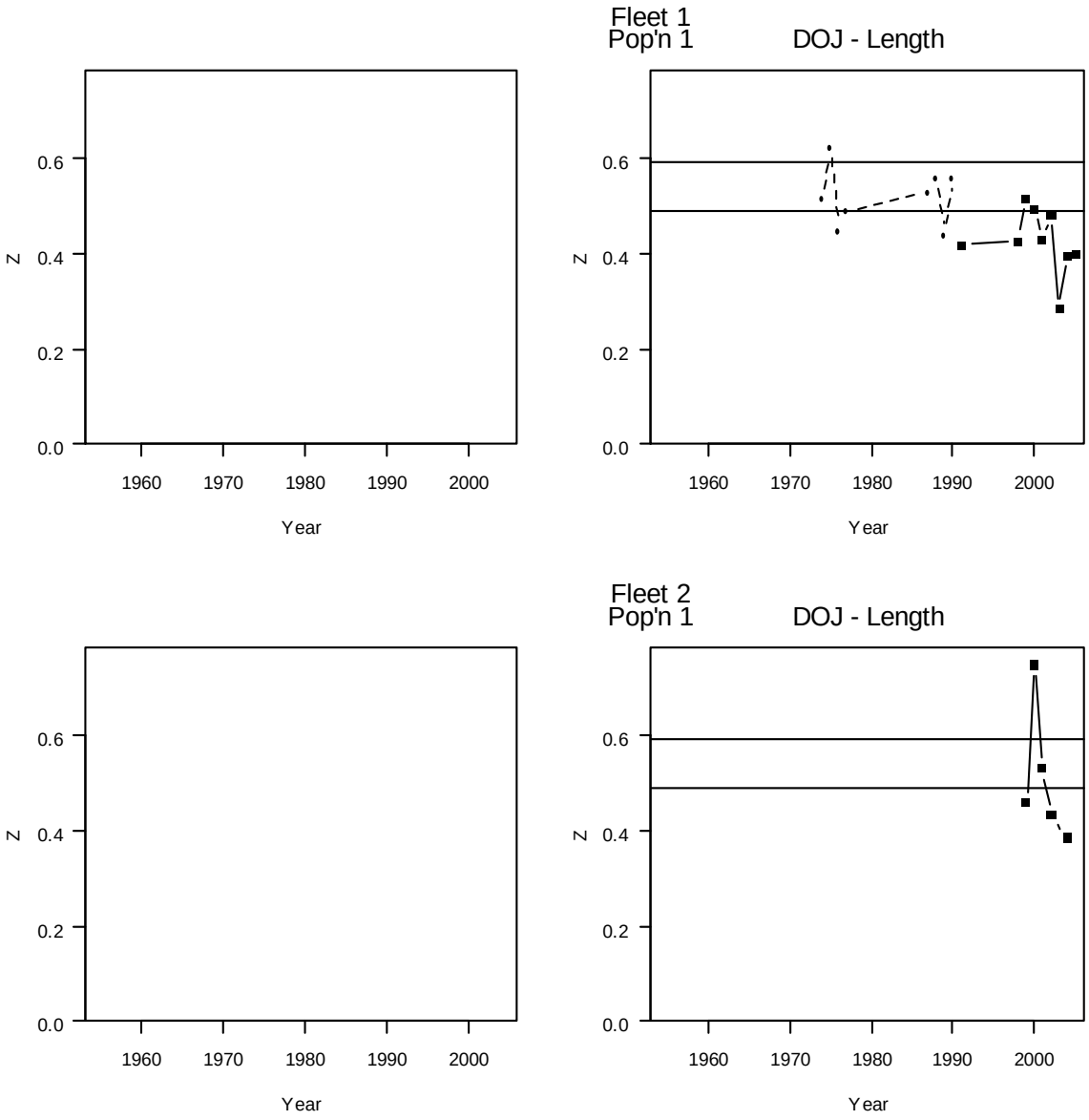


Figure 28.19 John dory

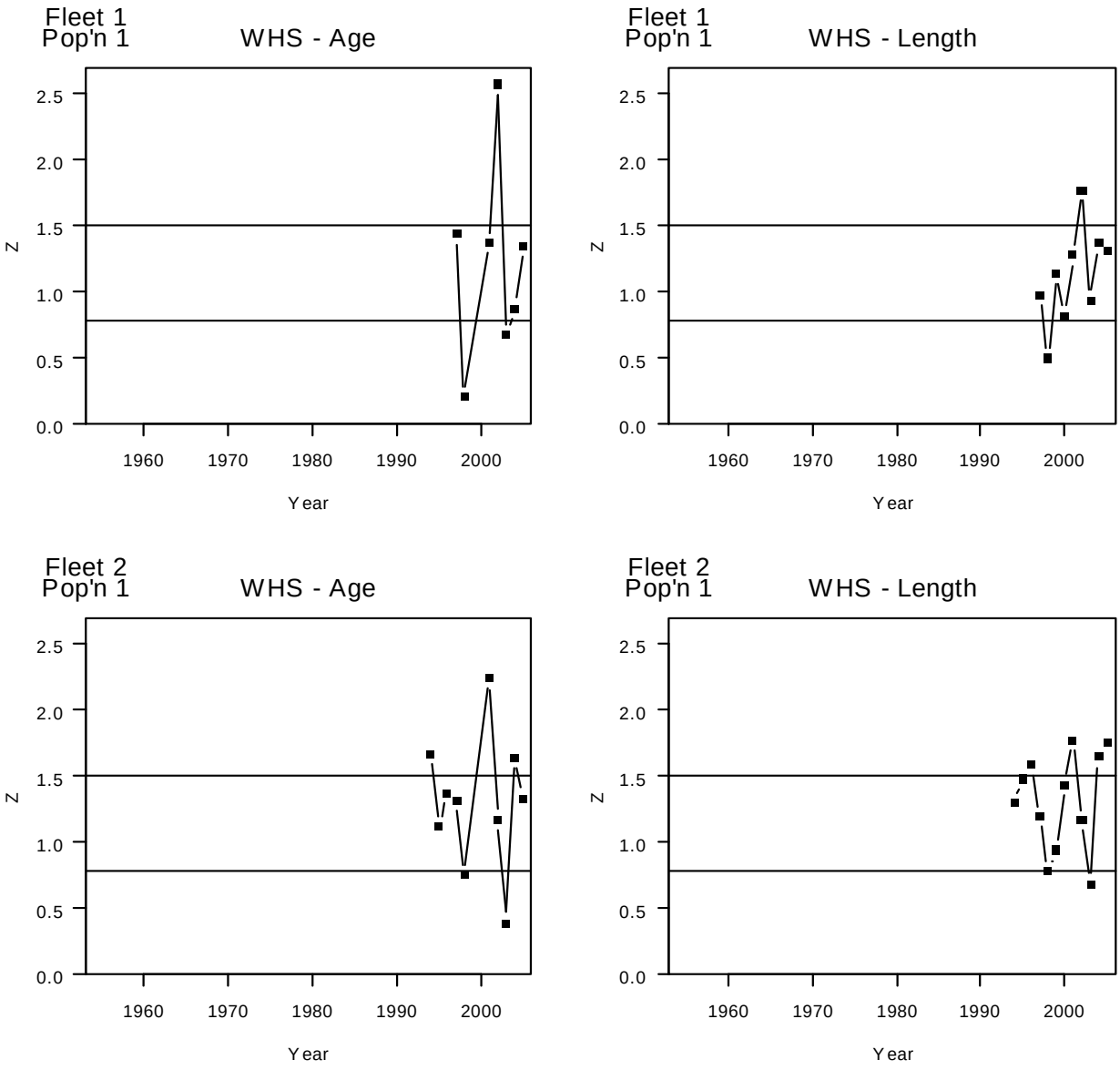


Figure 28.20 School whiting

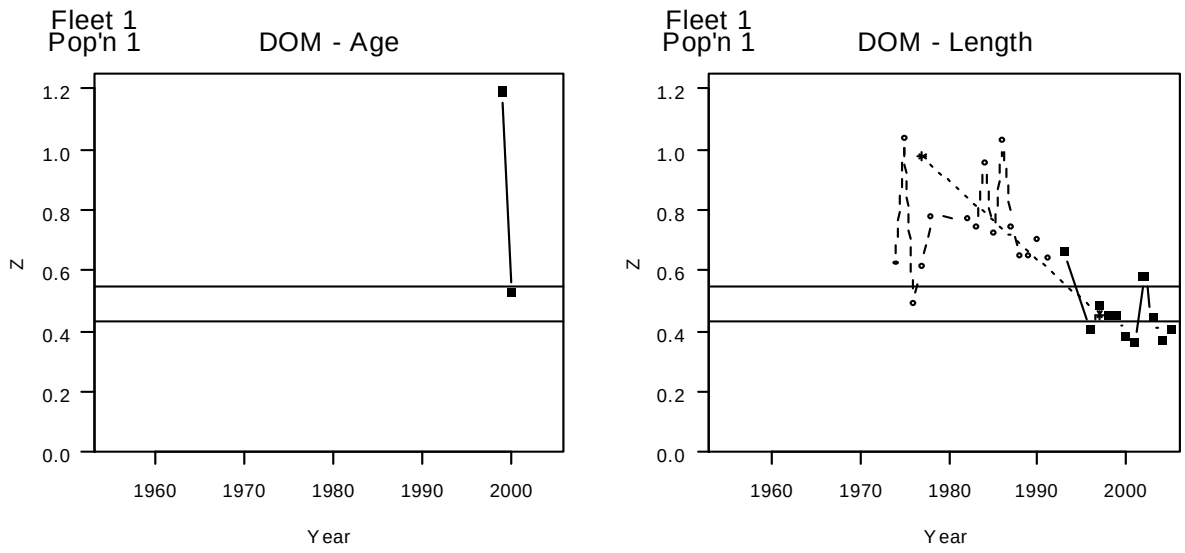


Figure 28.21 Mirror dory

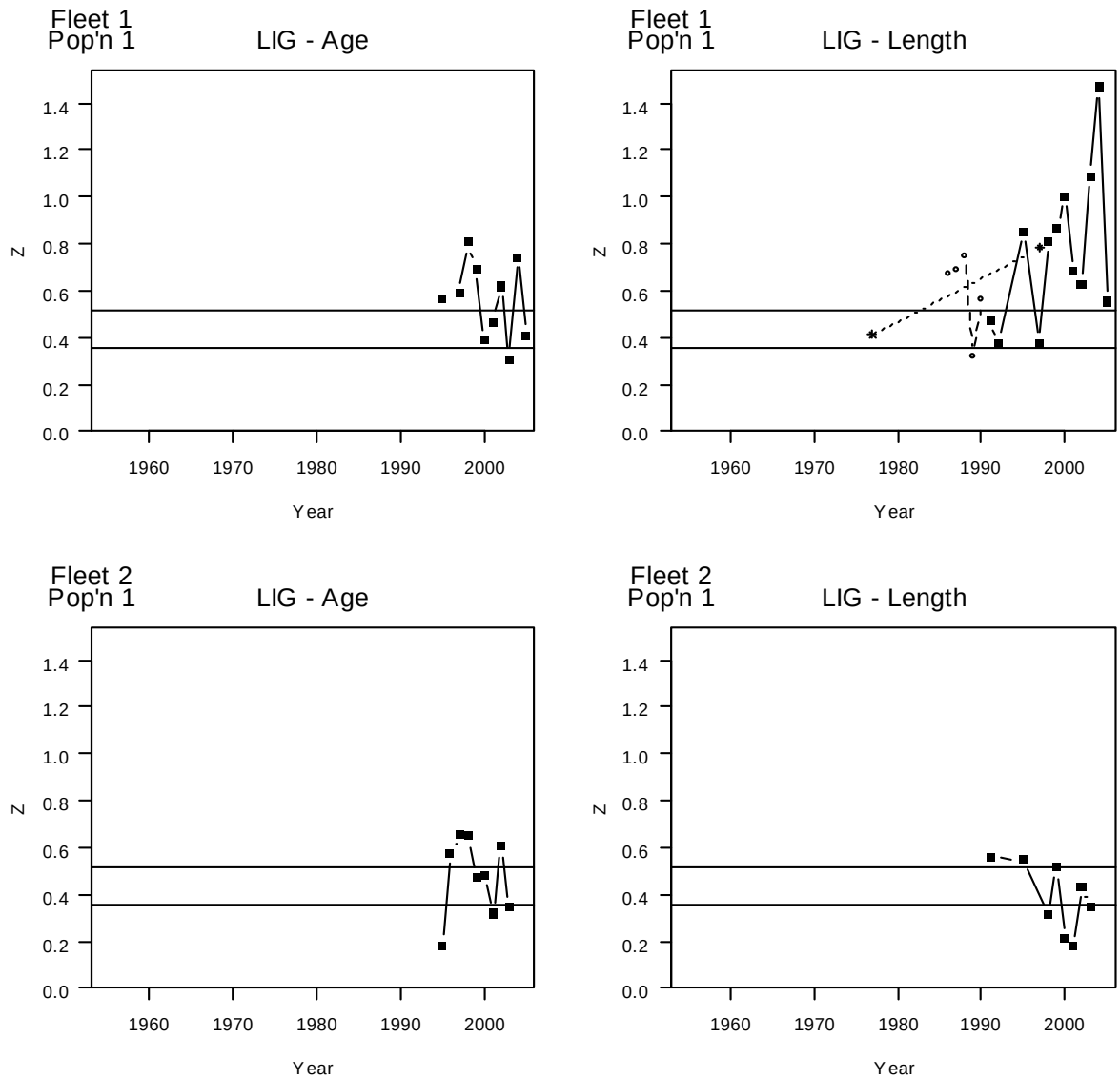


Figure 28.22 Ling

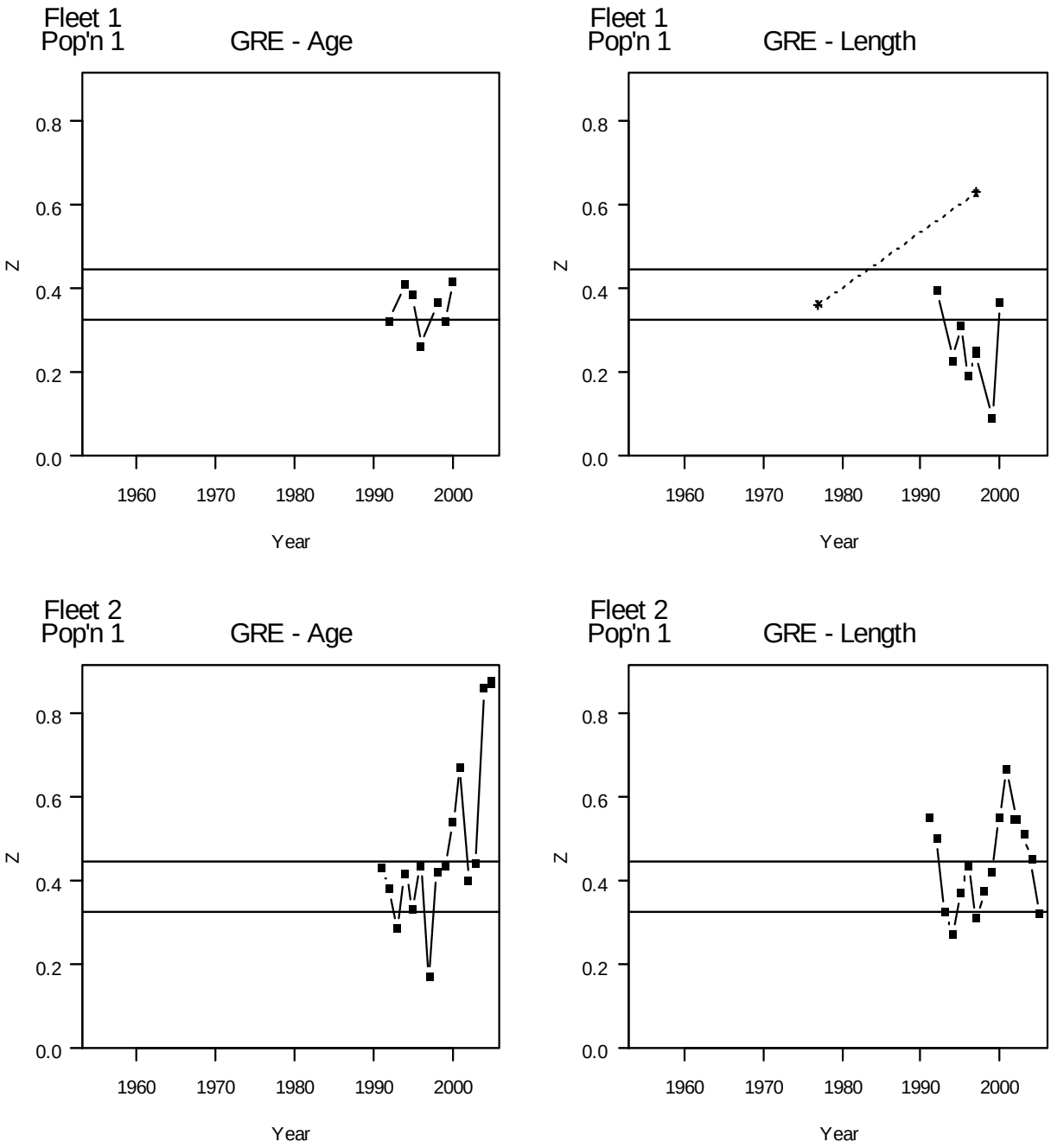


Figure 28.23 Blue grenadier

28.4 Tier 3 Calculations

The means for calculating recommended biological catch using the Tier 3 harvest control rule (HCR3) is given in Smith (2005).

HCR3 will apply to species and/or stocks where there are robust estimates of natural mortality rate M and current fishing mortality rate F_{cur}, but no direct estimates of current biomass B_{cur}. Since there is no quantitative assessment, the RBC can not be calculated by applying a target fishing mortality rate to an estimate of current biomass. Instead, the RBC is calculated by varying the current catch level up or down depending on whether F_{cur} is above or below the target fishing mortality rate, which for Tier 3 is set at $F_{targ} = M$. The current catch level C_{cur} is calculated as the average catch over the past 4 years (where catch = landings + estimated discards). The discard rate applied to the average catch is weighted using a multiple of 8 for the most recent year (y), 4 for y-1, 2 for y-2 and 1 for y-3. The formula for calculating the RBC is:

RBC = 1.2 * C_{cur}	$F_{cur} < 0.5M$
RBC = 1.1 * C_{cur}	$0.75M > F_{cur} > 0.5M$
RBC = C_{cur}	$M > F_{cur} > 0.75M$
RBC = 0.9 * C_{cur}	$1.25M > F_{cur} > M$
RBC = 0.8 * C_{cur}	$1.5M > F_{cur} > 1.25M$
RBC = 0.5 * C_{cur}	$2M > F_{cur} > 1.5M$
RBC = 0	$F_{cur} > 2M$

Single current Z values (Z_{cur}) are created for those stocks with multiple fleets or sub-stocks simply by averaging across fleets or sub-stocks using equal weighting.

The functional form of the Tier 3 multiplier (p) calculated using the Tier 3 control rule is currently a step function in relation to the current F/M value. This means that if the F/M value for a species is near the edge of a step, a small change can cause a large change in the p value used to calculate the RBC. To remove this behavior it has been suggested that a smooth function be fitted to the current F/M vs p relationship. A simple functional relationship could not be found that fitted well through the step function, so a polynomial or spline function was used. The parameters for the fitted smooth function are as follows:

$$p = 1.2 + (-0.0295 * r) + (0.2313 * r^2) + (-1.209 * r^3) + (1.0413 * r^4) + (-0.283 * r^5)$$

where $r = F_{cur}/M$

The fitted smooth relationship and step function are shown below.

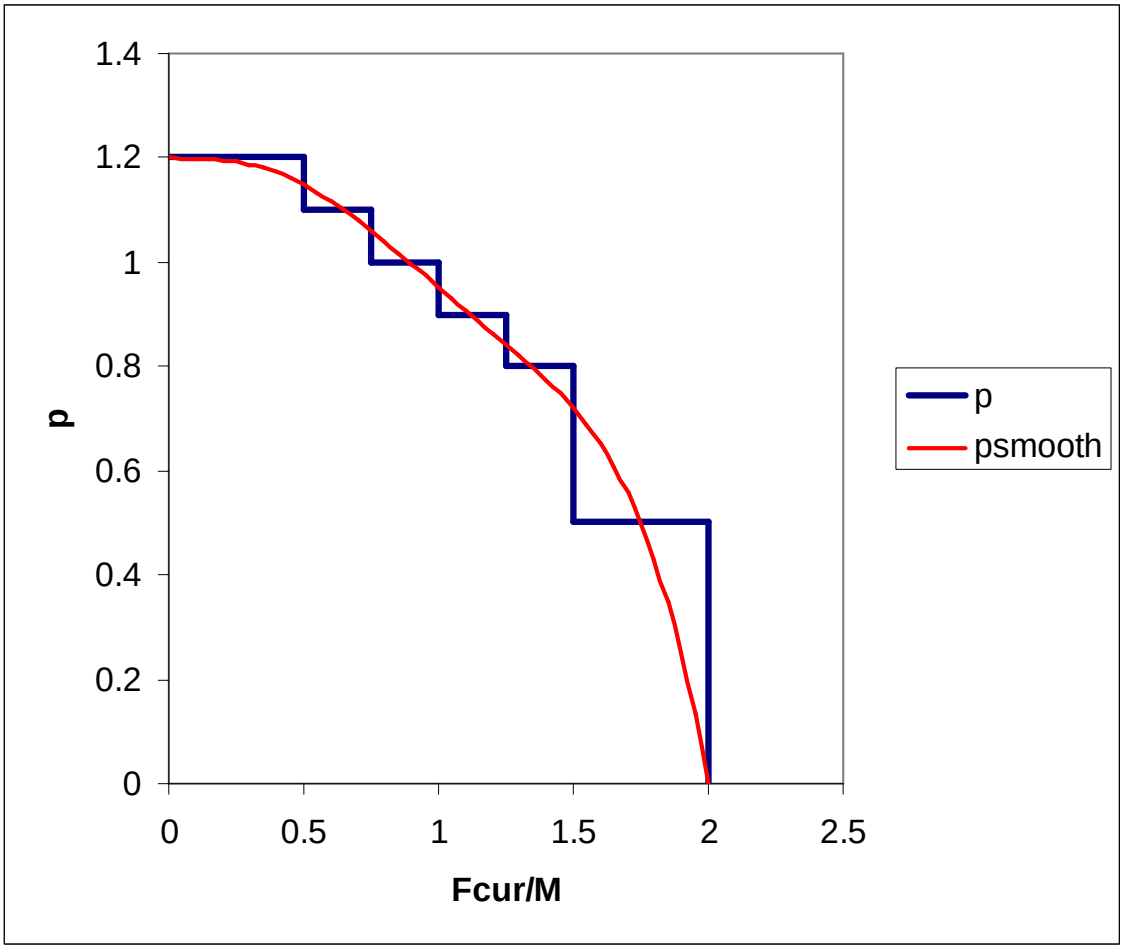


Table 28.3. Tier 3 Results

	Flathead	Redfish	Morwong	Silver trevally	Spotted warehou	Blue warehou	John dory	School whiting	Mirror dory	Ling	Blue grenadier	Blueeye
Z_{cur}	0.481	0.225	0.261	0.402	0.408	1.022	0.423	**1.010**	0.435	0.466	0.648	**0.172**
F_{cur}	0.281	0.125	0.151	0.302	0.158	0.572	0.063	0.510	0.135	0.266	0.448	0.092
M	0.200	0.100	0.110	0.100	0.250	0.450	0.360	0.500	0.300	0.200	0.200	0.080
p	0.80	0.80	0.80	0.00	1.10	0.80	1.20	0.90	1.20	0.80	0.00	0.90
p smooth	0.77	0.84	0.79	0.00	1.11	0.83	1.20	0.94	1.16	0.81	0.00	0.89
Ccur (t)	3,435	695	820	521	3,347	327	174	1,316	640	1,602	7,086	633
Ccur+disc	3,608	945	884	526	3,774	543	176	1,362	721	1,605	7,173	633
RBC	2,777	795	695	0	4,177	452	211	1,283	837	1,293	0	560

* Note: selectivity for silver trevally is likely to be dome shaped, invalidating this method. Z values given here for school whiting and blue-eye were calculated using methods documented in the assessments specific to those species.

There are two species where results indicate recent *F* values greater than 2*M*: silver trevally and blue grenadier. In the case of silver trevally, it has generally been recognised that selectivity by trawl is likely to be dome-shaped, which would lead to overestimation of *Z* values, invalidating this method for that species unless selectivity is taken into account. The result for blue grenadier differs considerably from previous years because there are now no *Z* estimates in the last 5 years for the summer non-spawning fishery. Stock assessment results for blue grenadier show a high level of inter-annual variability in recruitment. The reliability of simple catch curve analysis is greatly reduced by this variability, so the results here for blue grenadier should be treated with caution.

At the time of writing, current catch estimates were not available, so only the Tier 3 multipliers are presented here.

28.5 Acknowledgements

Central Age Facility data was provided by Kyne KrusicGolub (PIRVIC), ISMP and AFMA logbook data was processed and provided by Matthew Koopman and Anne Gason (PIRVIC). Estimates of recent catch per sector per species and total discard rates were provided by Matthew Koopman.

28.6 References

Andrew, N.L., Graham, K.J., Hodgson, K.E. and Gordon, G.N.G. 1997. Changes after twenty years in relative abundance and size composition of commercial fishes caught during fishery independent surveys on SEF trawl grounds. NSW Fisheries Final Report Series No. 1. FRDC Project No. 96/139. 210pp.

Bax, N.J., and Knuckey, I.A. 2002. Draft. Evaluation of selectivity in the South-East fishery to determine its sustainable yield. Final Report to the Fisheries Research and Development Corporation. FRDC Project 96/140.

Francis, R. I. C. C. 1992a. Use of risk analysis to assess fishery management strategies: a case study using orange roughy (*Hoplostethus atlanticus*) on the Chatham Rise, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences. 49: 922-30.

Francis, R. I. C. C. 1992b. Recommendations regarding the calculation of maximum constant yield (MCY) and current annual yield (CAY). New Zealand Fisheries Assessment Research Document.92/8: 29pp.

Haddon, M. 2005. TIER 4 Analyses. Presented to the Shelf and Slope Assessment Groups, 2005.

Klaer, N. 2003. Yield and total mortality estimates for principal shelf species in the South East Fishery. Presented to the Shelf Assessment Group, June 2003.

Klaer, N. and Thomson, R. 2004. Yield and total mortality estimates for principal shelf species in the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2004.

Klaer, N. and Thomson, R. 2005. Yield, total mortality and Tier 3 estimates for selected shelf and slope species n the South East Fishery. Presented to the Shelf and Slope Assessment Groups, 2005.

Knuckey, I.A., Berrie, S.E. and Gason, S.H. 2001. South East Fishery Integrated Scientific Monitoring Program. 2000 Report to the South East Fishery Assessment Group. 108pp.

Koopman, M.T., Punt, A.E. and Smith, D.C. 2001. Production parameters from the fisheries literature for SEF-like species. Final Report to the Australian Fisheries Management Authority Research Fund.ARF Project R99/0308.

Smith, A.D.M. and Wayte, S.E. (eds) 2002. The South East Fishery 2002. Compiled by the South East Fishery Assessment Group. 271pp.

Smith, A.D.M. 2005. A harvest strategy framework for the SESSF. Presented to the Shelf and Slope and Deepwater Assessment Groups, 2005.

Thomson, R.B. 2002a. South East Fishery data for stock assessment purposes. Draft version. May 2002. 26pp.

Thomson, R.B. 2002b. Automated catch curve analysis of South East Fisheries quota species. Presented to the South East Fishery Assessment Group, July 2002.

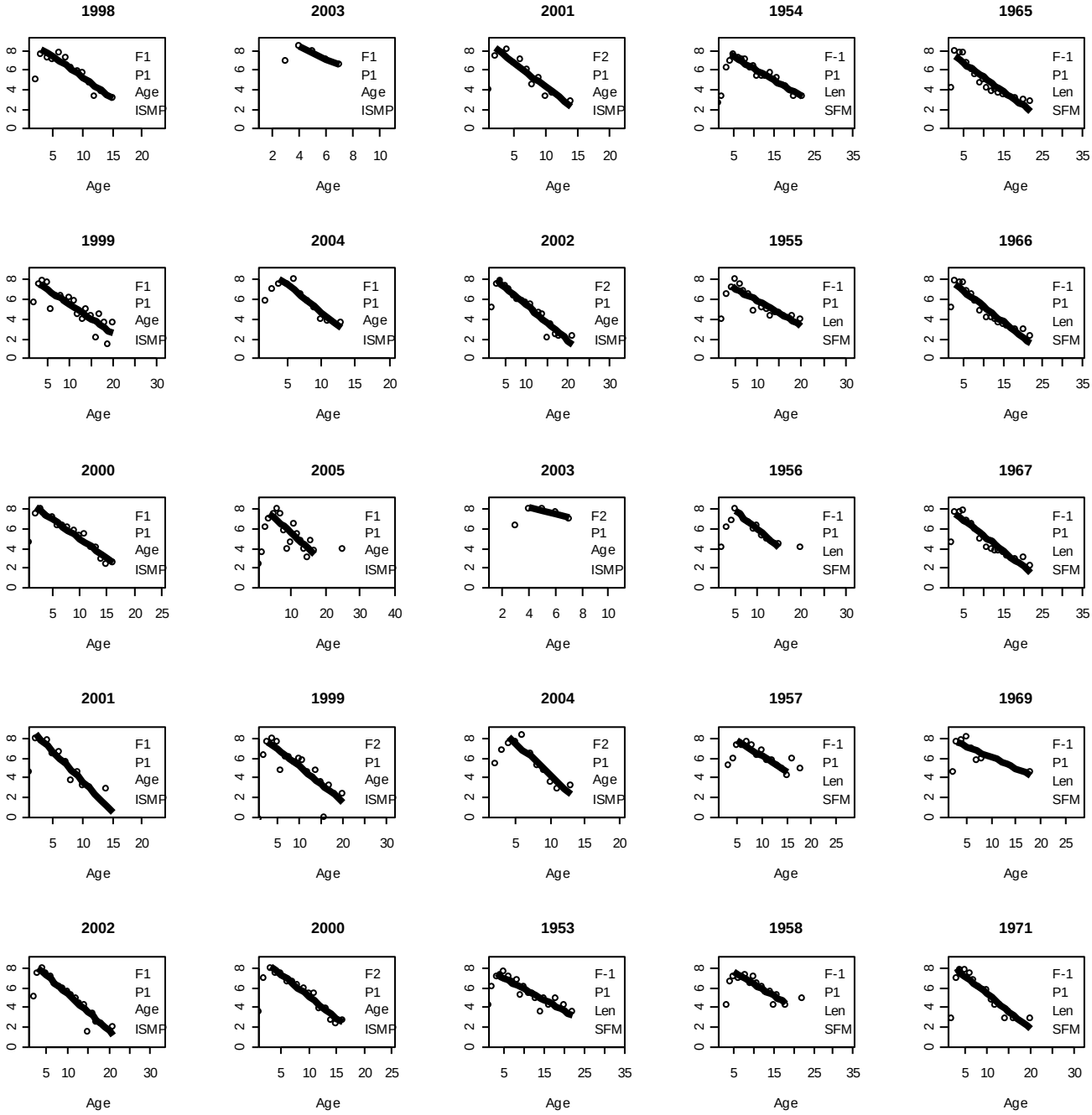
Thomson, R.B. 2002c. South East Fishery data for stock assessment purposes. Draft CSIRO Report.

Thomson, R. and Smith, A. 2002. Yield-per-recruit calculations for SEF quota species. CSIRO Report.

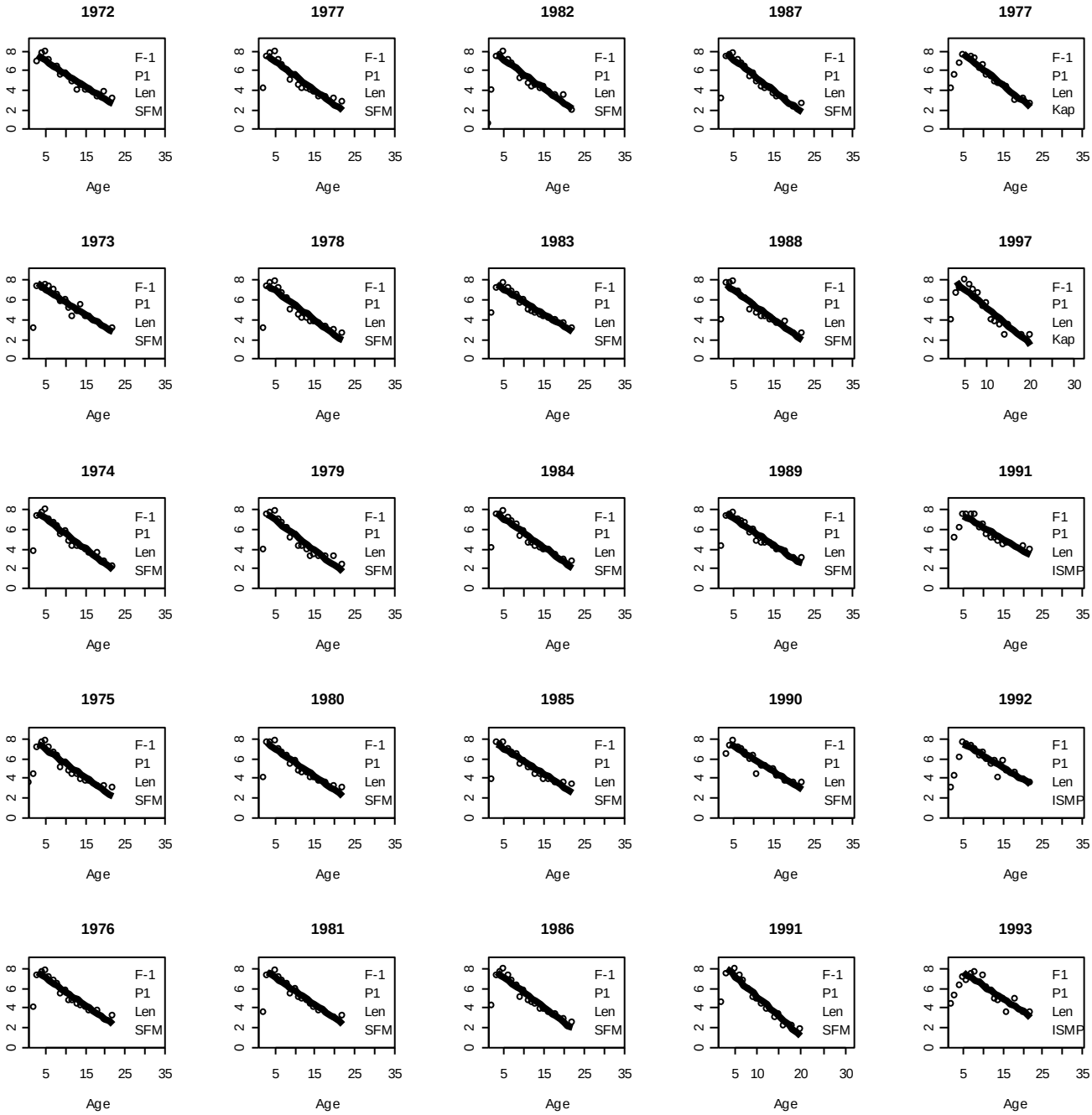
Zar, J.H. 1984. Biostatistical analysis. Second edition. Prentice Hall inc. New Jersey.

28.7 Appendix: Detailed catch curve results

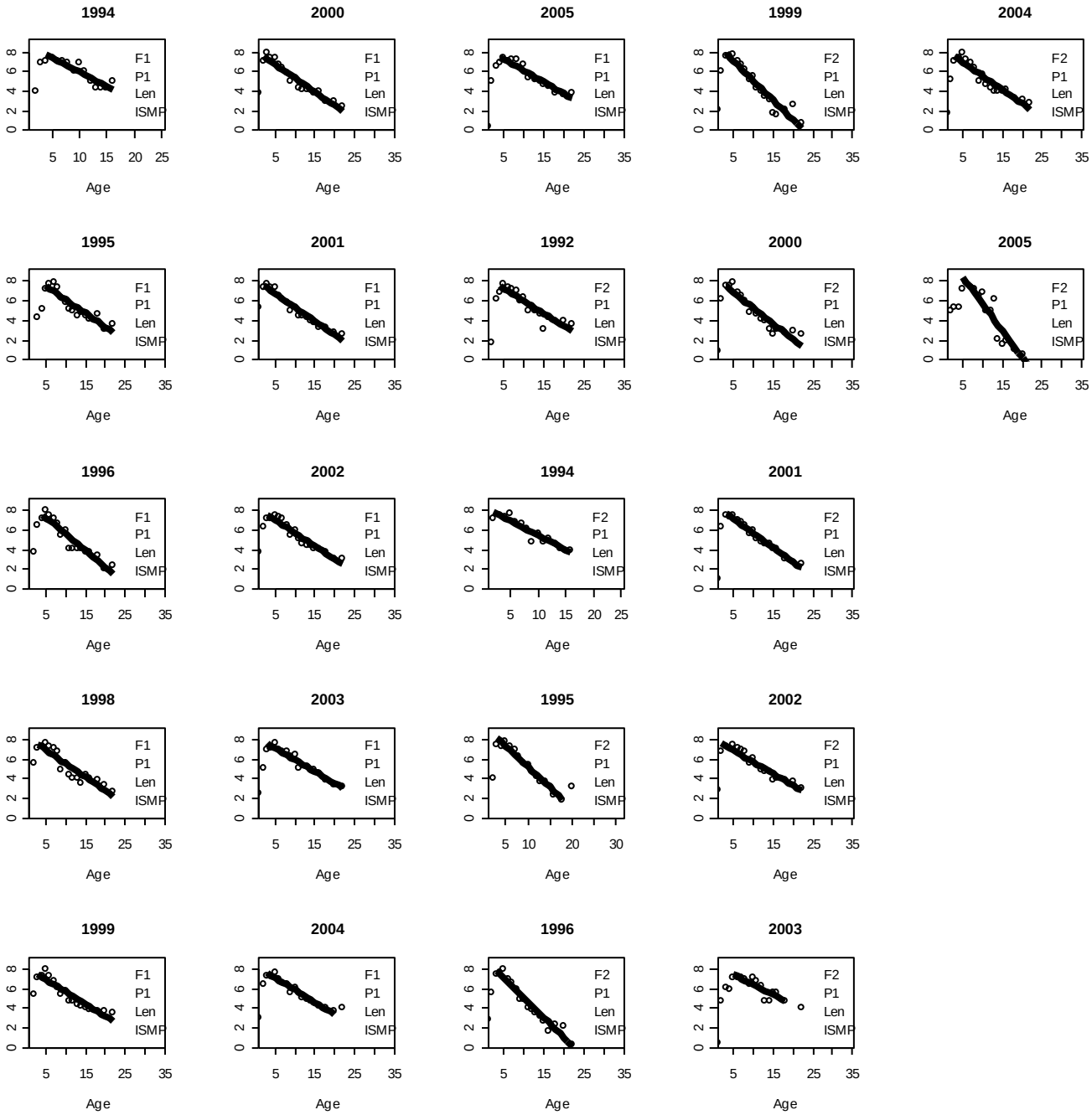
Detailed catch curve results: Flathead



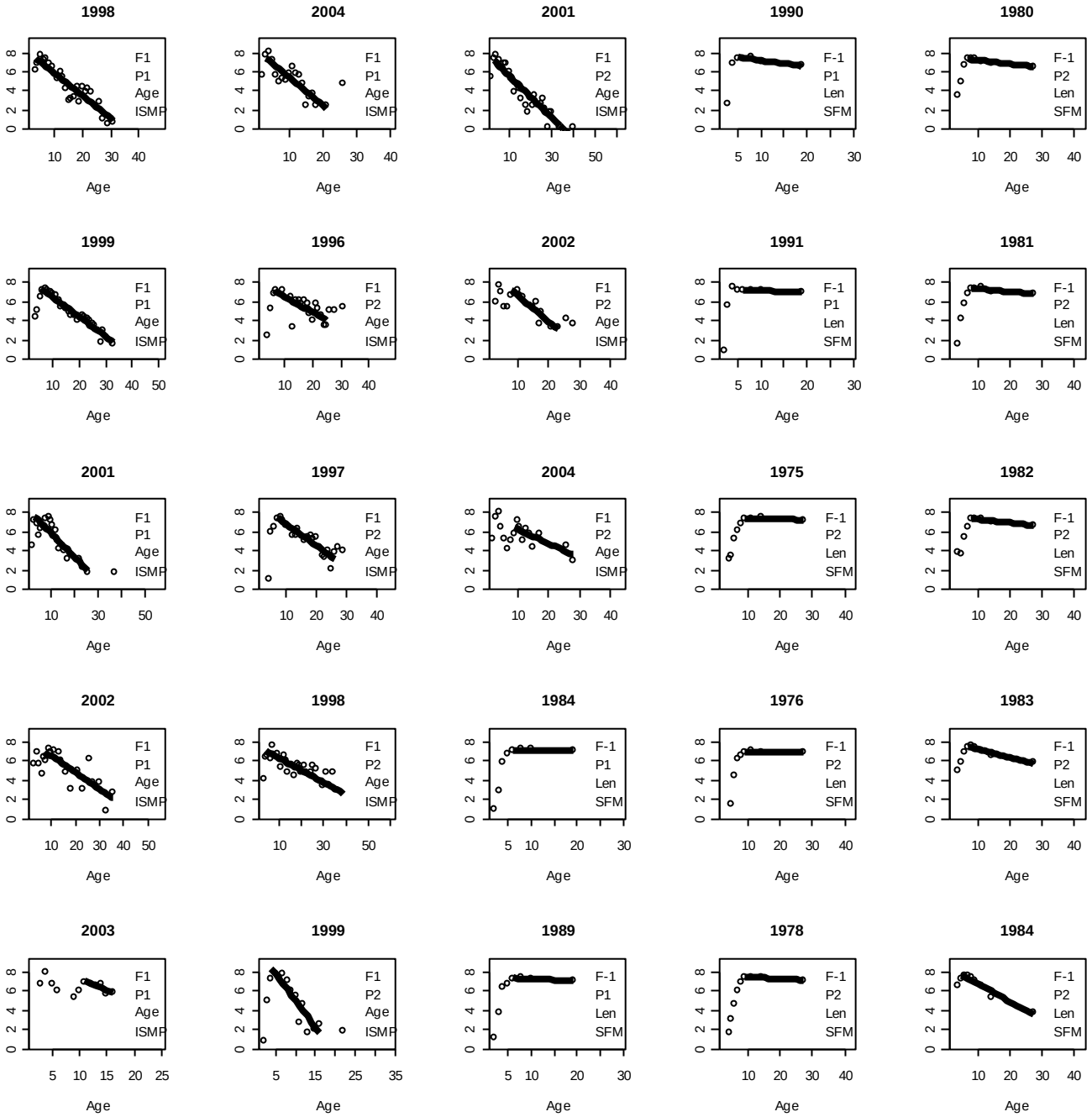
Detailed catch curve results: Flathead continued



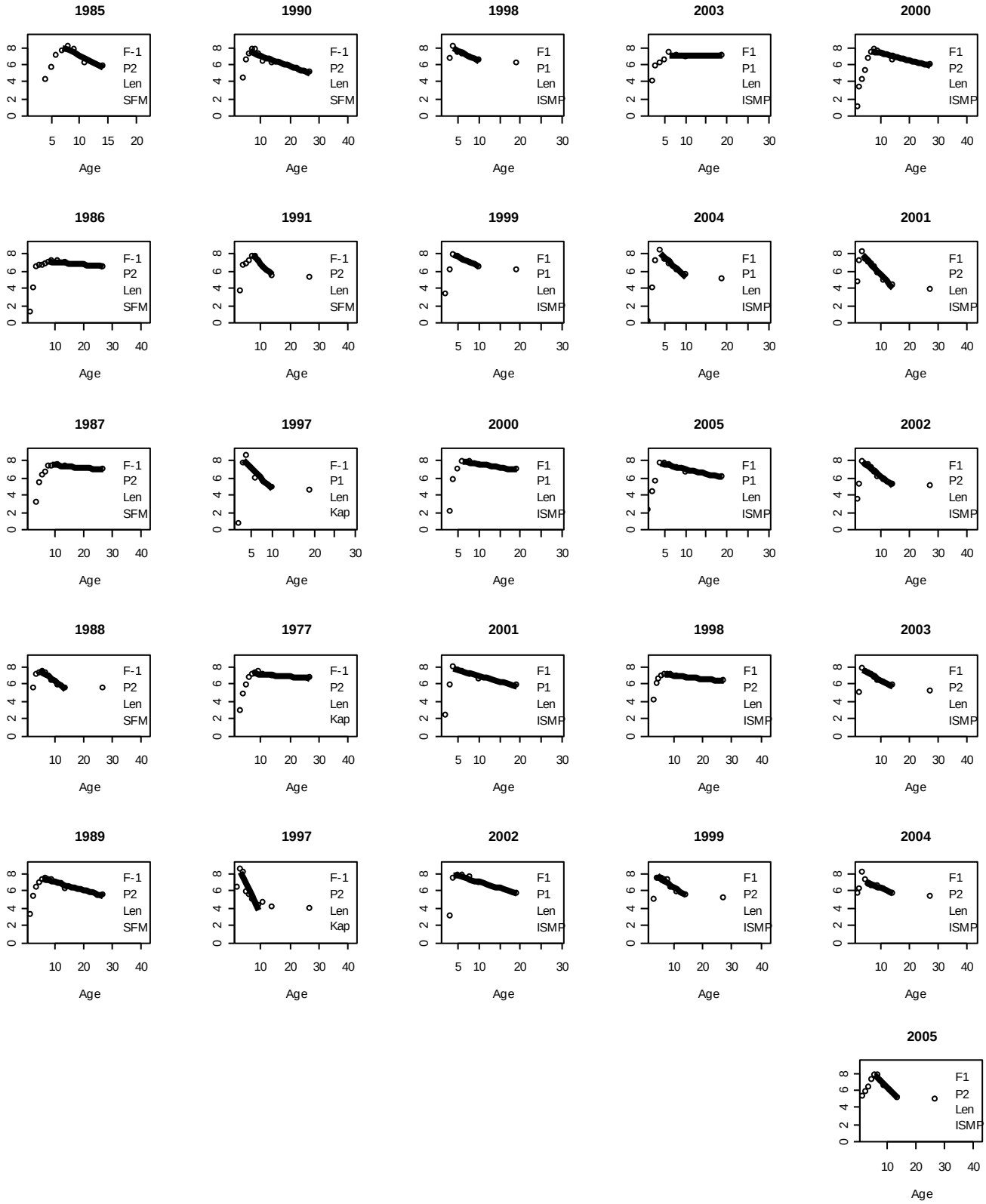
Detailed catch curve results: Flathead continued



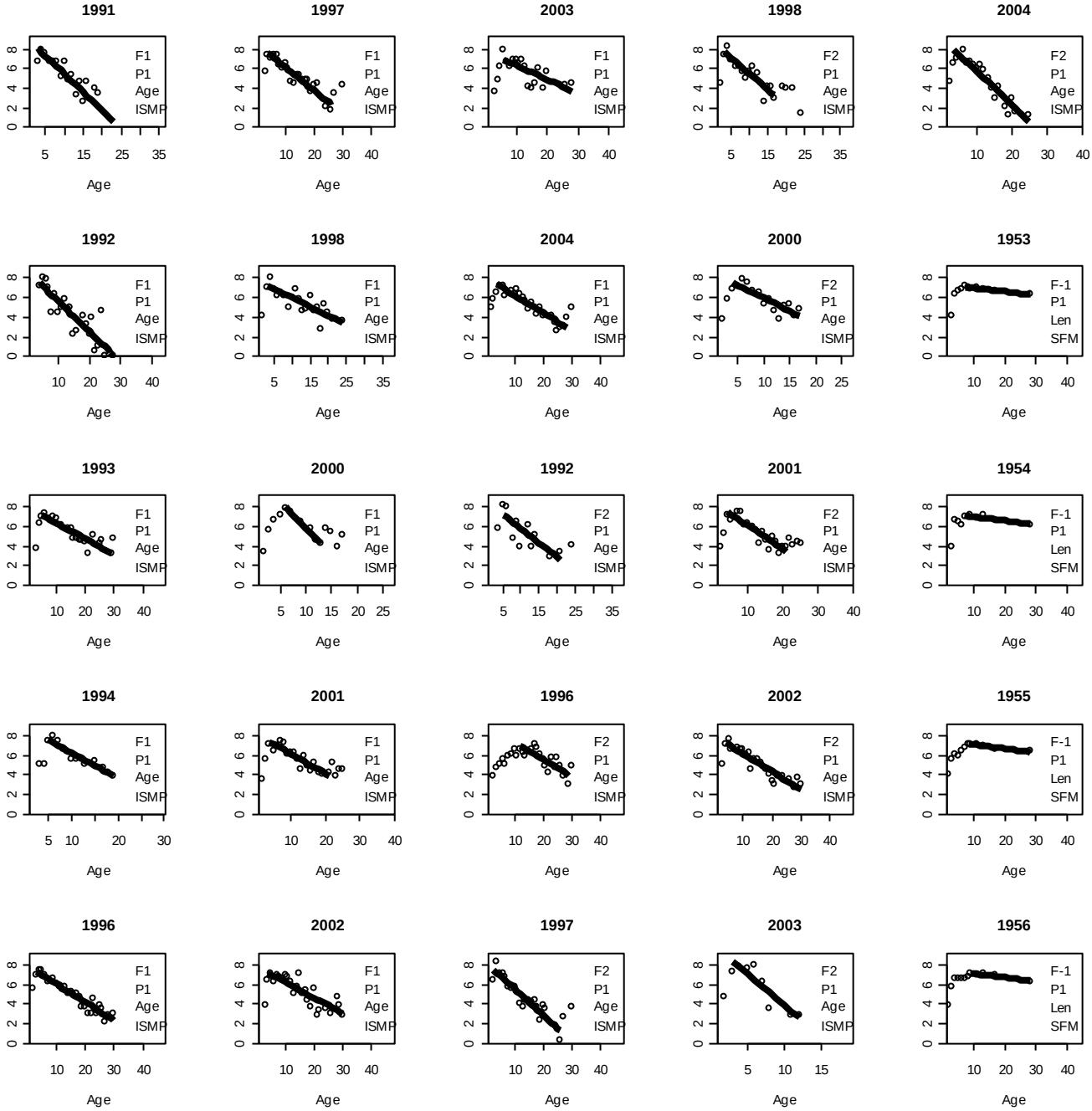
Detailed catch curve results: Redfish



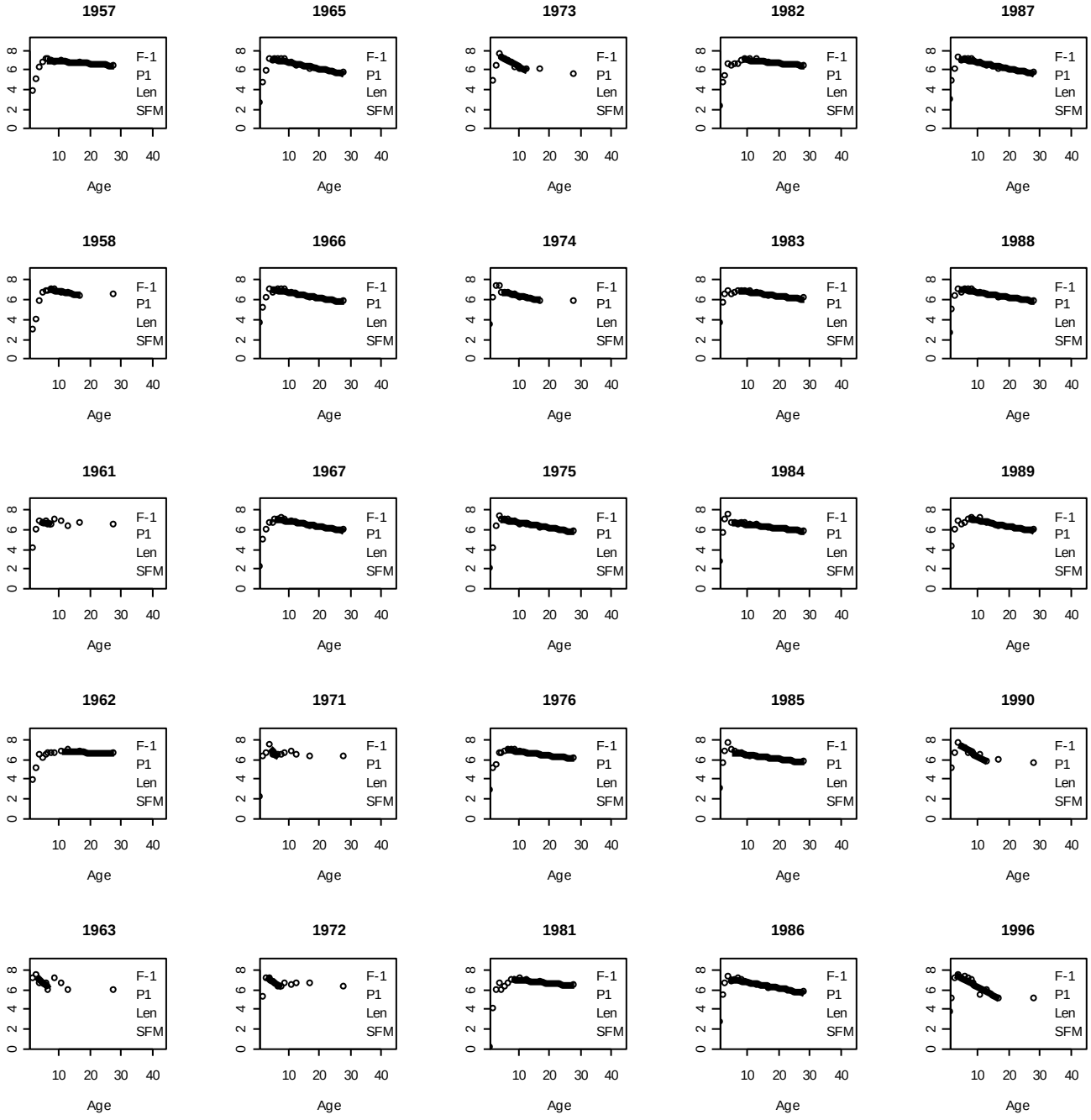
Detailed catch curve results: Redfish continued



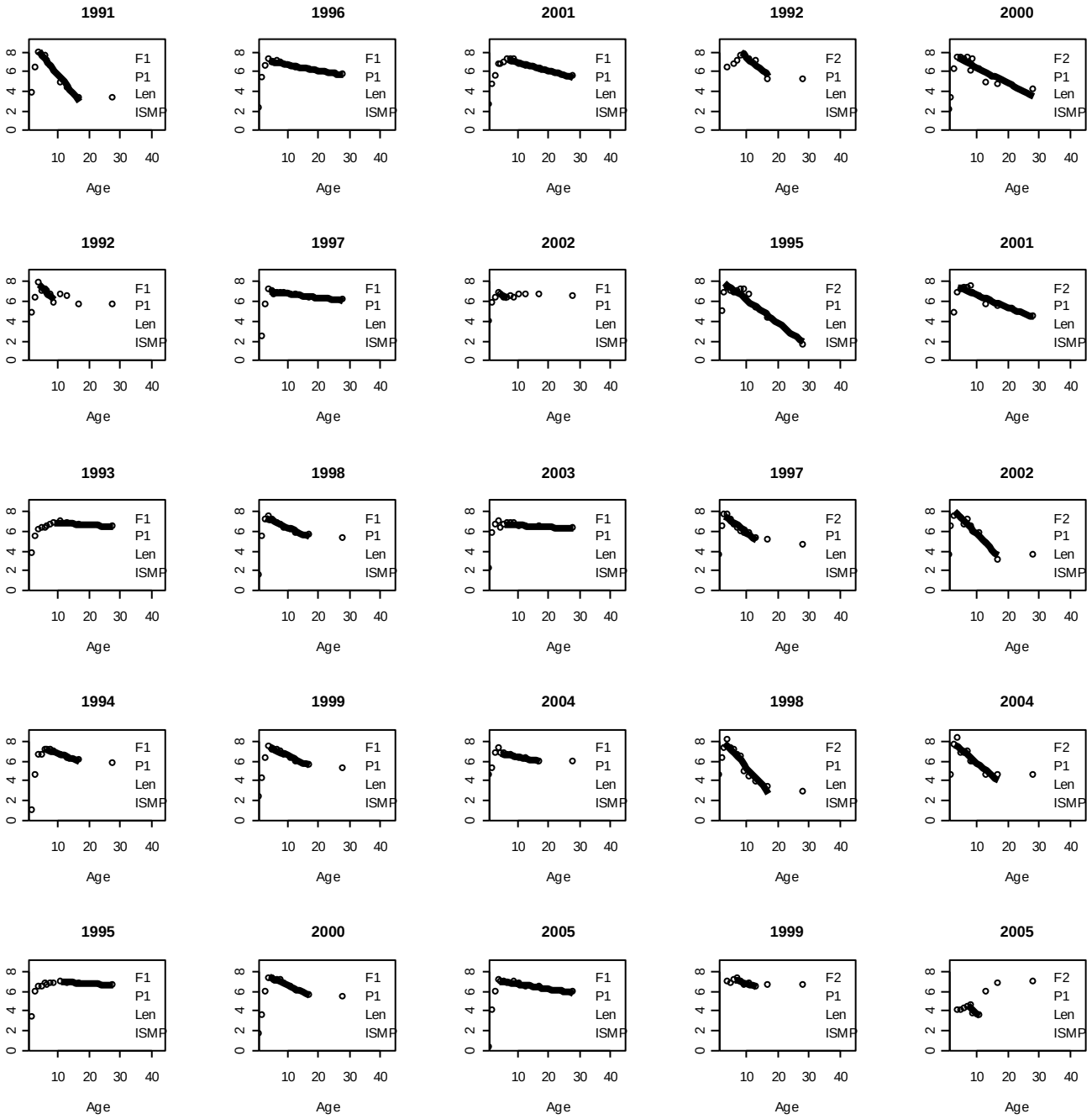
Detailed catch curve results: Morwong



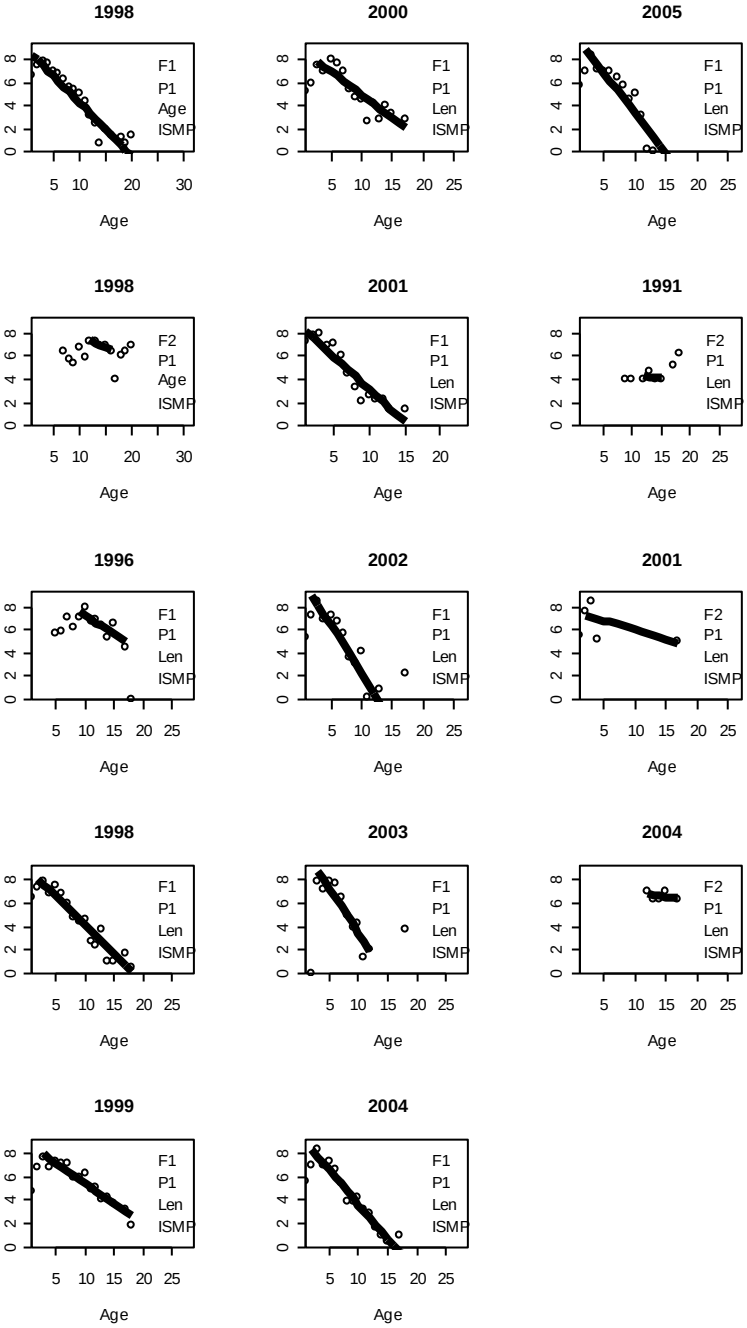
Detailed catch curve results: Morwong continued



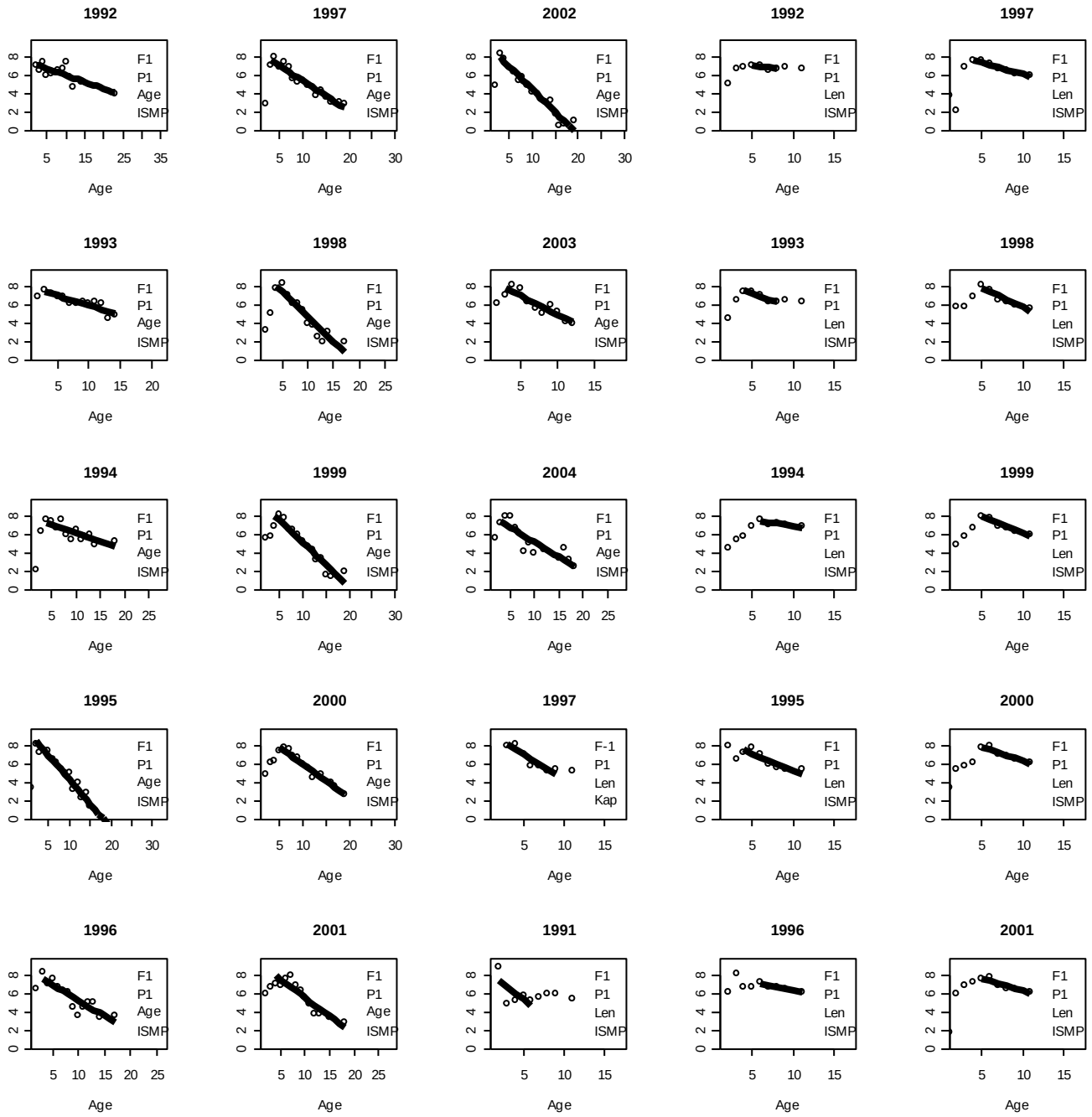
Detailed catch curve results: Morwong continued



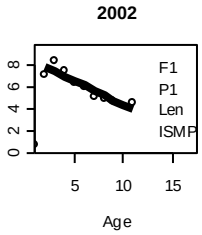
Detailed catch curve results: Silver trevally

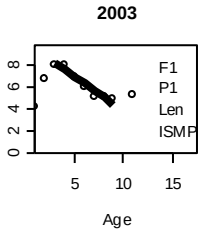


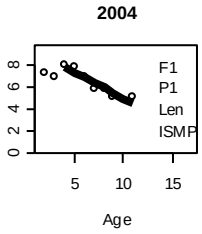
Detailed catch curve results: Spotted warehou

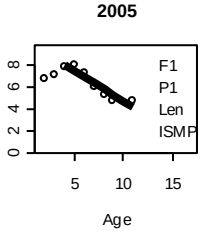


Detailed catch curve results: Spotted warehou continued

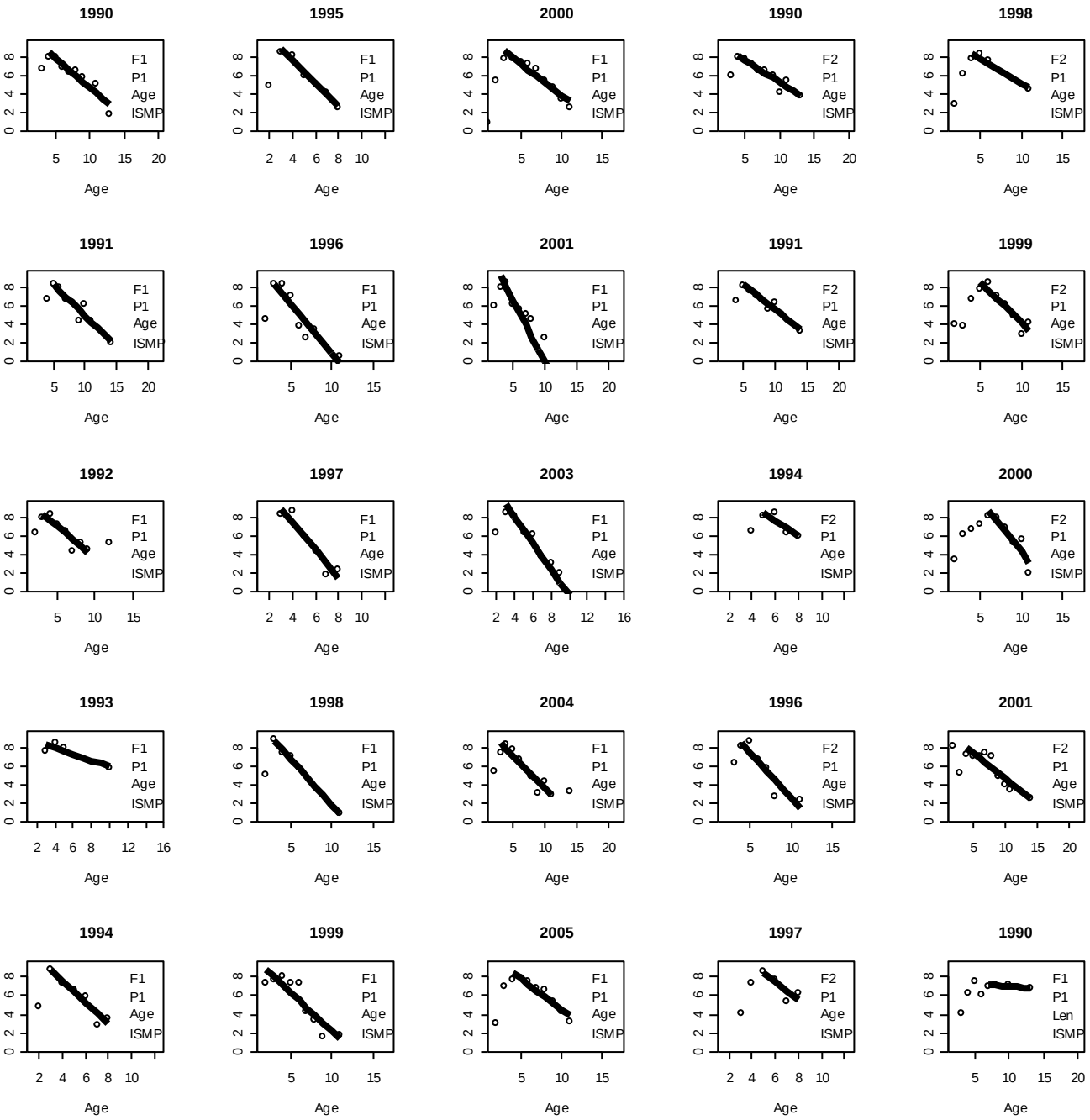




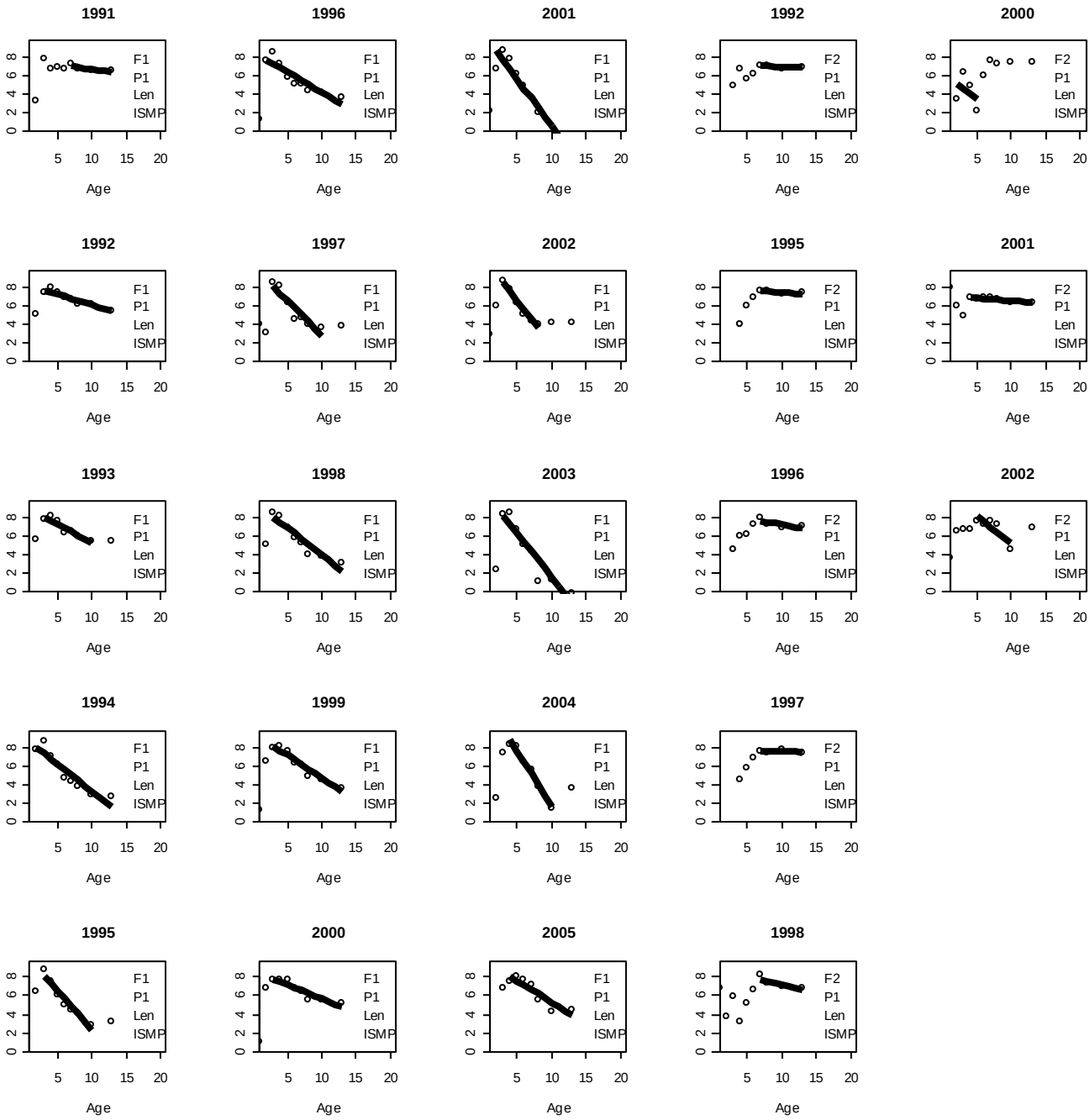




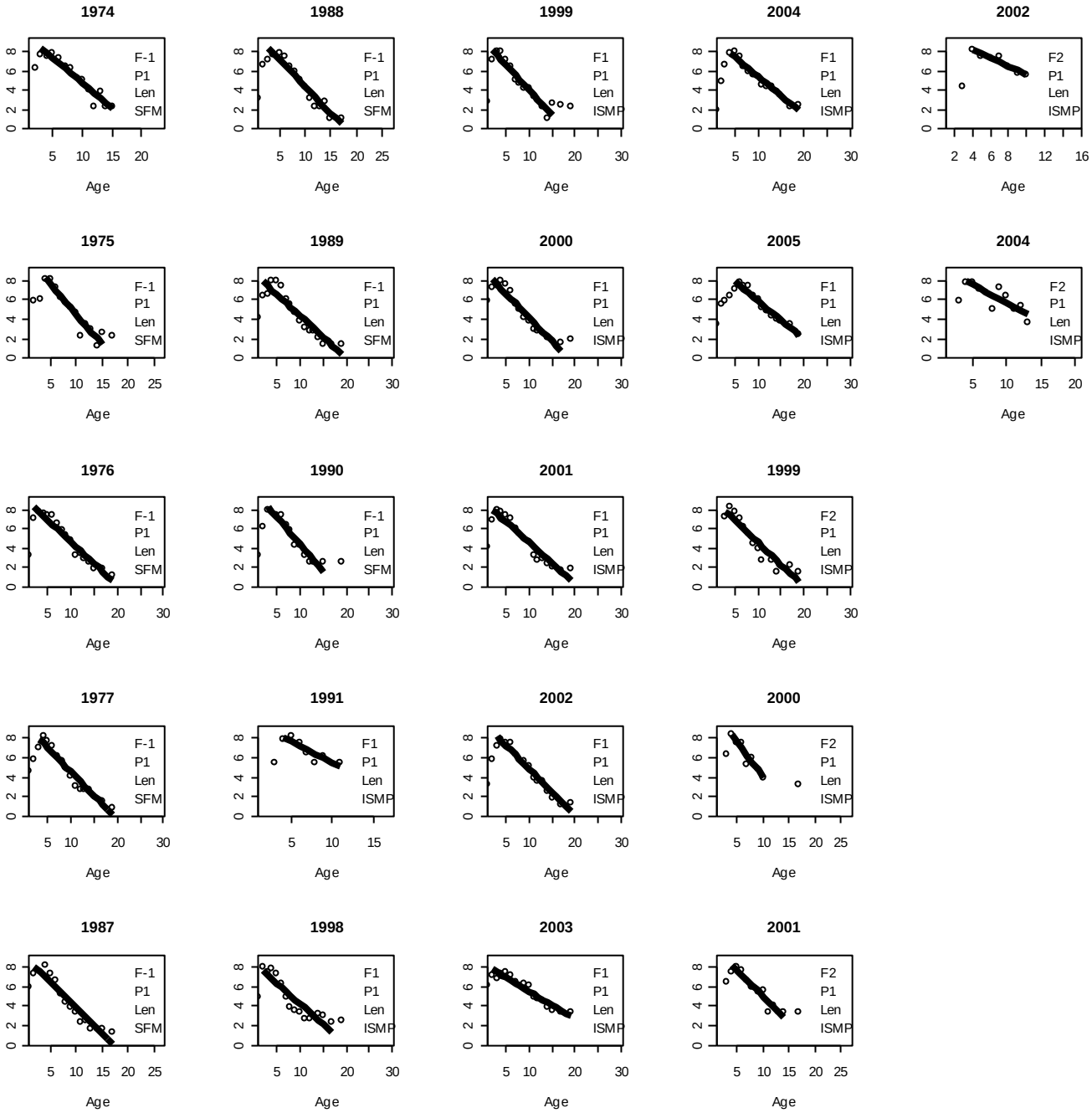
Detailed catch curve results: Blue warehou



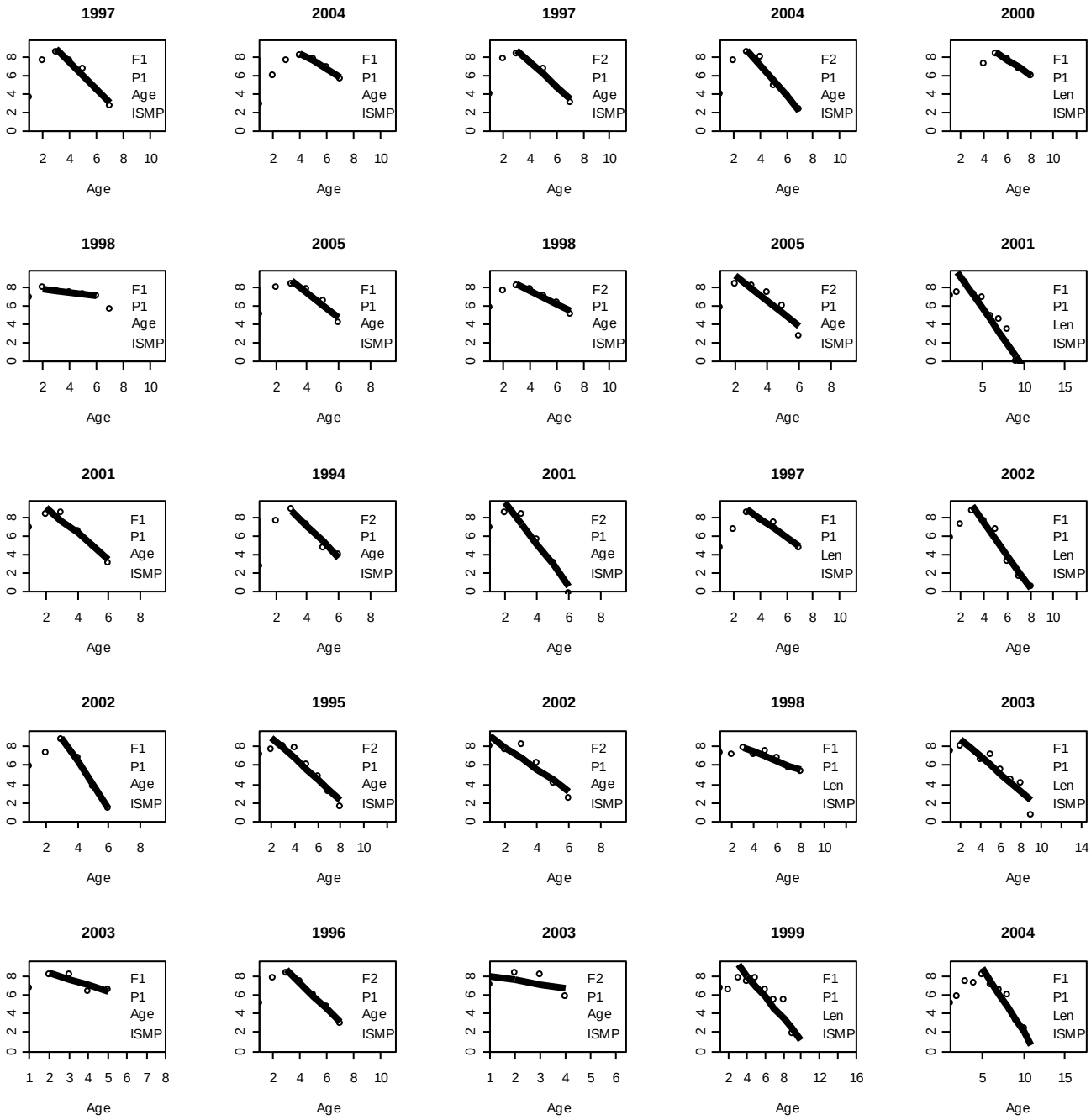
Detailed catch curve results: Blue warehou continued



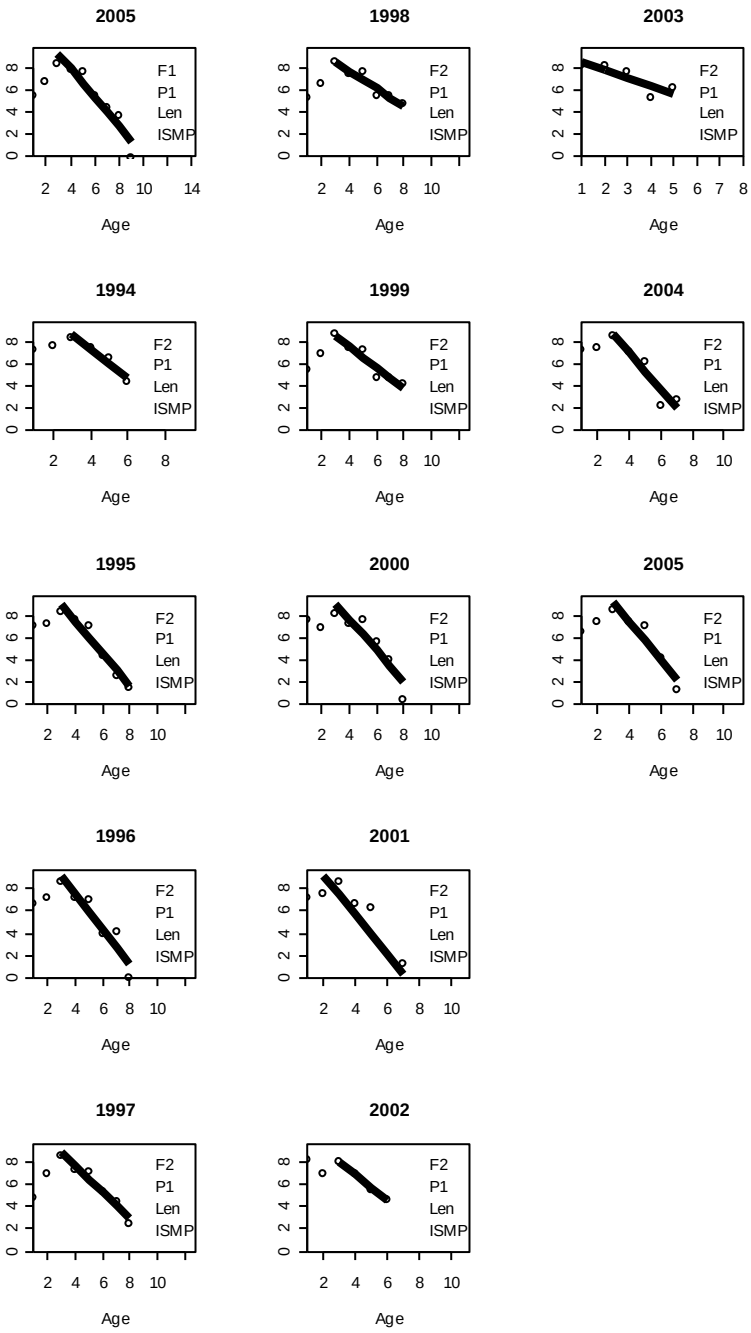
Detailed catch curve results: John dory



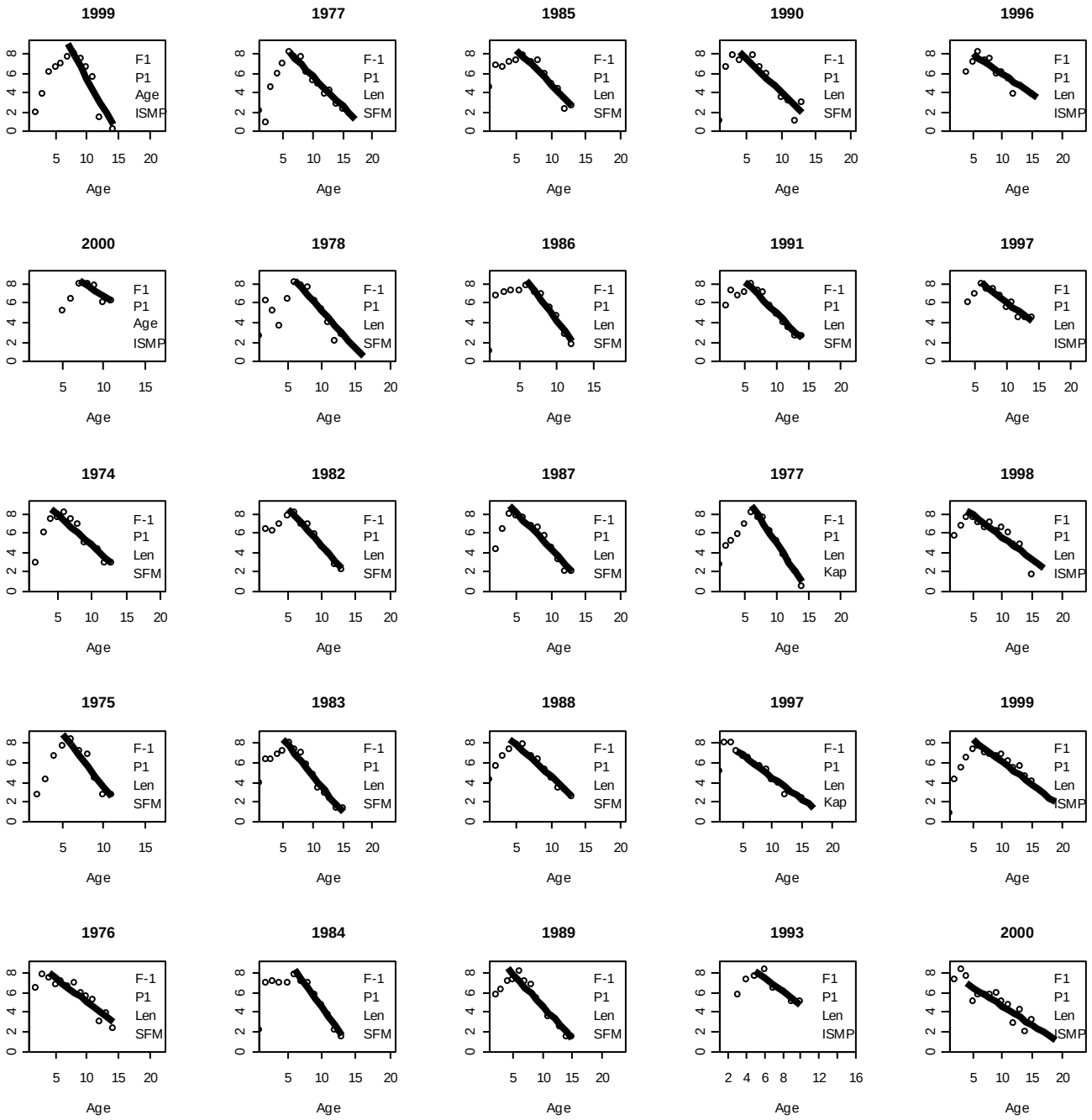
Detailed catch curve results: School whiting



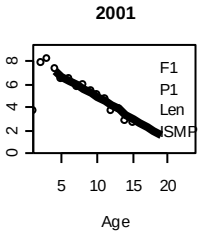
Detailed catch curve results: School whiting continued

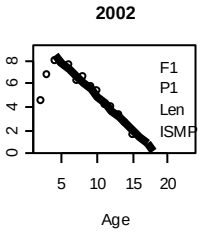


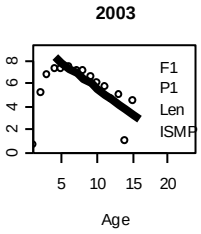
Detailed catch curve results: Mirror dory

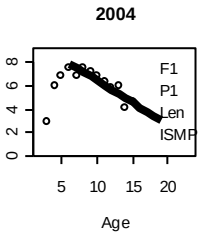


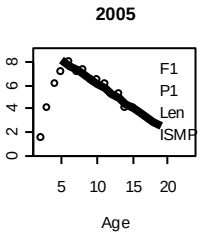
Detailed catch curve results: Mirror dory continued



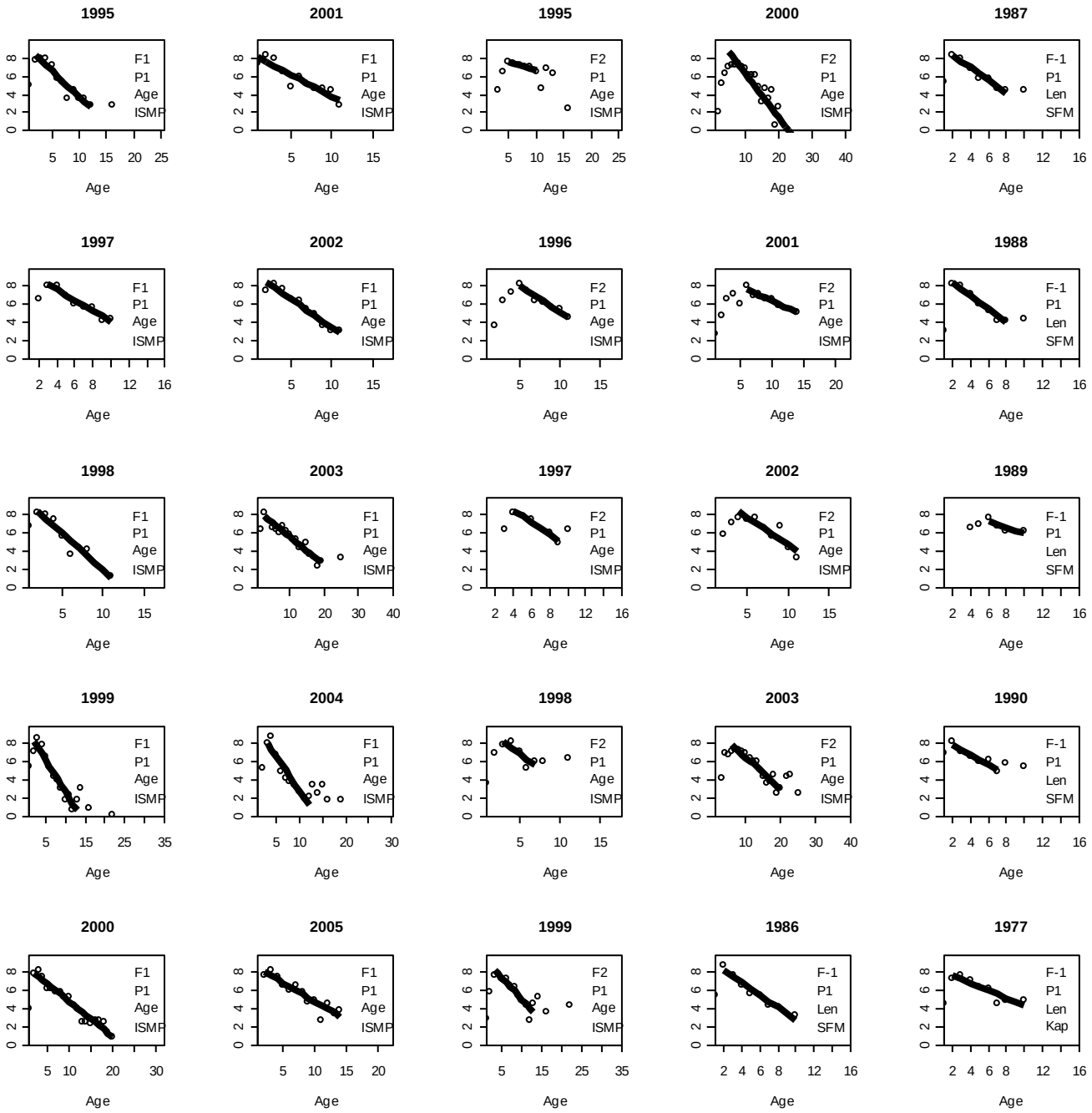




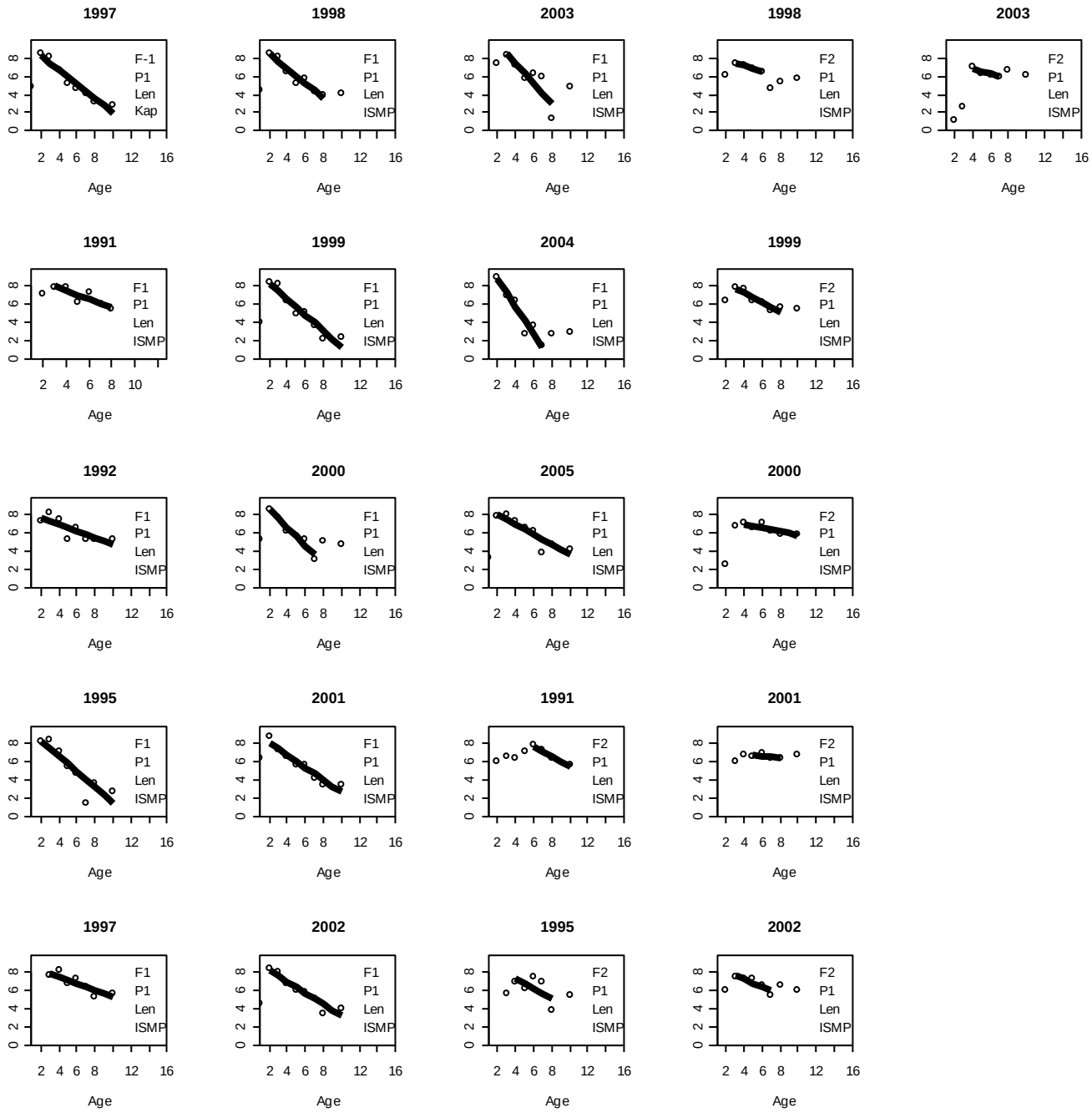




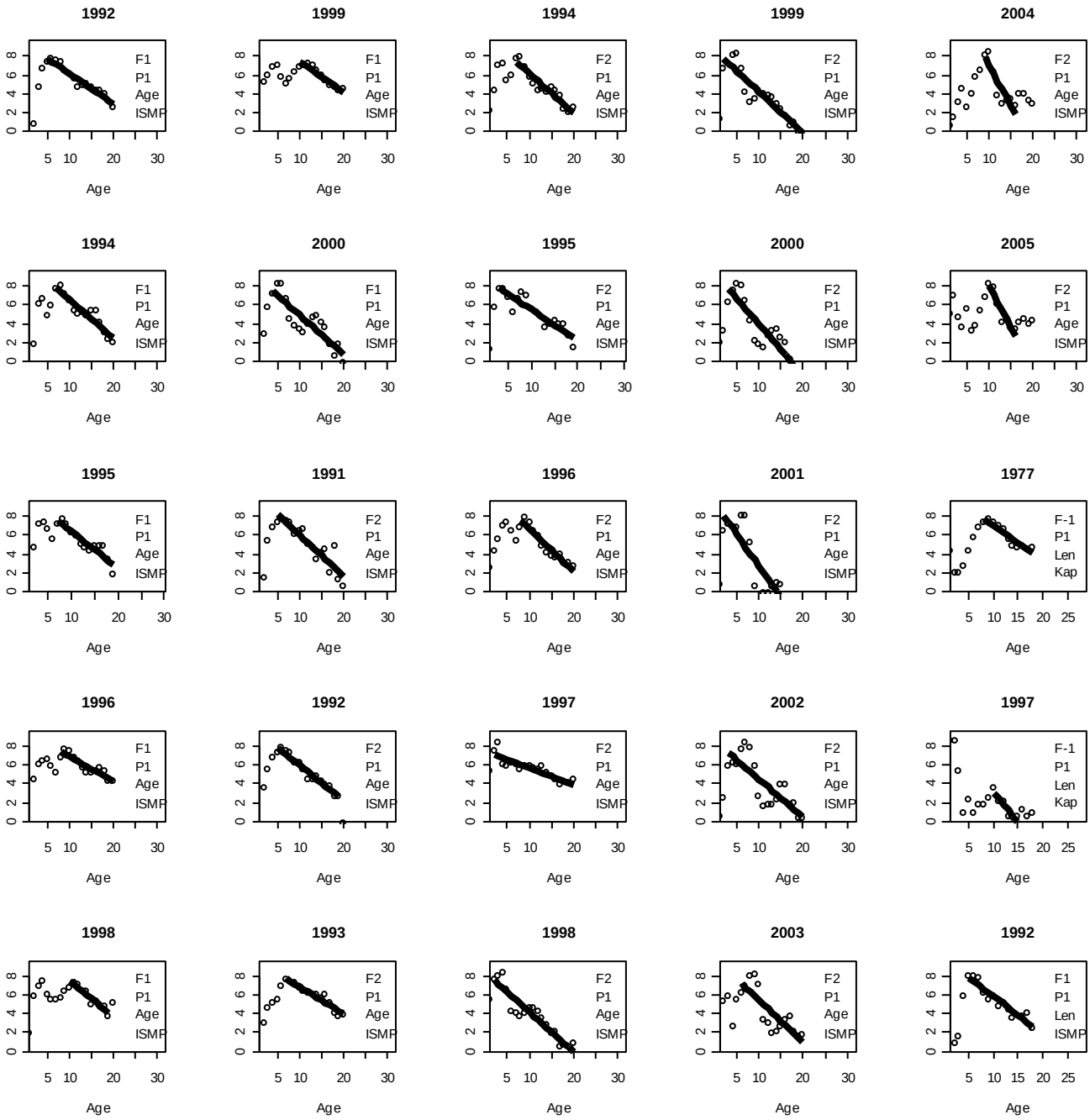
Detailed catch curve results: Ling



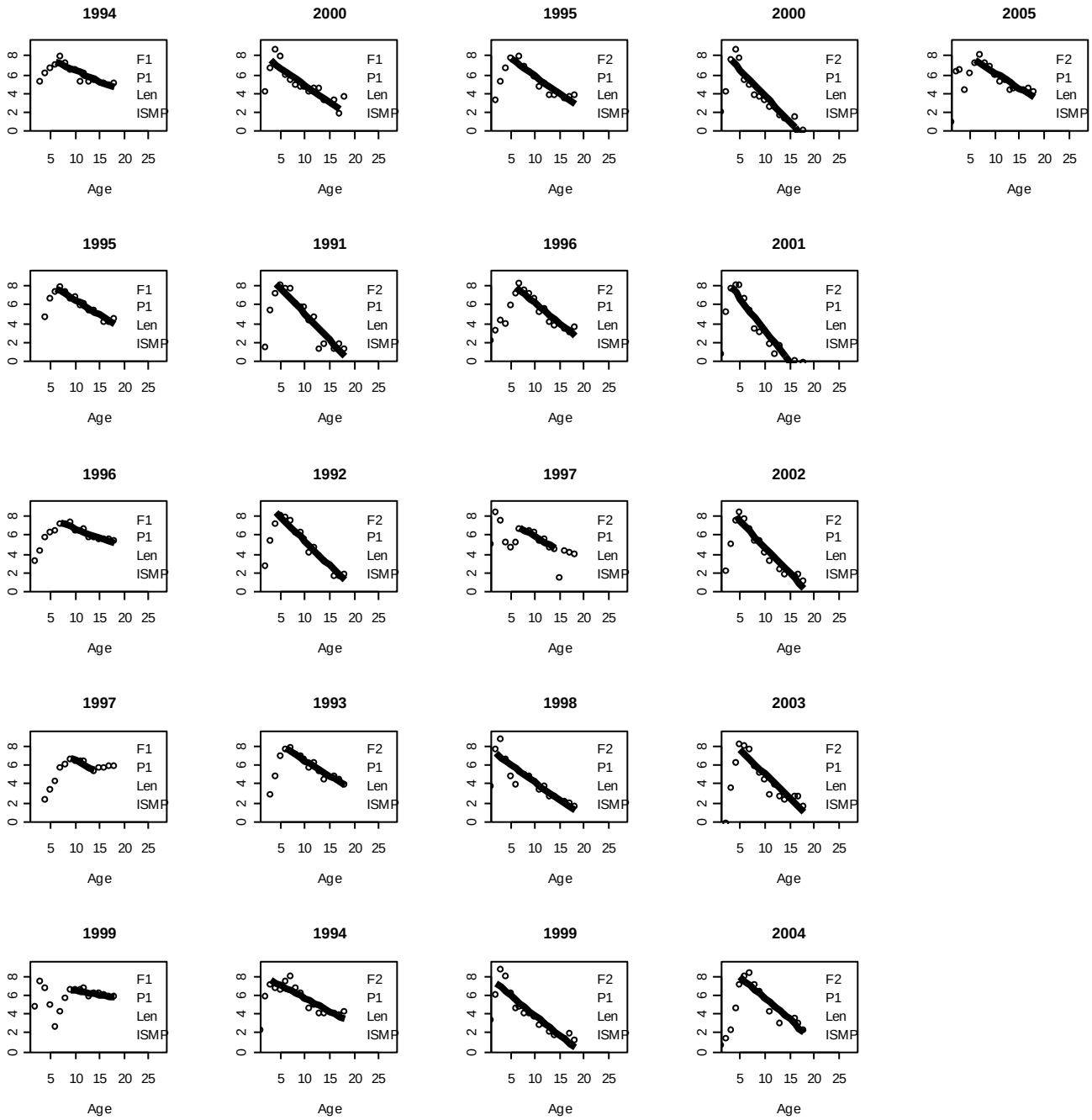
Detailed catch curve results: Ling continued



Detailed catch curve results: Blue grenadier



Detailed catch curve results: Blue grenadier continued



29. Tier 3 Calculations for Blue Eye Trevalla *(Hyperoglyphe antarctica)* Using Data up to and Including 2005

Gavin Fay[1]

[1]School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195-5020, USA

29.1 Summary

Estimates of total mortality *Z* for blue eye trevalla (blue eye) are presented, and recommended biological catch (RBC) multipliers of current catch are calculated under the tier 3 harvest control rule (HCR, Klaer and Thomson 2005). Analyses are limited to data from the longline sector, as catches from this gear type have recently increased to currently constitute over 60% of the total landings of blue eye within the SESSF. Results of analyses which use dropline data, and apply multi-year catch curve analysis to the longline data are presented for comparison. Estimation methods and assumed values for *M* are guided by the results of a MSE of the tier 3 HCR for blue eye. Estimates of *Z* are generally consistent among estimation methods and the types of data included in the analyses. Assuming a value for *M* of 0.08 yr^{-1}, calculated tier 3 multipliers to current catch range from 0.5 – 1.1, with lower multipliers (implying larger reductions in catch) being obtained when the catch curves are applied on an area-specific basis.

29.2 Data

Estimates of *Z* are obtained using a) only age data from the Central Ageing Facility (CAF), and b) both age (CAF) and length data from the Integrated Scientific Monitoring Program (ISMP). Using just the age data to estimate *Z* assumes that fish are selected for ageing at random from the catch. In the latter case, the age data are used to calculate annual age-length keys (ALKs) which are then applied to gear and area-specific length frequency data to obtain age composition information. This second approach assumes that the length data (which frequently have greater sample size) are representative of the catch, as opposed to the ages. However, because of sample sizes and problems when creating the ALKs, this approach does not account for possible area/gear specific differences in length at age. An alternative approach which would permit area-specific stratification of the age data would be to use the raw conditional age at length information when estimating *Z*. This method is not employed here.

Age data are available for the longline sector for the years 2003, 2004, and 2005. Table 29.1 and Table 29.2 show the sample sizes of both aged fish and those sampled for lengths from the ISMP for these years. The number of aged fish in 2004 is appreciably lower than that in the other 2 years. Data are available from a number of areas within the SESSF, with most of the samples coming from eastern Tasmania (E Tas) and east Bass Strait (EBS).

29.3 Estimation methods

The methods used to calculate *Z* were determined from simulation modeling exercises that evaluated the performance of the tier 3 HCR using a number of estimation methods over a range of plausible hypotheses regarding population parameters, fishery selectivity, and spatial structure (Fay, *in prep*). Three estimation methods were applied to the blue eye data: the Chapman and Robson (1963) estimator (CR); a modified version of the Chapman and Robson estimator which discounts younger ages in the sample that may not be fully selected (CR2); and a regression estimator that truncates the age sample at both young and old ages (R1). These methods were chosen because they showed superior performance over other methods when attempting to correctly update the fishing mortality rate using the HCR, and the CR2 and R1 estimators were found to be almost unbiased in estimating Z as selectivity approached asymptotic behaviour.

Annual estimates of *Z* were obtained using these methods by both analyzing each area for which data were available separately, and by pooling data from all areas in a given year together. Table 29.1 and Table 29.2 show estimates of *Z* along with estimated standard errors for the three estimation methods, for the two different data combinations. Estimates are relatively consistent despite whether analyses are based on just the age data, or include the length frequencies. Samples with fewer aged fish generally result in higher, but less precise estimates of *Z*. There appears to be some evidence for differential mortality rates by area, with higher *Z*'s in the western areas, although it is unclear whether this is due to the effect of sampling (sample sizes in these areas are generally lower than eastern areas).

Estimates of *Z* from the dropline sector (Table 29.3) are somewhat higher than those estimated for longlines. An alternative method of estimating total mortality, multi-year catch curve analysis (Bravington and Poole, *in prep*), was also applied to the longline data. Advantages of this method are that data from all years are fitted to simultaneously, enabling the inclusion of 'cohort' effects, and that age-specific selectivities are accounted for directly. Figure 29.1 shows the estimated time trajectory of *Z* for blue eye obtained by this method applied to the longline data (results presented for application of method that uses both the CAF age data and the observer length frequencies). The results suggest that *Z* has declined in recent years, and that current *Z* is around 0.11 yr^{-1}. Although these estimates are lower than those obtained from the other estimators, the results are comparable when the age range in the samples are considered (the high estimates of *Z* in the 1990s are obtained from the progression of older cohorts within the 2003-2005 data).

29.4 Current estimate of Z

The tier 3 HCR operates by applying a multiplier to the recent catch level in order to predict the RBC for the fishery. This multiplier is based on the estimated *F/M* ratio, and is therefore dependent on both the estimate of *Z* and the value assumed for *M*, the rate of natural mortality. Tier 3 calculations for SESSF species in 2005 used an average Z from annual catch curves over a number of recent years (e.g. the last 3 years for which data are available). However, a decision must also be made in terms of which *Z* to use for a

given year when multiple estimates are available (such as those from multiple areas), as the RBC is calculated on a SESSF-wide basis (that is, *F* is not updated on an area-specific basis). The simulation modeling by Fay (*in prep*) evaluated the performance of the HCR under several assumptions regarding which *Z* to use when age data are available from multiple areas and there is some uncertainty regarding the degree of spatial structure in the population among areas. These analyses suggested that *F* was updated in the correct direction in all areas most frequently when the maximum estimate of *Z* from area catch curves was used when applying the HCR. This method also showed the lowest degradation in performance with estimated values of *M* other than that of the 'best'. However, pooling data from multiple areas to conduct a single catch curve for the fishery gave almost as good performance for the 'best' estimated value of *M*. Although these analyses accounted for differences in population size among areas, they did not examine the sensitivity of results to varying sample size by area, a feature common in the actual blue eye data (Table 29.1 and Table 29.2). As such, both this "maximum *Z*" approach and that where a single catch curve was applied on a fishery-wide basis were used to obtain the annual *Z* estimates for application of the HCR.

Given annual estimates of *Z* for the years 2003-2005, estimates of current *Z* were obtained by finding the average, weighted by the inverse of the variance. Table 29.4 through to Table 29.6 show the resulting *Z* estimates for the different estimation methods. These range from 0.13 – 0.172 yr^{-1} when using the pooled data approach (Table 29.4 and Table 29.5), and are slightly higher when using the maximum area-specific estimates (0.156 – 0.201 yr^{-1}, Table 29.6).

29.5 Values for M

The HCR is dependent on the assumed value for *M*. Plausible values for *M* for blue eye trevalla could be obtained by fitting growth curves to the available age and length data, and using an appropriate relationship between the Brody growth coefficient, *k*, and the rate of natural mortality. However, the available data for blue eye trevalla provide little information on the value of *k*, and so this approach was not used. Application of Hoenig's (1983) estimator for mortality rates based on empirical longevity data results in a value for *M* of ~0.08 yr^{-1} (max aged blue eye of 54 yrs old). Using Jensen's (1996) relationship of M with age of maturity, gives values for *M* of ~0.18 yr^{-1}. The estimate of *M* for blue eye in New Zealand (bluenose) in 2005 was also 0.18 yr^{-1}. However, this estimate was based on Hoenig's estimator given a maximum age of 25 years, and is likely high for blue eye in the SESSF given the ageing data from the CAF (Assessment scientists in New Zealand suggest that the estimate for *M* of 0.18 is likely biased high due to dome-shaped selectivity of trawl gear). Values used for *M* by Fay when evaluating the HCR spanned this range. For analyses with no spatial structure, results of the HCR evaluation analyses gave best performance when *M* was 0.08 (CR), 0.10 (R1), and 0.12 (CR2). In addition to updating *F* in the correct direction most frequently, the 0.08 and 0.10 estimates also resulted in a probability of *F* not being increased when it shouldn't (according to the HCR) > 90%. Addition of multiple areas and the possibility of spatial structure among areas resulted in decreased performance. These analyses suggested that given the additional uncertainty, the lower value for *M* of 0.05 yr^{-1} provided the best performance, with the CR2 estimator and the "maximum *Z*" rule giving values for the performance measure closest to those under an ideal scenario

where it is possible to make decisions on an area-specific basis. In these cases, a value for *M* of 0.08 yr^{-1} gave almost as good performance in terms of correcting *F* in the right direction in all areas, with essentially no drop in the probability of not increasing *F* in any area when it shouldn't be. It should be noted that although the performance of the HCR was evaluated to be low by Fay, the estimated performance of the best methods were appreciably higher than could be expected by randomly making a decision. This was particularly so when accounting for multiple areas of varying sizes and uncertainty in spatial structure.

29.6 Tier 3 multipliers

Table 29.4 through to Table 29.6 show the value of the tier 3 multiplier for blue eye for the 3 estimators and the different values for *M* discussed above. There is some consistency among approaches to data treatment (i.e. age and length data vs just age data). With the exception of 0.05 for *M*, which predicts sharp reductions in catch, the multipliers are around 1 (suggesting *F* is approximately equal to *M*), with slight reductions in catch (multiplier of 0.9) when *M* is assumed to be 0.08 (Table 29.4 to Table 29.6). Given the results of the simulation exercises by Fay (*in prep*), choosing a value of 0.08 for *M* along with either the CR2 or R1 estimator seems reasonable. Given the uncertainty regarding spatial structure, the results in Table 29.6 that use the maximum *M* should be considered in addition to the results based on pooling age and length data over all areas.

29.7 Discussion

As demonstrated, the results of the tier 3 MSE for blue eye can be used to guide an assessment using the HCR. However, these analyses only tested the performance of the control rule being able to correctly adjust catch given itself, they did not evaluate whether the HCR is effective at maintaining the blue eye population at or near the target. Also, the data show that there are some issues regarding sample size that may influence the performance of the rules used to decide which estimates of *Z* to use when applying the HCR. Differences in sample size among areas was not addressed in the MSE, nor was the matter of averaging *Z* estimates over a number of years. The results of the decision analyses in the MSE are also dependent on the probabilities assigned to the states of nature (true values for *M* and the degree of spatial structure). The simulations assumed no knowledge over a plausible range for these parameters. Results from simple population models fitted to data suggest that the higher values for *M* considered in the anlaysis are perhaps somewhat less likely. As such, any effect this would have on the results of the decision analysis would likely be in the selection of a lower value for *M* as giving the optimum performance. The multi-year catch curve analysis seems to provide a more intuitive means of accounting for population processes pertinent to the estimation of mortality rates, and the similarity of results with the more standard methods is encouraging. This methodology should be included in a more complete evaluation of the harvest strategy framework for blue eye and SESSF species in general, a project that is currently ongoing.

29.8 References

Chapman, D.G. and D.S. Robson. 1960. The analysis of a catch curve. Biometrics 16:354-368.

Dunn, A., R.I.C.C. Franics, and I.J. Doonan. 2002. Comparison of the Chapman-Robson and regression estimators of *Z* from catch-curve data when non-sampling stochastic error is present. Fisheries Research 59:149-159.

Fay, G. *in prep.* Risk analysis of methods used to calculate recommended biological catches (RBCs) for blue eye trevalla (*Hyperoglyphe antarctica*).

Hoenig, J.M. 1983. Empirical use of longevity data to estimate mortality rates. Fishery Bulletin 82:898-903.

Jensen, A.L. 1996. Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. Canadian Journal of Fisheries and Aquatic Sciences 53:820-822.

Klaer, N. and R.Thomson. 2005. Yield, total mortality and Tier 3 estimates for Mirror Dory in the South East Fishery. Presented at the Slope RAG Meeting, August 2005.

Table 29.1. Estimates of *Z* by year and area for the longline fleet, using just the age data. N_a corresponds to the number of aged fish for that year / area.

			CR		CR2		R1	
Year	**Area**	**N_a**	***Z***	**SE**	***Z***	**SE**	***Z***	**SE**
2003	Total	437	0.131	0.006	0.151	0.008	0.154	0.011
	EVic / EBS	43	0.154	0.024	0.170	0.036	0.626	0.362
	E Tas	340	0.124	0.007	0.140	0.008	0.157	0.016
	W Tas	54	0.172	0.024	0.226	0.033	0.052	0.093
2004	Total	197	0.246	0.018	0.246	0.018	0.202	0.031
	EVic / EBS	51	0.210	0.030	0.243	0.036	0.138	0.054
	E Tas	87	0.239	0.026	0.281	0.037	0.256	0.066
	W Tas	22	0.186	0.041	0.217	0.055	-0.024	0.335
	WVic / WBS	37	0.430	0.072	0.430	0.072	0.311	0.053
2005	Total	625	0.138	0.006	0.166	0.008	0.171	0.013
	EVic / EBS	162	0.165	0.013	0.195	0.017	0.135	0.013
	E Tas	380	0.120	0.006	0.144	0.009	0.151	0.013
	WVic / WBS	78	0.241	0.028	0.410	0.068	0.407	0.183

Table 29.2. Estimates of *Z* by year and area for the longline fleet, using both age and length data. N_a corresponds to the number of aged fish for that year / area, while N_l is the number of fish sampled for lengths in the ISMP data.

				CR		CR2		R1	
Year	**Area**	**N_l**	**N_a**	***Z***	**SE**	***Z***	**SE**	***Z***	**SE**
2003	Total	2,699	436	0.120	0.006	0.138	0.007	0.166	0.014
	EVic / EBS	853	43	0.131	0.020	0.239	0.052	0.225	0.022
	E Tas	1,351	339	0.110	0.006	0.125	0.007	0.159	0.016
	W Tas	475	54	0.134	0.018	0.153	0.023	0.170	0.016
2004	Total	3,822	197	0.151	0.011	0.189	0.014	0.184	0.026
	EVic / EBS	672	51	0.163	0.023	0.195	0.028	0.206	0.021
	E Tas	2,277	87	0.137	0.015	0.169	0.019	0.160	0.030
	W Tas	574	22	0.187	0.041	0.296	0.077	0.280	0.026
2005	Total	2,175	623	0.140	0.006	0.178	0.009	0.176	0.015
	EVic / EBS	50	160	0.090	0.007	0.130	0.014	0.122	0.040
	E Tas	426	380	0.160	0.008	0.160	0.008	0.163	0.015

Table 29.3. Estimates of *Z* by year and area for the dropline fleet, using both age and length data. N_a corresponds to the number of aged fish for that year / area, while N_l is the number of fish sampled for lengths in the ISMP data.

				CR		CR2		R1	
Year	**Area**	N_l	N_a	***Z***	**SE**	***Z***	**SE**	***Z***	**SE**
1999	Total	780	152	0.182	0.015	0.216	0.018	0.212	0.060
	E Tas	58	62	0.096	0.012	0.105	0.014	0.115	0.143
	WVic / WBS	584	90	0.225	0.024	0.279	0.030	0.251	0.060
2000	Total	1,328	624	0.221	0.009	0.273	0.011	0.264	0.034
	E Tas	296	316	0.128	0.007	0.143	0.008	0.076	0.058
	W Tas	788	29	0.274	0.052	0.366	0.071	0.368	0.029
	WVic / WBS	244	270	0.267	0.016	0.351	0.022	0.427	0.055
2001	Total	775	363	0.246	0.013	0.258	0.015	0.220	0.039
	W Tas	716	98	0.244	0.025	0.254	0.029	0.215	0.040
2002	Total	1,574	632	0.142	0.006	0.166	0.007	0.053	0.067
	E Tas	601	360	0.282	0.015	0.394	0.021	0.317	0.070
2003	Total	1,249	497	0.098	0.004	0.111	0.005	0.122	0.014
	EVic / EBS	377	64	0.134	0.017	0.150	0.021	0.184	0.017
2004	Total	198	302	0.281	0.016	0.390	0.023	0.279	0.031
2005	Total	53	183	0.359	0.027	0.359	0.027	0.310	0.019

Table 29.4. Tier 3 multipliers to current catch for different values of *M* given average estimates of *Z* from 2003-2005 longline data (ages only, annual *Z* estimates weighted by the inverse of variance estimates).

	Z		
	CR	**CR2**	**R1**
M	**0.141**	**0.166**	**0.164**
0.05	0.5	0	0
0.08	1	0.9	0.9
0.1	1.2	1.1	1.1
0.12	1.2	1.2	1.2

Table 29.5. Tier 3 multipliers to current catch for different values of *M* given average estimates of *Z* from 2003-2005 longline data (age and length data, annual *Z* estimates weighted by the inverse of variance estimates).

	Z		
	CR	**CR2**	**R1**
M	**0.133**	**0.158**	**0.172**
0.05	0.5	0	0
0.08	1.1	1	0.9
0.1	1.2	1.1	1.1
0.12	1.2	1.2	1.2

Table 29.6. Tier 3 multipliers to current catch for different values of *M* given average estimates of *Z* from 2003-2005 longline data based on the maximum area estimates (age and length data, annual *Z* estimates weighted by the inverse of variance estimates).

	Z		
	CR	**CR2**	**R1**
M	**0.156**	**0.163**	**0.201**
0.05	0	0	0
0.08	1	0.9	0.5
0.1	1.1	1.1	0.9
0.12	1.2	1.2	1.1

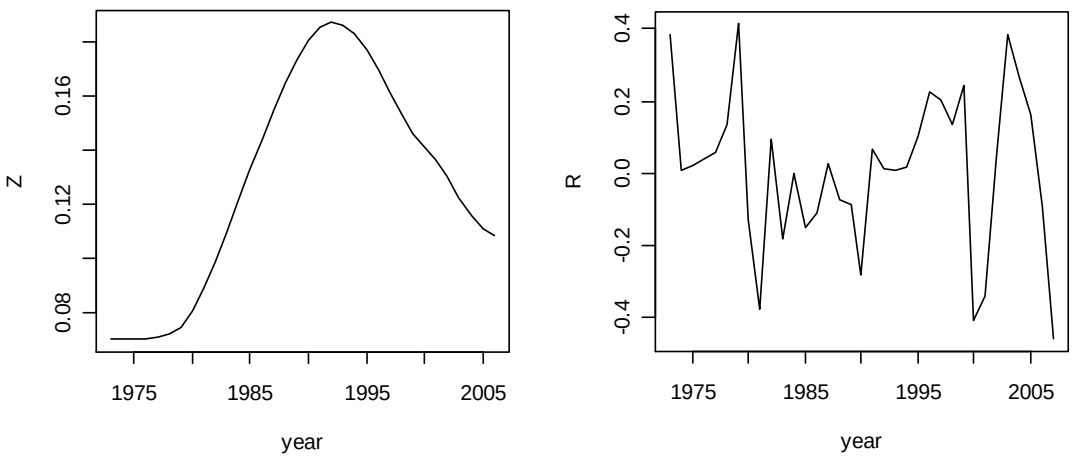


Figure 29.1. Estimates of *Z* and recruitment deviations from multi-year catch curve analysis of longline age and length data.

30. School Whiting Catch Curves 2006

Mark Bravington[1], David Peel[1] and Neil L. Klaer[1],

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

We have fitted the school whiting data for 1991-2005 using the multi-year catch curve method as presented last year. It is designed to be robust to some of the difficulties that beset automated log-regressions; in particular, variability in cohort strength, sampling variability, and possible changing Z. Results based on age data alone suggest recent Z values of about 1.0, and when length data was included, about 0.7. Both of these estimates are lower than the estimate of about 1.4 from Klaer and Thomson (May 2006), "Yield, Total mortality and Tier 3 estimates for selected shelf and slope species in the South East Fishery" Report to SE Shelf AG/Slope AG. Incorporating length data lowers the Z-estimate, but seems to introduce more noise.

30.1 Summary of multi-year catch curve method

- All years fitted simultaneously
- Recruitment variability i.e. "cohort effects", are allowed for
- Z can follow a random walk
- Uses plus-group-- no truncation at older ages
- Youngest fully-selected age class must be input (but can be estimated beforehand)
- Takes correct account of sampling noise & correlations in age and/or length data
- Age and length data pre-processed to handle boat/month/zone/batch effects as far as possible
- Assumes that aged fish are sampled at random from the population

The statistical framework is a Generalized (non)-Linear Mixed Model with dependent-data quasi-likelihood, as follows.

- "non-linear" because of the plus-group (otherwise it would be fully linear on the log-scale);
- "mixed" because recruitment and Z-steps are random effects, whereas Z_0 amd initial plus-group are fixed effects;
- "dependent-data" because each year's data is a set of proportions, not a single number;
- "quasi-likelihood" to account for correlations induced by length-to-age inference, while retaining the mean-variance relationship typical of count data.

30.2 Steps in fitting school whiting

We have assumed that the age data can be treated as unbiassed samples from the catch[19], in other words that large fish or small fish are not deliberately over-represented in the otolith samples[20]. A comparison of the overall length frequency from the on-board data (aggregated across years) with the LF from the aged fish shows no obvious evidence of length-specific bias[21], so the assumption seems reasonable (although we have not checked this on a year-specific basis).

We ran two different analyses: one using age data only, and the other using in addition length data. To deal with the length data, we first fitted growth curves to describe the frequency distribution of length-at-age (assumed constant over time, in this case), and then used these distributions in fitting a mixture model of proportion-at-age to the length distribution in any year[22], along with the direct estimates from the age data if available. If the assumptions about length-at-age are correct, then this method is optimally efficient, but the simple version used here could be biassed if there are strong cohort-specific effects on growth. This last point needs further investigation.

30.2.1 Data

Gear = Danish Seine only

Age data: from EBS and EASTA

Years= 1991- 2005 (the analysis presented last year was also to 2005, but small amount of data for 2006 was not included this year)

Length Data = On-board only, all zones

Selectivity assumed constant from age 3 up (based on pre-analysis)

[19] But see “Pre-processing” below for a note on within-batch correlation.
[20] Length-stratified subsampling is a deliberate policy in many fisheries where different analyses are planned
[21] except that very small fish are absent in the aged samples, presumably due to discarding—but these don’t matter for catch curves anyway.
[22] See Martin & Cook (1990, Journal du Conseil...) or Morton & Bravington (2003, CCSBT paper) for full explanation.

30.2.2 Growth Curve

We fitted a seasonally-adjusted von Bertalanffy growth curve to data from both sexes, as there was no evidence of differential growth by sex. The variance in Length at Age was described by

$$\theta_a = \left(\frac{sd_a}{\overline{L}_a} \right)^2$$

with

$$sd_a = \sigma_1 + \frac{(\sigma_x - \sigma_1)}{(\overline{L}_x - \overline{L}_1)} (\overline{L}_a - \overline{L}_1)$$

where x is the maximum age and $\overline{L}_1$ and $\overline{L}_x$ are the values given by the Von Bertalanffy function at age 1 and x (maximum age) respectively. The parameters σ_x and σ_1 are the standard deviations at age 1 and x.

30.2.3 Pre-processing of length and age data

There is much more variability between length samples from different sets, zones and months than can be explained just on the basis of the sample sizes alone; the same is true for age samples from different batches. A large sample size from a single set is not very informative about the population if there is considerable variability between sets. We used a hierarchical aggregation procedure to account for between-sample variability and to optimally combine the samples. The overall effect is that the effective sample sizes of the aggregates are much smaller than the total number of samples, but the aggregate estimate can be statistically treated as if it was a truly independent sample of the given size; this wouldn't be valid if all samples were simply "lumped" together. The aggregation process also ensures that the correct relative weights are given to age data versus length data when making inferences about proportions-at-age.

30.2.4 Results and discussion

Results for age data only are shown in Figure 30.1 and Figure 30.2, and for age+length data in Figure 30.3 and Figure 30.4. Although it is possible in principle to estimate V(log R) and V(ΔZ) within the model, this is not yet implemented, so we experimented with a range of plausible values. Estimates of Z were not sensitive to values of V(log R) higher than 0.8, or to V(ΔZ) slightly higher than 0.004 (corresponding to a 95% CI on annual change in mortality of +/-0.12—more seems unreasonable). In essence, there is not enough strong evidence of any trend in Z to "drive" the random walk very far, at least not with the age data alone.

The general fit to the age-only-data is good, although all the plus-groups are over-estimated (but sample sizes are very small). The effects of large cohorts coming through the population are not very pronounced, particularly when compared to the length+age results.

The Z-estimates from the age-only are lower than those in Klaer and Thomson (2006). The difference partly reflects the data, and partly the method. No direct comparison is possible, because the "age" results in Klaer and Thomson (2006) actually come from applying ALKs to the length frequency data whereas the "age" results here come from treating the age frequency as an unbiassed sample from the catch. If this assumption is OK, however, the results shown here should be statistically more reliable and efficient than the automated log-regressions used in Klaer and Thomson (2006).

30.2.4.1 Length+age data

The "raw" estimated proportions-at-age are much noisier when length data is incorporated, and the fit in Figure 30.4 does not seem as good as in Figure 30.2. To some extent, the appearance is deceptive, because the points for old ages (where the fit is poor) are based on much smaller samples and so are bound to be noisier. Note that the length+age data seems to show stronger cohort effects in recent years that for age data alone. In a conventional catch curve analysis, these cohorts would artificially inflate the estimate of Z in those years. The analysis shown here should be less sensitive to such cohort effects.

The apparent extra noise induced by using the length data suggests that the age-only analysis may be best to use for now; perhaps there are cohort effects in growth that need accounting for.

30.2.5 Fit with age data only

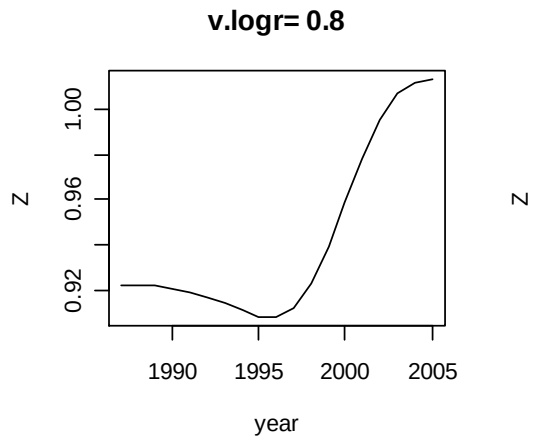


Figure 30.1. Fitted mortality (Z) for V(logR)=0.8 and V(ΔZ)=0.004 using age data only

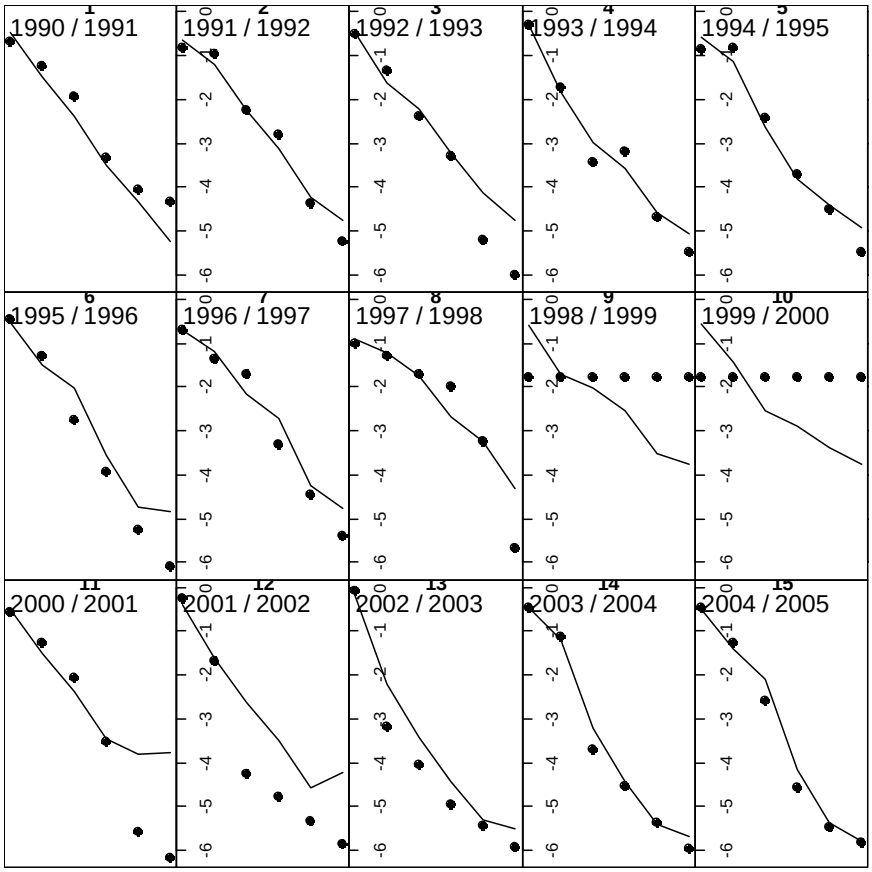


Figure 30.2. Plots comparing log of observed age frequency (dots) and the fitted age distribution (lines) for each year using age data only. Leftmost dot is age 3, rightmost is age 8.

30.2.6 Fit with age and length

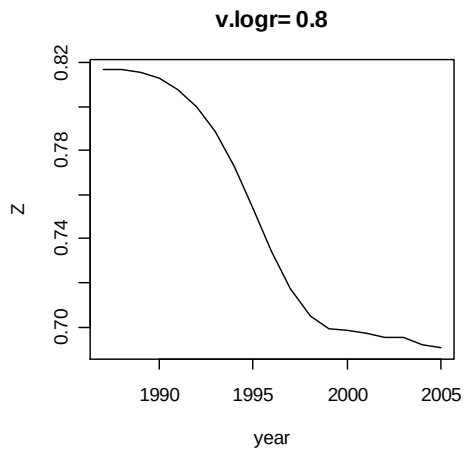


Figure 30.3. Fitted mortality (Z) for V(logR)=0.8 and V(ΔZ)=0.004 using age and length data.

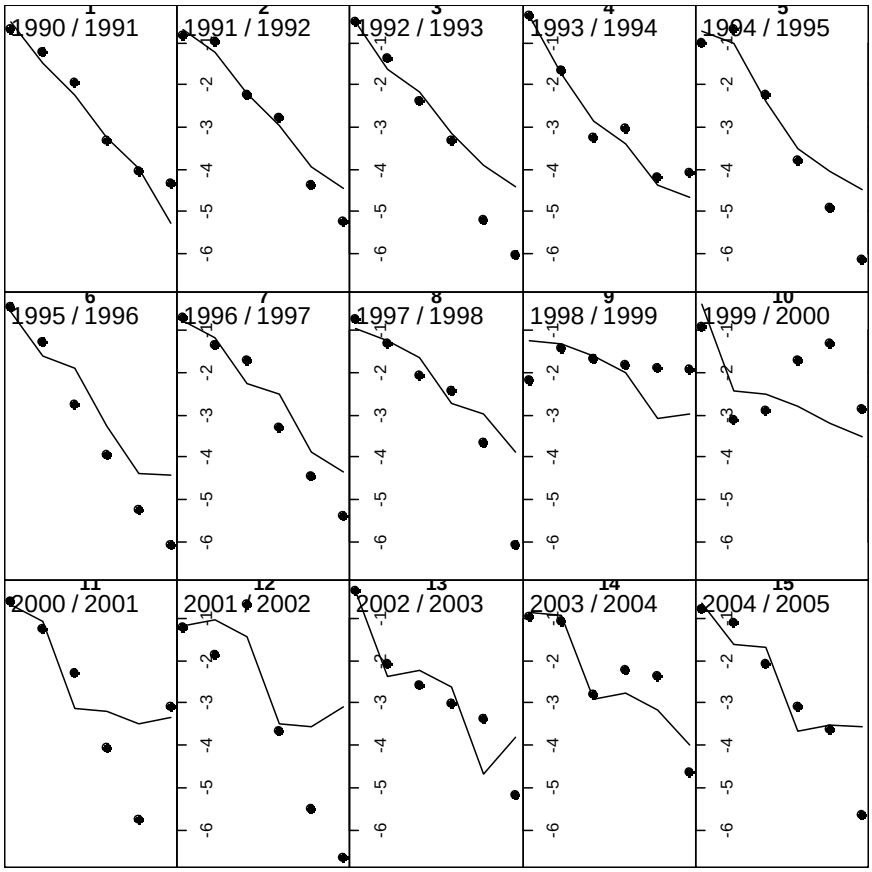


Figure 30.4. Plots comparing log of observed age frequency (dots) and the fitted age distribution (lines) for each year using age and length data. Leftmost dot is age 3, rightmost is age 8.

31. TIER 4 Analyses 1994 - 2005

Malcolm Haddon[1]

[1]Marine Research Laboratory, Tasmanian Aquaculture and Fisheries Institute,
University of Tasmania, Private Bag 49, Hobart TAS 7001

31.1 Introduction

The TIER 4 harvest control rules are to be applied to species with the least amount of information. In essence it requires knowledge of the time series of total catches and of catch rates, either standardized or simple geometric mean catch rates. A simple regression of catch rates against year over a four year time frame is used to provide a gradient for modifying the Recommended Biological Catch (RBC) from which a decision may be made as to what TAC to apply. The regression has the form of:

$$RBC = (1 + \alpha * slope) * C_{CUR}$$

where α is a constant decided before-hand, the 'slope' is the gradient of the regression between catch rates and year, (for the previous 4 years) and C_{CUR} is the total removals that includes total SEF catch by trawl and non-trawl, State catches, and discards, averaged over the previous four years.

The SESSF Harvest Strategies Framework document (2005) describe the TIER 4 analyses thus:

The steps in calculating the RBC for HCR4 are as follows:

1. Calculate current catch level C_{CUR} as the average catch (landings plus discards) over the past NC years, where NC will depend on the period of "stable" effective (= binding) TACs. The default for NC is suggested to be 4 years.
2. Calculate the slope of the trend in CPUE over the past NS years. NS will depend on whether trends in CPUE tend to be relatively stable, or cyclic. For "stable" stocks, it is suggested that NS = NC (i.e. 4 years). For "cyclic" stocks, NS would need to be set at >= 2 cycle periods.
3. Calculate the RBC as

$$RBC = (1 + \alpha * slope) * C_{CUR}$$

where the value of α is yet to be determined, and may need to increase as the (negative) slope increases.

The definitions of overfishing and overfished are even harder to determine at Tier 4, and will need to be investigated using simulation. In addition, there are problems with

determining particular values for the number of years to use in the analysis as the notions of stability and cyclicity are not defined for any species.

31.2 Methods

The Tier 4 analyses from 2005 demonstrated that the use of standardized catch rates led to more consistent results and reduced the need to use arbitrary alpha values for each species. The scaling of the relationships brought about by the different absolute levels of catch rate confuse the analyses and highlight the advantages of using the standardized data (Haddon, 2005). Therefore, for each species, analyses are presented only for standardized CPUE data (standardized relative to rates in 1994). By regressing against the proportional changes in catch rates rather than absolute catch rates difficulties in setting the alpha value (the slope multiplier in the equation above) to values that suite all species are alleviated.

31.3 Results

For the SLOPE assessment group TIER 4 analyses were required for eastern Blue Warehou, Western Gemfish, and both inshore Ocean Perch and Offshore Ocean Perch.

31.4 Discussion

The use of averaged catches over the previous four years certainly smoothes the catch history. However, its use could lead to a change in catches between years even when the analysis recommends no change (i.e. exhibits a zero slope). All that would be required is for catches in previous years to be higher than in the most recent year and a zero change will still lead to a reduction from the previous year's catch.
More analyses, comparisons, and discussion concerning the implications of the TIER 4 analyses is required.

31.4.1 Acknowledgements

Thanks to Matthew Koopman provided the SEF2 data, non-trawl data, and related State and discard catches.

31.5 Western Gemfish

Table 31.1. Western Gemfish. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years.

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	138.266		1.0000	0.000	0.000	0.000	138.266
1995	124.409		0.7220	0.000	0.000	0.000	124.409
1996	208.329		0.8092	0.000	0.000	0.000	208.329
1997	226.983	174.497	0.8094	0.000	0.000	0.000	226.983
1998	197.371	189.273	0.8036	12.000	0.000	0.000	185.371
1999	276.813	227.374	0.7785	5.000	0.000	0.000	271.813
2000	379.236	270.101	0.8142	30.000	0.000	0.000	349.236
2001	262.393	278.953	0.7668	9.000	0.000	0.363	253.030
2002	147.915	266.589	0.4540	9.000	0.000	0.441	138.474
2003	190.524	245.017	0.6653	13.000	0.000	3.918	173.606
2004	158.840	189.918	0.4845	9.000	0.000	3.655	146.185
2005	164.317	165.399	0.6443	2.000	0.000	5.732	156.585

Table 31.2. Western Gemfish. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.04845), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	138.266					
1995	0.72200	124.409					
1996	0.80922	208.329					
1997	0.80943	226.983	174.497	-0.04845	166.042	157.588	140.679
1998	0.80355	197.371	189.273	0.02449	193.908	198.542	207.812
1999	0.77850	276.813	227.374	-0.00980	225.145	222.916	218.459
2000	0.81420	379.236	270.101	-0.00107	269.810	269.520	268.939
2001	0.76676	262.393	278.953	-0.00747	276.870	274.786	270.620
2002	0.45396	147.915	266.589	-0.10210	239.369	212.149	157.710
2003	0.66527	190.524	245.017	-0.07596	226.406	207.795	170.573
2004	0.48445	158.840	189.918	-0.06356	177.846	165.775	141.632
2005	0.64433	164.317	165.399	0.03903	171.854	178.309	191.220

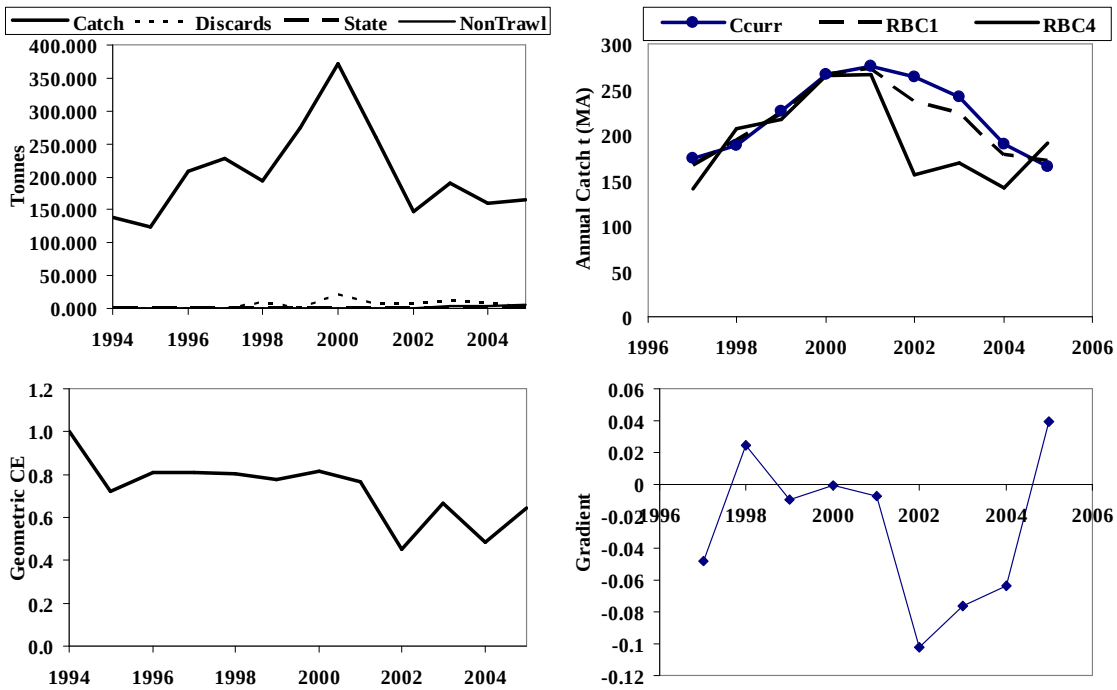


Figure 31.1. Plots of the various analyses for Western Gemfish using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.6 Inshore Ocean Perch (<=200 m depth)

Table 31.3. Inshore Ocean Perch. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	253.355		1.0000	0.000	226.542	0.000	26.813
1995	259.580		0.9061	0.000	232.117	0.000	27.463
1996	210.837		0.7619	0.000	182.062	0.000	28.776
1997	129.735	213.377	0.6319	0.000	106.649	0.380	22.706
1998	199.060	199.803	0.6016	124.000	41.056	13.912	20.092
1999	142.688	170.580	0.5770	78.000	43.461	0.462	20.766
2000	184.215	163.924	0.5206	100.000	42.683	0.758	40.774
2001	156.540	170.626	0.5100	89.000	35.993	0.225	31.322
2002	230.023	178.367	0.3316	145.000	45.519	0.441	39.064
2003	120.830	172.902	0.2751	61.000	34.671	0.345	24.814
2004	236.437	185.957	0.2727	194.000	20.454	0.452	21.532
2005	78.376	166.416	0.3677	42.000	14.943	0.050	21.383

Table 31.4. Inshore Ocean Perch. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.13759), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	253.355					
1995	0.93222	259.580					
1996	0.73458	210.837					
1997	0.60724	129.735	213.377	-0.13759	184.017	154.658	95.939
1998	0.59729	199.060	199.803	-0.11321	177.182	154.562	109.321
1999	0.53471	142.688	170.580	-0.06095	160.182	149.785	128.990
2000	0.51091	184.215	163.924	-0.03516	158.161	152.398	140.872
2001	0.46202	156.540	170.626	-0.04296	163.295	155.965	141.304
2002	0.30096	230.023	178.367	-0.07501	164.987	151.607	124.847
2003	0.25193	120.830	172.902	-0.09380	156.684	140.466	108.030
2004	0.21951	236.437	185.957	-0.07766	171.517	157.076	128.194
2005	0.29342	78.376	166.416	-0.00551	165.500	164.584	162.752

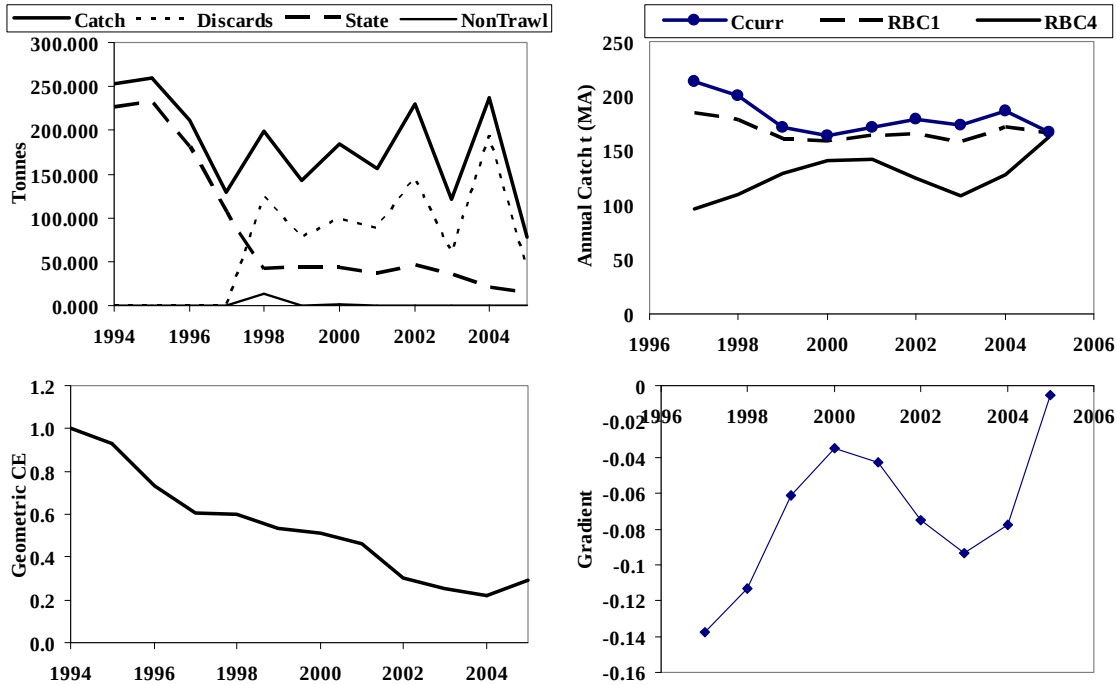


Figure 31.2. Plots of the various analyses for Inshore Ocean Perch using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.7 Offshore Ocean Perch (> 200m depth)

Table 31.5. Offshore Ocean Perch. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	485.377		1.0000	0.000	226.542	0.000	258.835
1995	517.060		0.8659	0.000	232.117	0.000	284.942
1996	509.690		0.7860	0.000	182.062	0.000	327.629
1997	510.086	505.553	0.7270	0.000	106.649	5.312	398.126
1998	551.335	522.043	0.7077	174.000	41.056	6.250	330.030
1999	463.273	508.596	0.7533	64.000	43.461	7.018	348.795
2000	384.470	477.291	0.6242	34.000	42.683	9.086	298.700
2001	408.451	451.882	0.6526	46.000	35.993	8.597	317.861
2002	353.234	402.357	0.5758	22.000	45.519	18.885	266.830
2003	405.709	387.966	0.6259	27.000	34.671	30.940	313.098
2004	404.244	392.910	0.5768	41.000	20.454	66.129	276.661
2005	339.156	375.586	0.6580	17.000	14.943	34.518	272.696

Table 31.6. Offshore Ocean Perch. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.08989), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	485.377					
1995	0.86587	517.060					
1996	0.78600	509.690					
1997	0.72698	510.086	505.553	-0.08989	460.107	414.661	323.769
1998	0.70770	551.335	522.043	-0.05335	494.190	466.337	410.632
1999	0.75332	463.273	508.596	-0.01173	502.629	496.662	484.729
2000	0.62422	384.470	477.291	-0.02627	464.755	452.218	427.146
2001	0.65259	408.451	451.882	-0.02944	438.578	425.273	398.664
2002	0.57583	353.234	402.357	-0.05041	382.075	361.792	321.227
2003	0.62586	405.709	387.966	-0.00718	385.179	382.391	376.816
2004	0.57678	404.244	392.910	-0.01774	385.939	378.968	365.025
2005	0.65798	339.156	375.586	0.01974	382.999	390.412	405.237

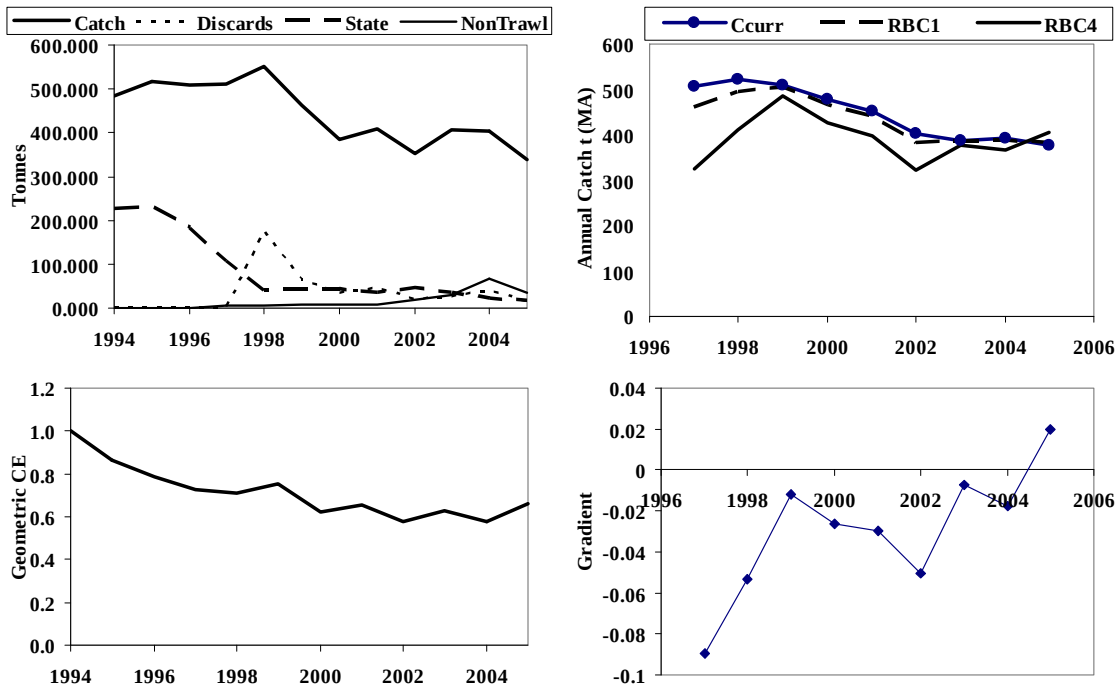


Figure 31.3. Plots of the various analyses for Offshore Ocean Perch using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.8 Blue Warehou (East)

Table 31.7. Blue Warehou (East). Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	1233.924		1.0000	32.924	257.000	389.000	555.000
1995	975.322		0.8367	75.322	138.000	199.000	563.000
1996	975.585		0.8777	11.585	119.000	213.000	632.000
1997	963.874	1037.176	1.0419	22.874	127.000	317.000	497.000
1998	874.322	947.276	1.0166	17.322	246.000	87.000	524.000
1999	750.354	891.034	0.5196	16.354	268.000	312.000	154.000
2000	403.040	747.898	0.5285	1.040	108.000	87.000	207.000
2001	165.034	548.188	0.2862	39.034	24.000	32.000	70.000
2002	144.265	365.673	0.2011	1.265	70.000	4.000	69.000
2003	103.606	203.986	0.1827	12.606	41.000	2.000	48.000
2004	121.000	133.476	0.2457	27.000	29.000	2.000	63.000
2005	115.745	121.154	0.1588	68.745	19.000	1.000	27.000

Table 31.8. Blue Warehou (East). The Trawl CPUE is the standardized catch rate data zone 10 – 30 (Haddon, 2006), relative to 1994, AnnC is the annual total catch in tonnes (includes all Tasmanian and Non-trawl catches), C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = 0.01666), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	1233.924					
1995	0.83674	975.322					
1996	0.87765	975.585					
1997	1.04189	963.874	1037.176	0.01666	1054.452	1071.729	1106.281
1998	1.01656	874.322	947.276	0.07037	1013.934	1080.592	1213.908
1999	0.51958	750.354	891.034	-0.10996	793.060	695.086	499.139
2000	0.52854	403.040	747.898	-0.20370	595.550	443.202	138.506
2001	0.28619	165.034	548.188	-0.21822	428.565	308.942	69.696
2002	0.20105	144.265	365.673	-0.11979	321.868	278.063	190.452
2003	0.18274	103.606	203.986	-0.11225	181.088	158.190	112.393
2004	0.24567	121.000	133.476	-0.01399	131.609	129.742	126.008
2005	0.15878	115.745	121.154	-0.00639	120.380	119.606	118.057

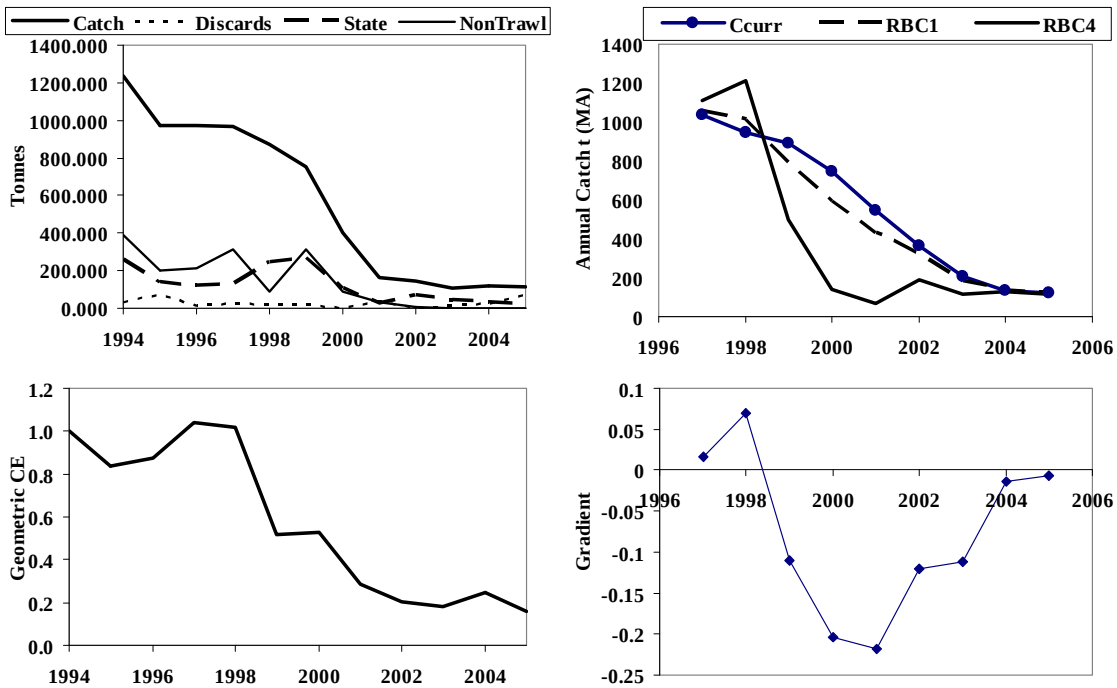


Figure 31.4. Plots of the various data sources used for Blue Warehou (East) using standardized CPUE (Haddon, 2006), along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.9 RedFish

Table 31.9. RedFish. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	1677.006		1.0000	0.000	977.976	0.000	699.030
1995	1393.352		0.7522	0.000	179.111	0.000	1214.241
1996	1588.337		0.6464	0.000	151.915	0.000	1436.422
1997	1623.241	1570.484	0.7161	0.000	80.457	0.000	1542.784
1998	2453.237	1764.542	0.9149	600.273	101.295	0.000	1751.669
1999	1421.286	1771.525	0.7641	41.705	121.882	0.000	1257.699
2000	922.873	1605.159	0.4925	49.450	37.315	0.000	836.108
2001	1598.592	1598.997	0.4289	739.908	63.446	0.545	794.693
2002	1838.007	1445.189	0.4114	894.855	58.105	0.155	884.892
2003	1079.739	1359.803	0.3746	347.498	52.753	0.828	678.660
2004	967.134	1370.868	0.3271	377.439	90.216	1.005	498.474
2005	689.360	1143.560	0.3519	93.415	63.110	0.568	532.268

Table 31.10. RedFish. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.09574), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	1677.006					
1995	0.75216	1393.352					
1996	0.64636	1588.337					
1997	0.71614	1623.241	1570.484	-0.09574	1420.130	1269.777	969.069
1998	0.91487	2453.237	1764.542	0.05579	1862.985	1961.429	2158.317
1999	0.76408	1421.286	1771.525	0.05519	1869.295	1967.064	2162.604
2000	0.49246	922.873	1605.159	-0.08218	1473.243	1341.326	1077.493
2001	0.42889	1598.592	1598.997	-0.17296	1322.442	1045.886	492.776
2002	0.41144	1838.007	1445.189	-0.11215	1283.110	1121.030	796.871
2003	0.37456	1079.739	1359.803	-0.03712	1309.333	1258.864	1157.925
2004	0.32707	967.134	1370.868	-0.03423	1323.940	1277.012	1183.157
2005	0.35187	689.360	1143.560	-0.02262	1117.695	1091.830	1040.101

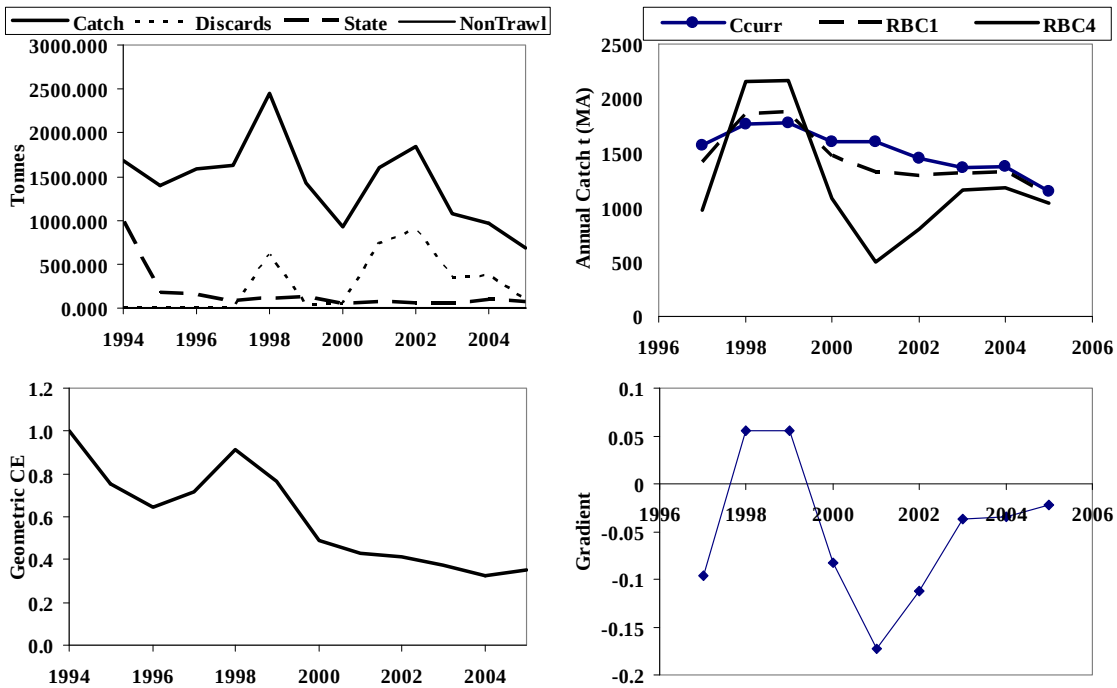


Figure 31.5. Plots of the various analyses for RedFish using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.10 Silver Trevally

Table 31.11. Silver Trevally. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	680.754		1.0000	0.000	547.974	0.000	132.78
1995	780.104		1.1092	0.000	577.901	0.000	202.203
1996	807.938		0.8305	0.000	592.166	0.000	215.772
1997	591.215	715.003	0.8823	0.000	423.555	0.000	167.66
1998	715.993	723.812	0.7282	0.458	615.311	0.000	100.224
1999	490.175	651.330	0.6729	0.822	416.426	0.000	72.927
2000	535.667	583.262	0.4997	0.000	442.792	0.000	92.875
2001	692.354	608.547	0.6696	10.122	525.620	2.170	154.442
2002	542.610	565.201	0.5240	1.098	380.147	2.444	158.921
2003	608.407	594.760	0.6831	1.507	481.357	2.492	123.051
2004	953.885	699.314	0.8350	41.015	772.468	2.032	138.371
2005	621.756	681.665	0.8573	0.095	524.964	0.662	96.0357

Table 31.12. Silver Trevally. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.06319), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	680.754					
1995	1.10925	780.104					
1996	0.83045	807.938					
1997	0.88229	591.215	715.003	-0.06319	669.819	624.636	534.269
1998	0.72817	715.993	723.812	-0.10914	644.815	565.818	407.823
1999	0.67292	490.175	651.330	-0.06267	610.509	569.688	488.047
2000	0.49974	535.667	583.262	-0.12029	513.103	442.944	302.625
2001	0.66959	692.354	608.547	-0.03489	587.316	566.084	523.620
2002	0.52404	542.610	565.201	-0.02768	549.558	533.914	502.626
2003	0.68312	608.407	594.760	0.04046	618.821	642.883	691.006
2004	0.83499	953.885	699.314	0.06553	745.138	790.961	882.608
2005	0.85731	621.756	681.665	0.11517	760.171	838.678	995.691

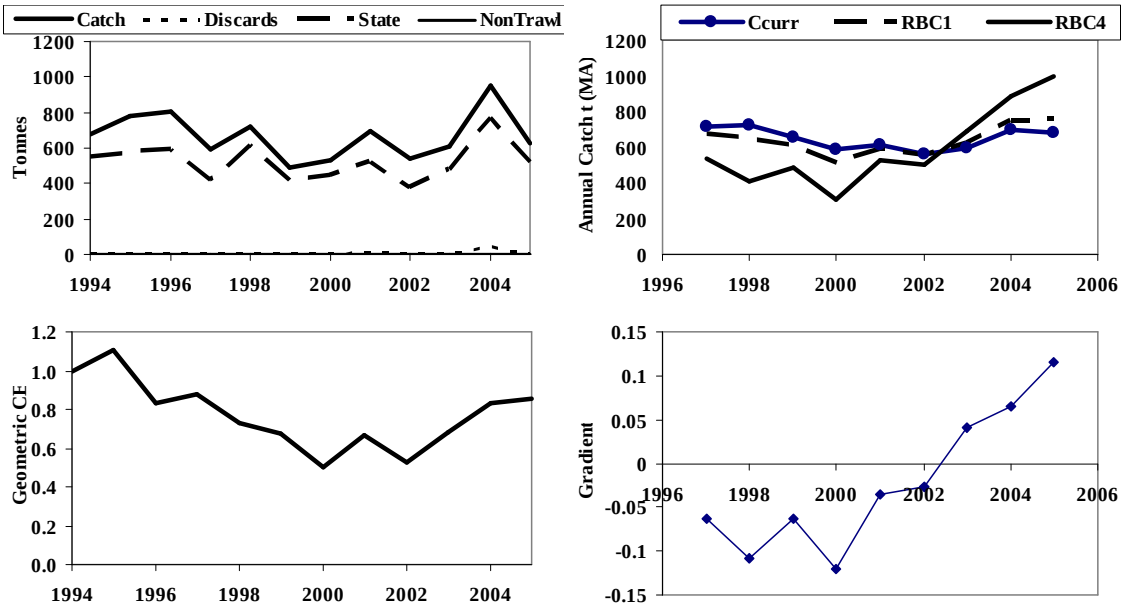


Figure 31.6. Plots of the various analyses for Silver Trevally using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.11 Flathead

Table 31.13. Flathead. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	2282.753		1.00000	0.000	786.484	0.000	1496.269
1995	2264.849		1.03018	0.000	552.812	0.000	1712.037
1996	2381.133		0.89793	0.000	487.894	0.000	1893.239
1997	2977.578	2476.578	0.90721	0.000	470.809	0.000	2506.769
1998	3336.525	2740.021	0.92163	391.706	402.188	0.000	2542.631
1999	4291.684	3246.730	1.08552	466.542	367.964	0.000	3457.178
2000	4051.452	3664.310	1.39508	430.893	398.865	0.000	3221.694
2001	3301.600	3745.315	1.25813	158.802	298.312	0.281	2844.205
2002	3554.219	3799.739	1.38793	193.196	217.215	0.337	3143.471
2003	3971.848	3719.780	1.40939	178.027	298.830	0.809	3494.182
2004	4040.577	3717.061	1.19732	228.383	429.417	0.858	3381.919
2005	3692.689	3814.833	1.04360	169.498	521.551	1.145	3000.495

Table 31.14. Flathead. The Trawl CPUE is the standardized catch rate data (Haddon, 2006), relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.04106), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	2282.753					
1995	1.03018	2264.849					
1996	0.89793	2381.133					
1997	0.90721	2977.578	2476.578	-0.04106	2374.885	2273.192	2069.805
1998	0.92163	3336.525	2740.021	-0.03164	2653.333	2566.645	2393.268
1999	1.08552	4291.684	3246.730	0.05772	3434.129	3621.529	3996.327
2000	1.39508	4051.452	3664.310	0.16275	4260.677	4857.044	6049.777
2001	1.25813	3301.600	3745.315	0.13191	4239.345	4733.375	5721.435
2002	1.38793	3554.219	3799.739	0.07703	4092.418	4385.098	4970.458
2003	1.40939	3971.848	3719.780	0.01727	3784.029	3848.278	3976.775
2004	1.19732	4040.577	3717.061	-0.01610	3657.222	3597.384	3477.706
2005	1.04360	3692.689	3814.833	-0.12451	3339.866	2864.899	1914.965

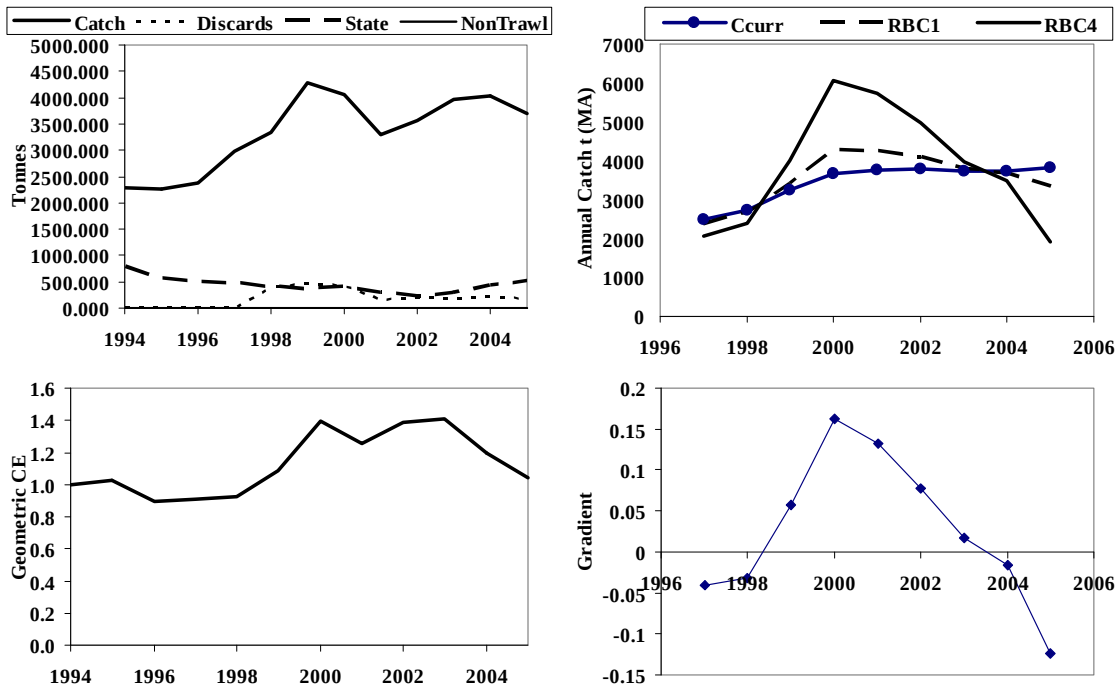


Figure 31.7. Plots of the various data sources used for Flathead using standardized CPUE (Haddon, 2006), along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.12 BlueEye

Table 31.15. BlueEye. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	730.292		1.0000	0.000	641.127	0.000	89.165
1995	724.890		0.6448	0.000	657.507	0.000	67.383
1996	890.393		0.6581	0.000	809.132	0.000	81.261
1997	988.654	833.557	0.5857	0.000	876.025	0.000	112.629
1998	569.770	793.427	0.5003	0.047	93.322	380.439	95.962
1999	688.528	784.336	0.5327	0.000	114.493	464.658	109.377
2000	734.941	745.473	0.4579	3.131	77.747	565.410	88.653
2001	679.120	668.090	0.7173	21.794	69.594	478.397	109.335
2002	600.917	675.876	0.4845	0.064	87.836	427.969	85.048
2003	637.419	663.099	0.4382	0.000	38.090	556.565	42.764
2004	650.677	642.033	0.3560	0.000	0.000	566.917	83.760
2005	549.198	609.553	0.3367	0.000	55.614	450.678	42.905

Table 31.16. BlueEye. The Trawl CPUE is the geometric mean catch rate data for trawls standardized relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.12295), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	730.292					
1995	0.64478	724.890					
1996	0.65809	890.393					
1997	0.58573	988.654	833.557	-0.12295	731.072	628.587	423.618
1998	0.50034	569.770	793.427	-0.05057	753.306	713.185	632.942
1999	0.53271	688.528	784.336	-0.04615	748.135	711.935	639.533
2000	0.45791	734.941	745.473	-0.03511	719.300	693.126	640.779
2001	0.71735	679.120	668.090	0.05762	706.586	745.083	822.076
2002	0.48451	600.917	675.876	0.01148	683.638	691.400	706.923
2003	0.43817	637.419	663.099	-0.02921	643.732	624.366	585.632
2004	0.35599	650.677	642.033	-0.11304	569.457	496.880	351.727
2005	0.33672	549.198	609.553	-0.05255	577.518	545.484	481.415

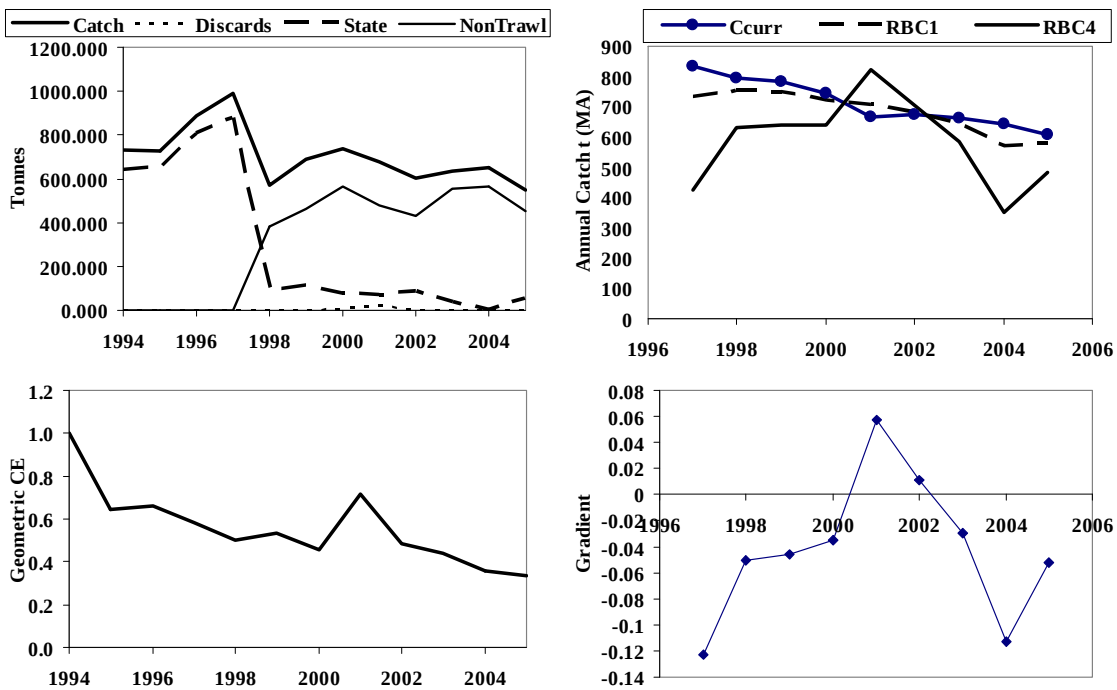


Figure 31.8. Plots of the various analyses for BlueEye using Geometric CPUE standardized to 1994, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.13 Jackass Morwong

Table 31.17. Jackass Morwong. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	1034.932		1.0000	0.000	243.396	0.000	792.862
1995	981.801		1.0038	0.000	160.992	0.000	817.132
1996	972.505		0.8560	0.000	89.283	0.000	886.843
1997	1213.726	1050.741	0.9350	0.000	85.365	0.000	1118.730
1998	942.082	1027.529	0.7568	53.245	61.340	0.000	878.260
1999	992.195	1030.127	0.7635	61.647	59.148	0.000	936.561
2000	950.483	1024.622	0.6466	43.122	70.381	0.000	880.851
2001	866.752	937.878	0.4390	11.712	52.561	2.241	814.128
2002	879.234	922.166	0.5073	26.874	31.319	1.849	849.360
2003	776.411	868.220	0.3807	71.847	31.894	3.615	742.822
2004	795.307	829.426	0.3756	47.318	39.950	4.424	754.013
2005	829.058	820.002	0.4573	42.394	36.982	6.023	797.755

Table 31.18. Jackass Morwong. Zone 10 & 20 Trawl CPUE is the standardized catch rate data for trawls (Haddon, 2006) relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994-1997 = -0.12483), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	1034.932					
1995	1.00376	981.801					
1996	0.85604	972.505					
1997	0.93500	1213.726	1050.741	-0.03427	1014.732	978.722	906.704
1998	0.75685	942.082	1027.529	-0.06618	959.530	891.531	755.532
1999	0.76347	992.195	1030.127	-0.04559	983.167	936.208	842.288
2000	0.64655	950.483	1024.622	-0.08587	936.634	848.647	672.673
2001	0.43903	866.752	937.878	-0.10704	837.491	737.103	536.328
2002	0.50725	879.234	922.166	-0.09762	832.145	742.125	562.084
2003	0.38066	776.411	868.220	-0.07295	804.887	741.554	614.889
2004	0.37565	795.307	829.426	-0.03167	803.155	776.883	724.341
2005	0.45730	829.058	820.002	-0.01549	807.302	794.602	769.202

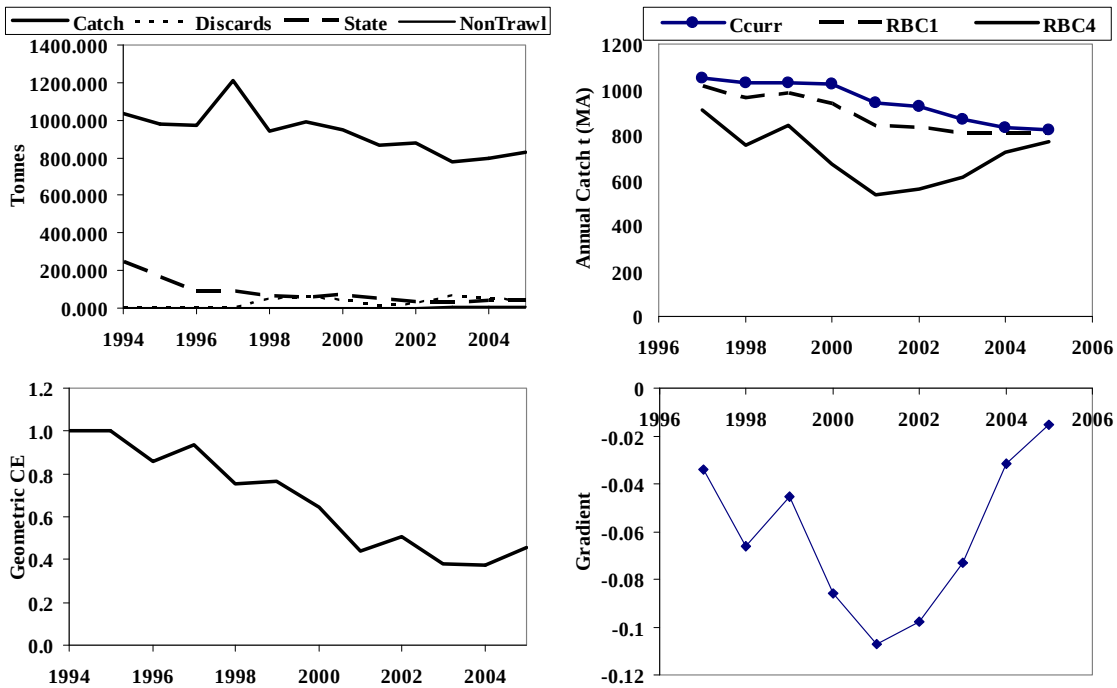


Figure 31.9. Plots of the various data sources used for Jackass Morwong using standardized CPUE (Haddon, 2006), along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches, and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997).

31.14 Royal Red Prawn

Table 31.19. Royal Red Prawn. Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	629.847		1.0000	0.000	482.073	0.000	147.774
1995	722.852		0.6935	0.000	529.336	0.000	193.516
1996	692.241		0.7362	0.000	424.963	0.000	267.278
1997	473.406	629.586	0.6758	0.000	285.669	0.000	187.737
1998	463.334	587.958	0.5129	24.418	228.345	0.000	210.571
1999	584.480	553.365	0.6482	3.156	205.320	0.000	376.004
2000	627.717	537.234	0.6644	4.080	206.945	0.000	416.692
2001	474.787	537.579	0.4917	4.748	227.810	0.000	242.229
2002	689.964	594.237	0.6392	15.580	240.645	0.000	433.740
2003	340.812	533.320	0.5617	17.370	135.277	0.000	188.165
2004	290.653	449.054	0.6875	43.460	74.965	0.000	172.228
2005	247.648	392.269	0.6318	40.290	40.871	0.000	166.487

Table 31.20. Royal Red Prawn all zones. Trawl CPUE is the catch rate data for trawls relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994 - 1997 = -0.09299), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression. SEF2 catches used.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	629.847					
1995	0.69350	722.852					
1996	0.73620	692.241					
1997	0.67580	473.406	629.586	-0.09299	571.041	512.496	395.405
1998	0.51290	463.334	587.958	-0.06022	552.551	517.144	446.331
1999	0.64820	584.480	553.365	-0.04269	529.742	506.119	458.873
2000	0.66440	627.717	537.234	0.01011	542.666	548.097	558.960
2001	0.49170	474.787	537.579	-0.00474	535.031	532.483	527.387
2002	0.63920	689.964	594.237	-0.01997	582.370	570.503	546.769
2003	0.56170	340.812	533.320	-0.01606	524.755	516.190	499.060
2004	0.68750	290.653	449.054	0.05099	471.951	494.849	540.643
2005	0.63180	247.648	392.269	0.01036	396.333	400.397	408.525

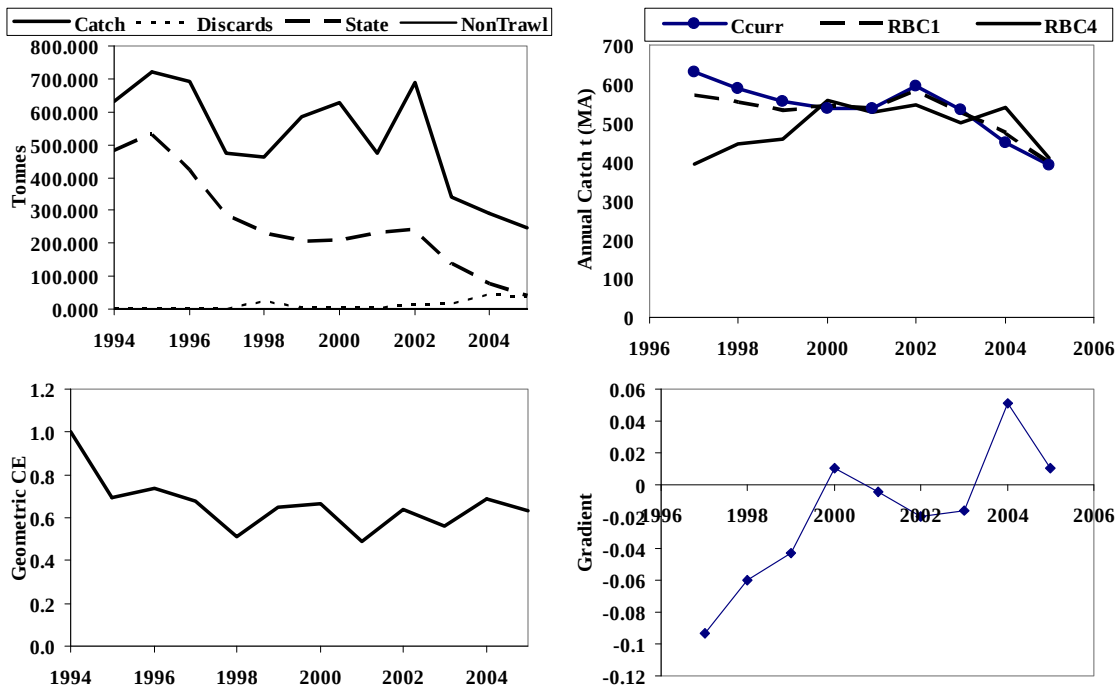


Figure 31.10. Plots of the various data sources used for Royal Red Prawn using Geometric mean CPUE, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches (primarily NSW), and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997). SEF2 catches used.

31.15 Pink Ling (East)

Table 31.21. Pink Ling (East). Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	1155.035		1.0000	0.000	508.804	0.000	646.231
1995	1239.117		1.1876	0.000	427.570	0.000	811.547
1996	1443.782		1.0289	0.000	554.255	0.000	889.527
1997	1261.239	1274.793	1.0342	0.000	251.809	0.000	1009.430
1998	1134.507	1269.661	1.0477	21.399	66.676	52.302	994.131
1999	1315.061	1288.647	1.0101	12.046	55.163	92.367	1155.485
2000	1093.779	1201.147	0.7994	7.244	22.668	121.496	942.372
2001	876.671	1105.005	0.6092	3.653	10.358	173.900	688.761
2002	742.424	1006.984	0.4934	3.201	17.107	205.957	516.159
2003	898.149	902.756	0.5647	0.532	8.189	246.510	642.918
2004	908.647	856.473	0.4899	0.456	12.576	381.688	513.928
2005	786.564	833.946	0.5584	1.433	16.133	267.280	501.717

Table 31.22. Pink Ling (East). Trawl CPUE is the catch rate data for trawls relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994 - 1997 = -0.00562), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression. SEF2 catches used.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	1155.035					
1995	1.18758	1239.117					
1996	1.02895	1443.782					
1997	1.03416	1261.239	1274.793	-0.00562	1267.635	1260.476	1246.159
1998	1.04768	1134.507	1269.661	-0.04145	1217.035	1164.409	1059.157
1999	1.01011	1315.061	1288.647	-0.00430	1283.106	1277.566	1266.484
2000	0.79942	1093.779	1201.147	-0.07418	1112.049	1022.951	844.755
2001	0.60924	876.671	1105.005	-0.15260	936.380	767.756	430.507
2002	0.49338	742.424	1006.984	-0.17404	831.730	656.476	305.967
2003	0.56469	898.149	902.756	-0.08201	828.724	754.692	606.629
2004	0.48990	908.647	856.473	-0.02867	831.919	807.364	758.256
2005	0.55840	786.564	833.946	0.01203	843.977	854.009	874.071

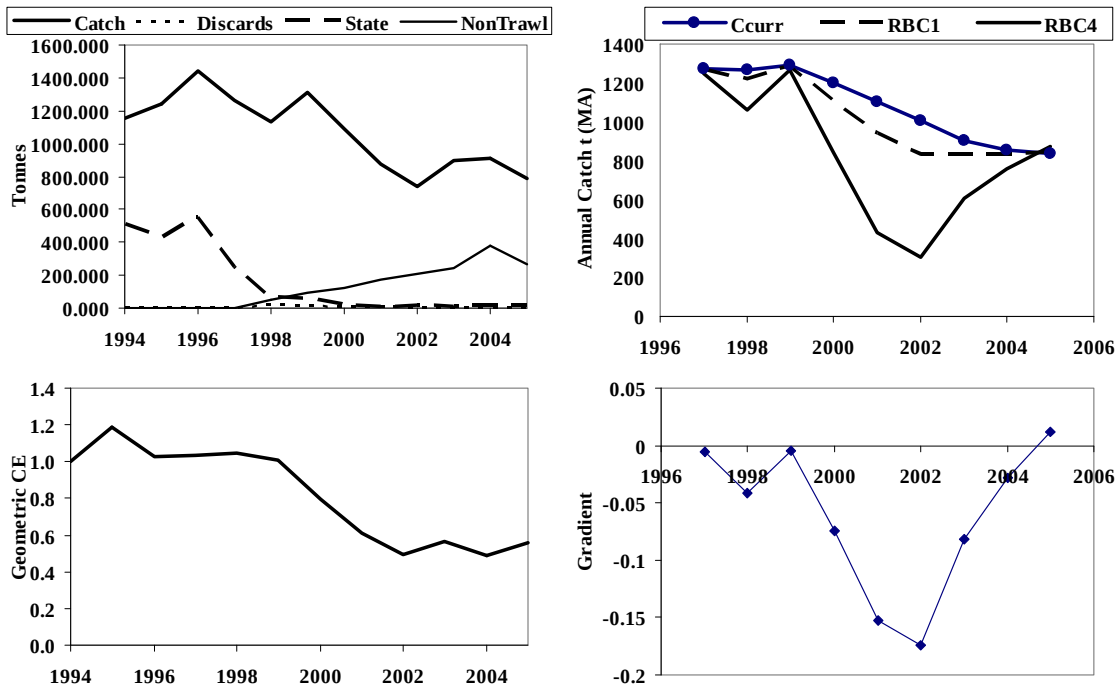


Figure 31.11. Plots of the various data sources used for Pink Ling (East) using standardized CPUE, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches (primarily NSW), and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997). SEF2 catches used.

31.16 Pink Ling (West)

Table 31.23. Pink Ling (West). Base data for the TIER 4 calculations. Catch is the sum of Discards, State, Non Trawl and SEF2 catches. All values in Tonnes. CPUE is the geometric mean catch rate relative to the catch rate in 1994. C_{cuur} is the average total catch (SEF2, non-trawl, discards, and State) over the previous 4 years,

Year	Catch	C_{curr}	CPUE	Discards	State	Non Trawl	SEF2
1994	765.788		1.0000	0.000	508.804	0.000	256.984
1995	884.405		1.1321	0.000	427.570	0.000	456.835
1996	1086.706		1.1969	0.000	554.255	0.000	532.451
1997	945.596	920.624	1.3120	0.000	251.809	0.000	693.787
1998	917.553	958.565	1.2179	14.767	66.676	150.083	686.027
1999	776.403	931.565	0.9437	5.603	55.163	178.137	537.500
2000	802.397	860.487	0.9959	4.953	22.668	130.495	644.281
2001	874.898	842.813	0.8025	3.491	10.358	202.683	658.366
2002	893.289	836.747	0.7087	3.451	17.107	316.252	556.480
2003	727.923	824.627	0.6894	0.404	8.189	230.965	488.365
2004	871.826	841.984	0.6106	0.346	12.576	468.760	390.144
2005	644.211	784.312	0.5155	0.715	16.133	377.212	250.151

Table 31.24. Pink Ling (West). Trawl CPUE is the catch rate data for trawls relative to 1994, AnnC is the annual total catch in tonnes, C_{CUR} is the average total catch (Commonwealth trawl and non-trawl, discards, and State) over the previous 4 years, Slope is the gradient of each previous four year block of catch rates against year (e.g. 1994 - 1997 = -0.00562), RBC1 is the recommended biological Catch with an α of 1.0, similarly RBC4 has an α of 4.0. Note the RBC is estimated for the year following the end year of each regression. SEF2 catches used.

Year	CPUE	AnnC	Ccurr	Gradient	RBC1	RBC2	RBC4
1994	1.00000	765.788					
1995	1.13208	884.405					
1996	1.19694	1086.706					
1997	1.31200	945.596	920.624	0.10009	1012.765	1104.906	1289.189
1998	1.21790	917.553	958.565	0.03725	994.272	1029.980	1101.394
1999	0.94374	776.403	931.565	-0.08537	852.037	772.509	613.453
2000	0.99587	802.397	860.487	-0.12225	755.289	650.090	439.692
2001	0.80250	874.898	842.813	-0.11941	742.175	641.536	440.260
2002	0.70871	893.289	836.747	-0.08985	761.567	686.387	536.027
2003	0.68944	727.923	824.627	-0.10131	741.086	657.544	490.462
2004	0.61059	871.826	841.984	-0.05950	791.887	741.790	641.595
2005	0.51546	644.211	784.312	-0.06586	732.660	681.007	577.703

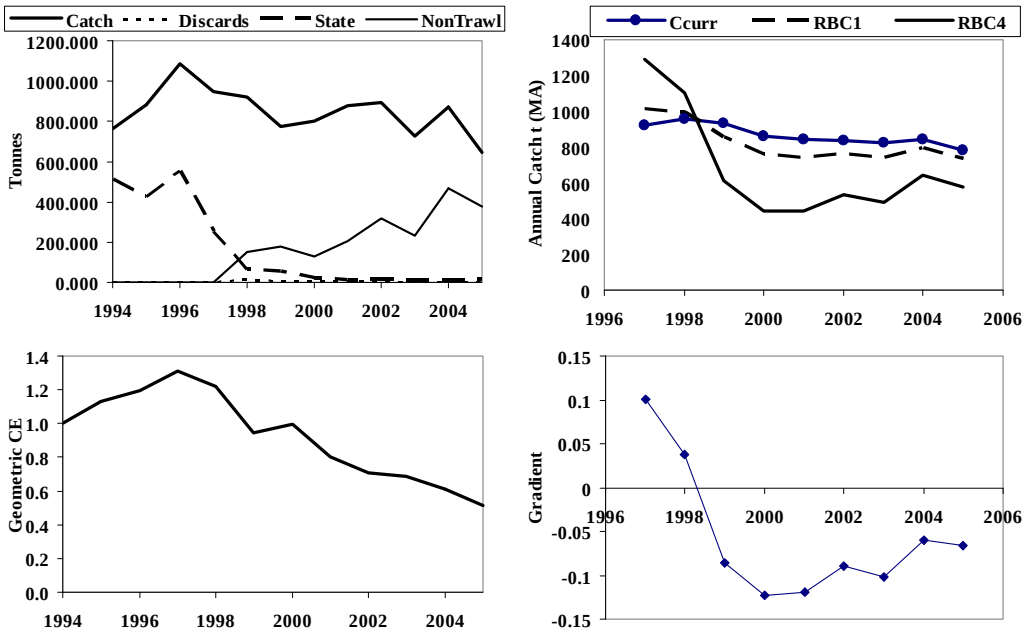


Figure 31.12. Plots of the various data sources used for Pink Ling (West) using standardized CPUE, along with the implied RBCs for alpha values of 1.0 and 4.0. Catch equates to total catches, Discards relates to discarded catches, State relates to all State catches (primarily NSW), and Ccur is the average total extractions over the previous four years. The gradient refers to the gradient of catch rates over four year periods (1997 refers to 1994-1997). SEF2 catches used.

31.17 Reference

Haddon, M. (2006) Standardized commercial catch-Effort data for selected Shelf and Slope Assessment Group Species for 1986–2005. SESSF Document 2006/50. 55 p.

32. Tier 4 Harvest Control Rule Applied to Deepwater Species

Sally Wayte[1]

[1] CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, TAS 7001, Australia

32.1 Introduction

TACs are the main management tool used in three of the four main sectors of the SESSF. The science to estimate sustainable harvest rates for SESSF species has gradually improved over recent years. However the basis for setting TACs has been very unclear, and different "rules" have been used across species, between sectors and over time. Adopting agreed harvest strategies, including clear decision rules for setting TACs, would greatly improve certainty for all stakeholders in the management process, and if chosen wisely, should also lead to much better performance in achieving ESD objectives.

The SESSF Harvest Strategy Framework (HSF) was developed during 2005 (Smith and Smith 2005). The HSF is built around 4 Tiers corresponding to different amounts and quality of information available on stock status. For each Tier, the HSF provides an explicit harvest control rule that produces an RBC (recommended biological catch), which in turn forms the basis for a TAC recommendation. The HSF was used to help set quotas for 28 of the 34 species/stocks in the SESSF quota management system during 2005. While the HSF was generally well received, some problems were identified during implementation in 2005, and further issues have come to light during the assessment phase in 2006. A management strategy evaluation (MSE) project has been funded to test and refine the current harvest strategies, but this will not start to deliver results until later in 2007 (Smith, 2006).

32.2 Tier 4

The Tier 4 harvest control rule (HCR4) applies to species with the least amount of information about current stock status – no reliable information available on either current biomass or current exploitation rate. It is assumed that there is information available on current catch levels and on trends in catch rates. The steps in calculating the RBC for HCR4 are as follows (Smith and Smith, 2005):

1. Calculate current catch level C_{CUR} as the average catch (landings plus discards) over the past NC years, where NC will depend on the period of "stable" effective (= binding) TACs. The default for NC is suggested to be 4 years.

2. Calculate the slope of the trend in CPUE over the past NS years. NS will depend on whether trends in CPUE tend to be relatively stable, or cyclic. For "stable" stocks, it is suggested that NS = NC (i.e. 4 years). For "cyclic" stocks, NS would need to be set at >= 2 cycle periods.

3. Calculate the RBC as

$$RBC = (1 + \alpha * slope) * C_{CUR}$$

Issues that have arisen regarding application of the HSF for Tier 4, either during 2005 or during the assessment process in 2006, include (Smith, 2006):

a. It is not sufficiently precautionary relative to Tiers 1 to 3

b. It fails to provide any benchmarks for stock status

c. It would probably fail to result in recovery for an overfished stock

The value for α in the control rule was not specified in 2005.

32.3 Suggested interim modifications for 2006

Several proposals were put forward to try to resolve issues a and b above. Although promising, there has been insufficient time to consider or properly test these suggested solutions, so they will not be implemented during 2006. Instead, it has been decided to continue to implement the current Tier 4 procedure (with some modifications outlined below), but to include further advice from the RAG on whether the resulting RBCs are appropriately precautionary given other information and considerations. The latter would include:

- Information to "scale" recent CPUE (e.g. comparison of recent average CPUE with similar data from earlier in the development of the fishery).
- Information on the biological productivity of the species (e.g. longevity)

For each Tier 4 species/stock, the RAG should provide explicit advice on

- The Tier 4 RBC (including the necessary supplementary information on state catches and discards)
- Additional considerations based on the dot points listed above
- Based on these additional considerations, advice on whether the RBC should be varied and by how much

For the basic Tier 4 calculations, there is still uncertainty about the value of α to use. The first step is to adopt a common scale for all calculations by standardising the first point in the CPUE series used for the calculation to 1. Having done this, RBCs should be calculated for α values of 1, 2 and 4. In the absence of reasoned alternatives, the value $\alpha = 4$ should be used for the base RBC. (This is based on the following argument: If the CPUE has declined by 50% over 4 years, the RBC should be set at half the recent average catch. A 50% decline over 4 years corresponds to a negative slope of 0.125, which would require $\alpha = 4$ to result in an RBC that halves the average catch).

32.3.1 References

Smith, A. and D.Smith (2005) A harvest strategy framework for the SESSF. Report to AFMA, June 2005

Smith, A. (2006) Guidelines regarding implementation of the SESSF Harvest Strategy Framework for 2006. July 2006

32.3.2 Ribaldo

Quotas were introduced for ribaldo in 2005.
Quota 2005 : 100 t
Quota 2006 : 165 t
Average catch in last 4 years : 189 t
Slope of trend in catch rate over last 4 years : -0.113

Table 32.1. Tier 4 RBCs for ribaldo based on 3 values of α

α	RBC (t)
1	168
2	146
4	104

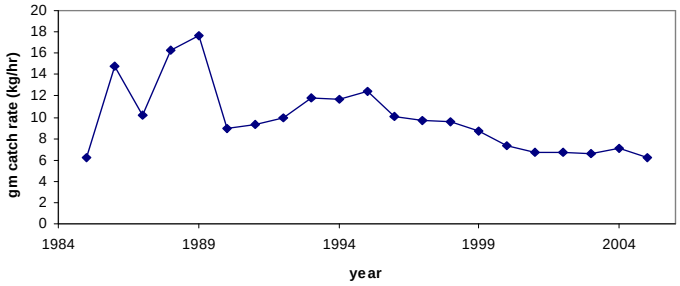


Table 32.2. Ribaldo catches and catch rates. Catches before 2002 are from the trawl logbook data, and catches from 2002 are from the SE Trawl landings database. The catch rate is calculated from logbook data, and is the geometric mean of catch(kg)/effort(hrs)

Year	Catch (t)	Geometric mean catch rate (kg/hr)
1985	1.48	6.21
1986	4.10	14.82
1987	7.69	10.19
1988	8.22	16.26
1989	8.10	17.62
1990	2.31	8.96
1991	7.62	9.26
1992	12.95	9.88
1993	21.69	11.76
1994	27.48	11.73
1995	89.87	12.37
1996	81.32	10.11
1997	97.50	9.69
1998	92.38	9.60
1999	60.68	8.69
2000	54.31	7.39
2001	54.01	6.73
2002	189.60	6.76
2003	202.12	6.60
2004	248.07	7.13
2005	116.79	6.21

This analysis only considers ribaldo catches from the trawl fishery, but a substantial proportion of the ribaldo catch is caught by auto-longliners. Estimates of discarding have not been included in this analysis. The SlopeRAG has completed a Tier 3 assessment for this species, so this would be the most appropriate assessment to use. It should be noted, however, that low quotas lead to higher discarding for the trawl fishery. Any assessment should include estimates of discarding from the ISMP.

32.3.3 Cascade smooth oreo

Quotas were introduced for Cascade smooth oreo in 2005.
Quota 2005 : 100 t
Quota 2006 : 100 t
Average catch in last 4 years : 134.1 t
Slope of trend in catch rate over last 4 years : 0.287

Table 32.3. Tier 4 RBCs for Cascade smooth oreo based on 3 values of α

α	RBC (t)
1	173
2	211
4	288

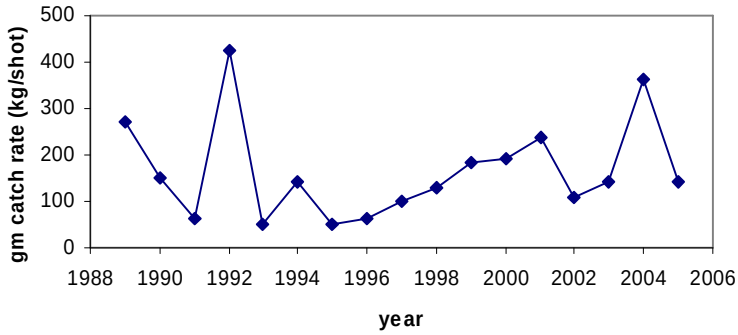


Table 32.4. Cascade smooth oreo catches and catch rates. Catches from 1989-2004 are from the logbook data. Catch in 2005 is from the landings data. The catch rate is calculated from logbook data, and is the geometric mean of catch(kg).

Year	Catch (t)	Geometric mean catch rate (kg/shot)
1989	127.5	272.16
1990	91.6	151.09
1991	0.6	63.00
1992	11.3	426.82
1993	2.1	50.02
1994	94.6	140.83
1995	14.3	49.71
1996	142.3	64.33
1997	281.7	99.39
1998	103.3	129.66
1999	90.7	183.00
2000	293.9	191.74
2001	277.4	235.91
2002	276.0	109.17
2003	103.3	140.54
2004	89.2	361.73
2005	67.9	139.97

It has been suggested that the apparently anomalous point in 2004 was due to a changed fishing pattern by one vessel that started to target Cascade smooth oreos. However further investigation of the logbook data has shown that all five vessels that caught smooth oreo on the Cascade Plateau in 2004 achieved their highest catch rate for 4 years in that year, therefore the 2004 data point is retained in the analysis. The catch rate is based on catch per shot, rather than catch per unit effort, as the oreo fishery targets aggregations.

Smooth oreos on the Cascade are used primarily as a bycatch to cover expenses earlier in the year when searching for orange roughy. Although the RBC implies an increased TAC, DAG recommends that the TAC not be increased substantially for 2007 as targeted fishing should not be encouraged given the uncertainty in the assessment.

32.3.4 Other SEF smooth oreo

Quotas were introduced for other SEF smooth oreo in 2005.
Quota 2005 : 50 t
Quota 2006 : 50 t
Average catch in last 4 years : 216 t
Slope of trend in catch rate over last 4 years : -0.115

Table 32.5. Tier 4 RBCs for other SEF smooth oreo based on 3 values of α

α	RBC (t)
1	191
2	167
4	117

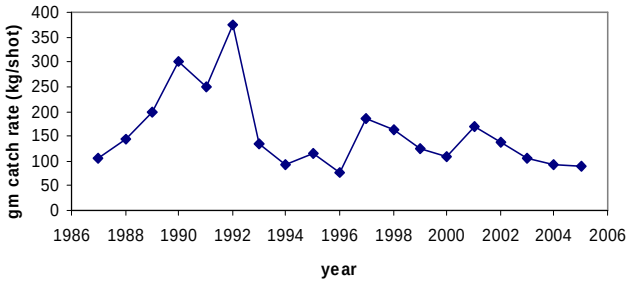


Table 32.6. Other SEF smooth oreo catches and catch rates. Catches from 1987 to 2001 are from the logbook data, and catches from 2002-2005 are from the landings data.The catch rate is calculated from logbook data, and is the geometric mean of catch(kg).

Year	Catch (t)	Geometric mean catch rate (kg/shot)
1987	7	105.73
1988	41	145.04
1989	182	197.14
1990	706	299.92
1991	974	250.33
1992	2308	373.00
1993	610	135.79
1994	569	93.34
1995	487	113.67
1996	182	75.59
1997	675	184.21
1998	604	162.07
1999	236	125.62
2000	203	107.29
2001	308	170.04
2002	300	136.68
2003	292	106.65
2004	234	93.41
2005	38	88.90

Other SEF smooth oreo comprises mostly Southern Zone oreo, where they are taken as a bycatch, being uneconomic to target. The RBC for alpha = 4 is 117 t, however, there is no evidence that the TAC should be increased. TACs should instead be linked to roughy TAC as that fishery recovers. Soon to be declared MPAs in the Southern Zone will provide some element of spatial protection on the deeper seamounts where oreo are abundant. A research quota is recommended, sufficient to collect 1000 otoliths from at least 10 shots (maximum of 100 otoliths per shot).

32.3.5 Other oreo

Quotas were introduced for a mixed basket of spikey, warty, black and rough oreos in 2005.
Quota 2005 : 200 t
Quota 2006 : 200 t
Average catch in last 4 years : 274.6
Slope of trend in catch rate over last 4 years : -0.061

Table 32.7 Tier 4 RBCs for oreo mixed basket based on 3 values of α

α	RBC (t)
1	258
2	241
4	207

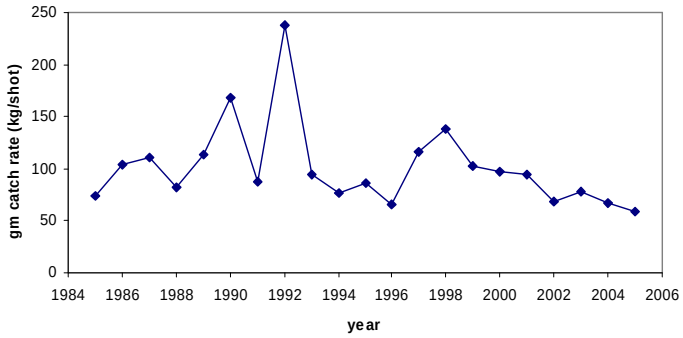


Table 32.8 Oreo mixed basket catches and catch rates. Catches from 1985-2004 are from the logbook data. Catch in 2005 is from landings data.The catch rate is calculated from logbook data, and is the geometric mean of catch(kg).

Year	Catch (t)	Geometric mean catch rate (kg/shot)
1985	12	73.39
1986	53	104.33
1987	63	111.23
1988	37	81.50
1989	185	113.17
1990	255	168.58
1991	109	87.41
1992	730	238.07
1993	404	94.52
1994	367	76.46
1995	498	86.59
1996	443	66.03
1997	1078	116.18
1998	1307	138.14
1999	546	103.01
2000	488	97.48
2001	505	94.58
2002	296	68.42
2003	441	78.05
2004	202	66.54
2005	159	58.26

Fishers report that some oreos could be reported as oxeye oreo, as the species are very similar. However, inspection of the logbook data showed that only 3 t of oxeye oreo was reported in 2005, and none in the preceding 3 years, so oxeye oreo have not been added to this analysis.

32.3.6 GAB orange roughy (Esperance)

Quotas were introduced for Esperance orange roughy in 2006.
Quota 2006 : 212 t (+200 t research quota)
Average catch in last 4 years : 98 t
Slope of trend in catch rate over last 4 years : -0.19

Table 32.9. Tier 4 RBCs for Esperance orange roughy based on 3 values of α

α	RBC (t)
1	79
2	61
4	24

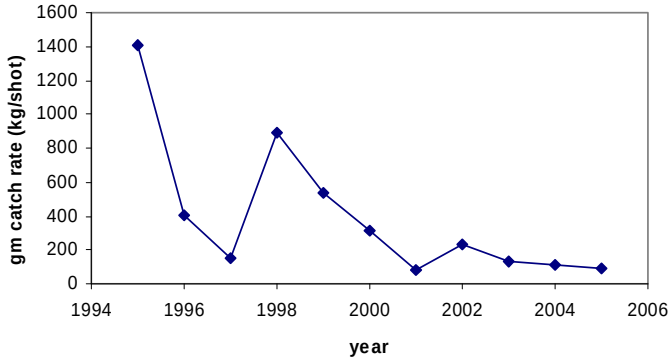


Table 32.10. Esperance orange roughy catches and catch rates. Catches are from the logbook data. The catch rate is calculated from logbook data, and is the geometric mean of catch(kg)

Year	Catch (t)	Geometric mean catch rate (kg/shot)
1995	246	1405.3
1996	334	406.0
1997	127	155.3
1998	546	894.9
1999	613	540.5
2000	261	314.9
2001	140	80.0
2002	217	230.2
2003	111	131.9
2004	60	107.5
2005	4	92.6

2005 catches were very low, presumably due to poor weather. Catches reported for 2006 to date are over 100 t. It is difficult to assess the meaning of catch rates in this fishery as schools of roughy seen on the sounder only rarely descend to the bottom where they are vulnerable to the fishery. There has however been a long term decline. The RBC for this

fishery (alpha = 4) is 24 t, however DAG recommends that the 2007 TAC not be reduced from 200 t due to the uncertainty in the CPUE. Scientifically compatible echo sounders are available on at least one vessel in this fishery, and DAG recommends that a calibrated acoustic survey of the Esperance schools be performed in the next 12 months. The annual 200 t research quota appears unwarranted, and DAG recommends this be reduced to a maximum 50t.

32.3.7 Deepwater sharks

(not reviewed by DeepRAG)

Quotas were introduced for a mixed basket of deepwater sharks in the eastern and western SESSF in 2005. The east/west boundary is the same as that used for gemfish.

Table 32.11. The deepwater shark species included in the basket quota

Common name	Scientific name	CAAB code
brier shark	*Deania calcea*	37020003
platypus shark	*Deania quadrispinosa*	37020004
Plunket's shark	*Centroscymnus plunketi*	37020013
roughskin shark	*Centroscymnus and Deania spp.*	37020904
pearl shark	*D. calcea and D. quadrispinosa*	37020905
black shark	*Centroscymnus spp.*	37020906
lantern shark	*Etmopterus spp.*	37020907

32.3.7.1 Eastern

Quota 2005 : 92 t
Quota 2006 : 92 t
Average catch in last 4 years : 167 t
Slope of trend in catch rate over last 4 years : -0.113

Table 32.12. Tier 4 RBCs for eastern deepwater sharks based on 3 values of α

α	RBC (t)
1	148
2	129
4	91

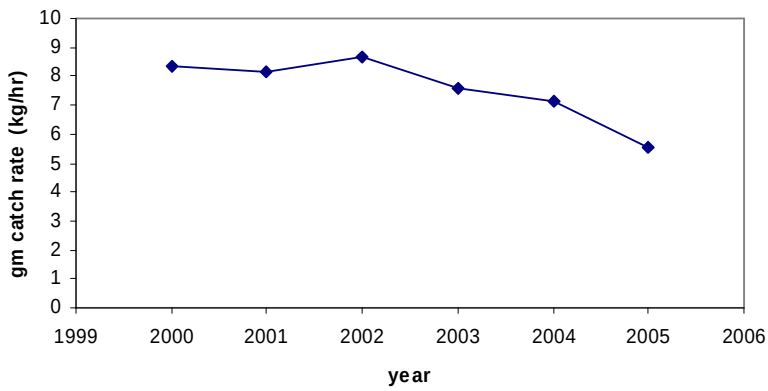


Table 32.13. Eastern deepwater sharks catches and catch rates. Catches from 2000-2004 are from the logbook data, using the species codes in Table 32.11 as well as species codes 37020000 (dogfish) and 37990003 (other sharks). Catch in 2005 is from landings data.The catch rate is calculated from logbook data, and is the geometric mean of catch(kg)/effort(hrs).

Year	Catch (t)	Geometric mean catch rate (kg/hour)
2000	346	8.37
2001	299	8.13
2002	267	8.68
2003	194	7.57
2004	140	7.13
2005	66	5.55

32.3.7.2 Western

Quota 2005 : 108 t
Quota 2006 : 108 t
Average catch in last 4 years : 191 t
Slope of trend in catch rate over last 4 years : -0.078

Table 32.14. Tier 4 RBCs for western deepwater sharks based on 3 values of α

α	RBC (t)
1	176
2	161
4	132

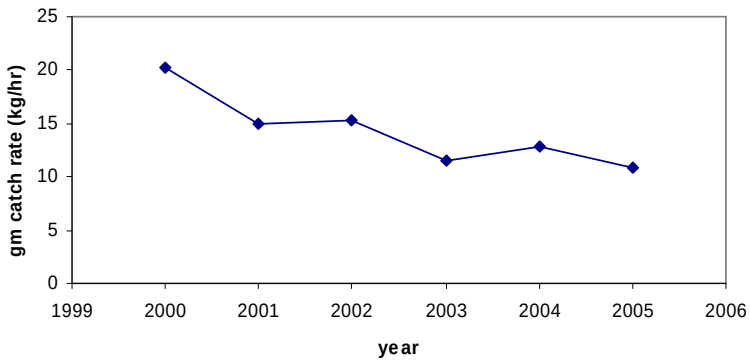


Table 32.15. Western deepwater sharks catches and catch rates. Catches from 2000-2004 are from the logbook data, using the species codes in Table 32.11 as well as species codes 37020000 (dogfish) and 37990003 (other sharks). Catch in 2005 is from landings data.The catch rate is calculated from logbook data, and is the geometric mean of catch(kg)/effort(hrs).

Year	Catch (t)	Geometric mean catch rate (kg/hour)
2000	313	20.20
2001	255	15.02
2002	266	15.30
2003	173	11.44
2004	225	12.81
2005	101	10.86

33. Benefits

The results of this project have had a direct bearing on the management of the Southern and Eastern Scalefish and Shark Fishery. Direct benefits to the commercial fishing industry in the SESSF have arisen from improvements to, or the development of, assessments under the various Tier Rules of the Commonwealth Harvest Strategy Policy for selected quota and non-quota species. Information from the stock assessments has fed directly into the TAC setting process for SESSF quota species. As specific and agreed harvest strategies are being developed for SESSF species (a process required by and agreed to under EPBC approval for the fishery), improvements in the assessments developed under this project have had direct and immediate impacts on quota levels or other fishery management measures (in the case of non-quota species).

Participation by the project's staff on SESSF Resource Assessment Groups has enabled not only the production of critical assessment reports, but also a clear communication of the reports' results to a wide audience (managers, industry). Project staff's scientific advice on quantitative and qualitative matters is also clearly valued.

The stock assessments presented in this report have provided managers and industry greater confidence when making key commercial and sustainability decisions for species in the SESSF. Some species did not have any (or recent) full quantitative assessments (e.g. silver trevally, school shark), others required the inclusion of major new population dynamic and fishery assumptions (e.g. jackass morwong) or further exploration of data (e.g. school and gummy shark, school whiting, jackass morwong), while others could now utilize improved or new information regarding stock size (e.g. blue grenadier, blue warehou). Clearly, these assessments have provided the most up-to-date information, in terms of data and methods, to facilitate the management of the Southern and Eastern Scalefish and Shark Fishery.

34. Conclusion

- Provide quantitative and qualitative species assessments in support of the four SESSFAG fishery assessment groups

The 2006 assessment of stock status of the key Southern and Eastern Scalefish and Shark fishery species is based on the methods presented in this report. Documented are the latest quantitative assessments for several of the key non-shark quota species (blue grenadier, blue warehou, silver trevally, tiger flathead, jackass morwong, orange roughy), two of the major shark species (gummy and school shark) and catch curve and cpue standardisations for shelf and slope species. Typical assessment results provided indications of current stock status, in addition to risk assessments that allow an evaluation of future impacts under different catch strategies, biological scenarios and the newly adopted harvest strategy framework. This framework is based on a set of harvest control rules, with the decision to apply a particular harvest control rule for a stock being dependent on the type and quality of information available that can determine stock status (Tiers 1 to 4).

The assessment outputs from this project are a critical component of the management and TAC setting process for these fisheries. The results from these studies are being used by SESSFAG, industry and management to help manage the fishery in accordance with agreed sustainability objectives.

Stock status and Recommended Biological Catch (RBC) conclusions:

For blue grenadier (*Macruronus novaezelandiae*), results of the 2006 assessment are consistent with previous assessments, with a continuing trend in declining spawning biomass, primarily due to poor recent recruitment. While an increase in recruitment is estimated by the model for years 2003 and 2004, these will not have been well estimated and the real strength of these cohorts will need to be determined over the next few years. Results conclude that the female spawning biomass in 2005 is around 40% of the reference biomass. However, not surprisingly, the magnitude of the biomass differs substantially between the two models (Low, High). This is reflected in the application of the harvest control rules, where the Recommended Biological Catches (RBCs) for 2007 are between 11,000 t and 18,000 t for the High model and between 2,000 t and 3,300 t for the Low model. The long-term RBCs also differ markedly; with RBCs of 20,000 t for the High model and 5,500 t for the Low model. Simulations showed that if the annual catch is fixed at the current TAC of 3,730 then, under the Low resource model, the depletion gradually rises to about 60% of the reference biomass in 10 years. For the High model, by 2016 the depletion is at or above 70% of the reference biomass

The 2006 stock assessment of blue warehou (*Seriolella brama*) is based on there being two stocks of blue warehou off southern Australia (east and west of Bass Strait). The results for the eastern stock are qualitatively identical to those from the 2004 and 2005

assessments; the stock is depleted to well below the target reference point and there is no evidence for a recovery. In contrast to the situation for the eastern stock, the western stock recovered from below the overfished threshold of $0.2B_0$ to close to the B_{MSY} proxy of $0.4B_0$ in 2005, but has declined since owing primarily to lack of good recruitment. Given the short-lived nature of blue warehou, RBCs for 2008 are predicted to be non-zero for both stocks, although the actual magnitude of the 2008 RBC depends on future recruitment. The assessments, particularly that for the eastern stock, remain highly uncertain.

The 2006 assessment of silver trevally (*Pseudocaranx dentex*) uses all catch data, starting from 1945. This assessment uses length based selectivity and a separate one fleet (base-case) and a 4 fleet model. Analyses of the 1 fleet model have shown that the model is sensitive to a number of key parameters and assumptions. Difficulties were encountered in getting stable results with both the one fleet and the four fleet version of this model, with some runs giving quite pessimistic results and others giving unrealistic very large single recruitments, resulting in a very large biomass being fished down.

The stock of tiger flathead (*Neoplatycephalus richardsoni*) off NSW and Eastern Bass Strait is estimated to be presently at 42% of unfished spawning stock biomass. If Tasmanian catches are included and Tasmania is treated as a separate fishing fleet the stock is estimated to be at 43% of unfished spawning stock biomass. The Recommended Biological Catch (including state catch and discards) for the combined stock including Tasmania was 2,903t for the 20:40:40 catch control rule and 2,245t using the 20:40:48 rule.

The results of the assessment for jackass morwong (*Nemadactylus macropterus*) in eastern areas are sensitive to the data included when calculating the standardised CPUE indices. Base-case estimates of 2006 spawning depletion when the model is fit to the updated CPUE indicate that the stock is at low levels, around 15% of the unfished equilibrium state, leading to 2007 RBCs of zero under all tier 1 and tier 2 harvest control rules. When fit to the CPUE indices used in the previous assessment, estimates of current stock status are more optimistic, with 2006 spawning depletion estimated to be 35% of the unfished state. 2007 RBCs using the 2004 CPUE range from 787–1,540 t under tier 1, and from 337–677 t under tier 2. Due to the sensitivity of the results to the standardised CPUE indices, it is of extreme importance to determine what CPUE data are representative of changes in relative abundance.

For Cascade Plateau orange roughy (*Hoplostethus atlanticus)*, the 2005 acoustic biomass estimate was approximately three times higher than the 2003 and 2004 estimates, and thus was used on its own as an absolute estimate, rather than as a third point in a relative index. Three alternative values of the 2005 acoustic biomass estimate, representing different assumptions about target strengths, proportion spawning and turnover, were used in sensitivity tests. For the base case, current female spawning biomass was estimated to be 73% of unfished biomass, for the lowest biomass index this proportion was 62%, and for the largest biomass index it was 82%. The RBC for 2007 ranges from 283 t to 1,307 t for the three estimates of 2005 biomass, and three versions of the harvest control rule.

The assessment model results for eastern zone orange roughy provided two scenarios. Firstly, when all data were used, a reduced recruitment of fish aged between 30-60 in 2006 led to a stock biomass below the 20% limit reference point, at which catches should be set at zero (under the SESSF harvest strategy framework). Stock biomass was predicted to rise above 20% in 2013. Secondly, when age composition data were not used to estimate recruitment residuals, and constant average recruitment was assumed, the stock biomass was estimated at 27% of unfished biomass, and the Recommended Biological Catch calculated using Tier 1 of the SESSF harvest strategy framework was between 672 t – 1,087 t (depending on which harvest control rule was used).

For deepwater flathead (*Neoplatycephalus conatus*) the unexploited biomass estimate for the base case models was 10,087t and current depletion was estimated to be 50%. Under the Tier 1 catch control rule using 20:40:40 the RBC value was 1,544t, and using a Tier 2 20:50:50 rule the RBC value was 1,070t. For Bight redfish (*Centroberyx gerrardi*) the unexploited biomass estimate for the base case models was 31,660t and current depletion was estimated to be 94%. Under the Tier 1 catch control rule using 20:40:40 the RBC value was >4,700t, and using a Tier 2 20:50:50 rule the was >4,040t.

The assessment of gummy shark (*Mustelus antarcticus*) is based on an age- and sex-structured population dynamics model and explicitly includes five gear-types (four mesh sizes of gillnets and longlines). The model is applied assuming that there are separate populations of gummy shark in Bass Strait and off Tasmania and South Australia. The populations of gummy shark in Bass Strait and off Tasmania are estimated to be comfortably above $0.4B_0$ while the population off South Australia is again estimated to be below this level. The RBC for Bass Strait for 2007 based on the Tier 1 rules is a landed catch between 750-1016t, depending on the target level for the Tier 1 control rule and the breakpoint in this control rule. Equivalent ranges for Tasmania and South Australia are 234-274t and 210-343t respectively. The total (all State) RBC for 2007 ranges between 1194 and 1632t. The long-term RBCs for Tasmania are lower than those for 2007 while the long-term RBCs for South Australia are higher than those for 2007.

Evaluation of stock status for school shark (*Galeorhinus galeus*) is based on the expected amount of pup production relative to that at the start of the fishery in 1927. The results of the 2006 assessment suggest that the size of the school shark resource at the start of 2000 is somewhat larger than inferred from the 2001 assessment. There is, however, no evidence for an increase in the abundance of school shark since 2000, although there is some evidence that the biomass and pup production may have stabilized. Pup production in 2005 is estimated to have been below 20% of the pre-fishery pup production, so the Recommended Biological Catch under both the Tier 1 and Tier 2 rules is zero.

Tier 3 RBC values for flathead, redfish, morwong, blue warehou, school whiting, ling, blue grenadier and blue-eye were all less than recent average catches. Tier 3 RBC values for spotted warehou and John dory and mirror dory were greater than recent average catches. Due to probable dome-shaped selectivity for silver trevally caught by trawl, it has been recognized that simple catch curve methods as these should not be applied to that species.

35. Appendix A - Intellectual Property

No intellectual property has arisen from the project that is likely to lead to significant commercial benefits, patents or licenses.

36. Appendix B – Staff

Mark Bravington	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Jemery Day	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Gavin Fay	School of Aquatic and Fishery Sciences, University of Washington, Seattle
Mike Fuller	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Malcolm Haddon	Tasmanian Aquaculture and Fisheries Institute, Taroona, Tasmania
Neil Klaer	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Fred Pribac	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
André Punt	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Tony Smith	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Bruce Taylor	Primary Industries Research Victoria, Queenscliff, Victoria
Geoff Tuck	CSIRO Marine and Atmospheric Research, Hobart, Tasmania
Sally Wayte	CSIRO Marine and Atmospheric Research, Hobart, Tasmania