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The complexity of the hoki stock assessment model

B. Bull

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Author: B. Bull

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7. Executive Summary

This report describes three different hoki stock assessment models of varying degrees of complexity. We present performance testing results for least squares estimation using the three models, based on simulated observations generated by the most complex of the three models. The most complex is the model which was used in the NIWA hoki stock assessment for 1999.

The results do not indicate that the intermediate model has worse estimation performance than the complex model in any respect. However, the simple model has been shown to have poor performance and is not recommended.

8. Programme Objectives:

1. To determine biomass, long-term sustainable yields and optimum exploitation rates of hoki (*Macruronus novaezelandiae*) stocks and to model the response of hoki stocks to exploitation.

9. Objectives covered by this report:

2. To determine the optimal level of model complexity for the assessment of the eastern and western hoki stocks.

10. Introduction

This report describes three different hoki stock assessment models of varying degrees of complexity. We present performance testing results for least squares estimation using the three models, based on simulated observations generated by the most complex of the three models. The most complex is the model which was used in the NIWA hoki stock assessment for 1999 (Cordue 2000).

The two-stock model used in recent NIWA assessments was tailored to use as much as possible of the available data. In achieving this end it may have become less than optimal for use as an estimation model, perhaps being too complex. It was suggested in the recent review of hoki stock assessment research that simpler models be explored for estimation purposes (Quinn & Sullivan 1999). Accordingly this work was carried out to test the performance of simpler estimation models.

<u>Hoki stock assessment</u>

Hoki is the most abundant commercial fish species in New Zealand waters, and has been our largest fishery for many years. Recent TACC levels have been in the region of 200 000–250 000 t.

Stock assessment of hoki in the 1990s has been in a constant state of development, with improved methods being used and a large increase in available data for stock assessment. NIWA's population models have progressed from an "off the shelf" simple single stock model used for just the western stock (Sullivan and Cordue 1990) to the latest two-stock model designed specifically for the hoki stocks and the available data (Cordue 2000). Estimation procedures have also undergone development, with the confidence distribution method of Francis (1990, 1992) replaced by successively improved methods of "Minimum Integrated Average Expected Loss" (MIAEL) estimation.

The stock structure of hoki is still not fully understood. However, there are two main spawning grounds, Cook Strait and WCSI, which are primarily supported by mature fish from the Chatham Rise and Sub-Antarctic respectively (Livingston 1990, Livingston et al. 1992). The bulk of the juvenile biomass is found on the Chatham Rise. It is thought that there are two stocks which both spend part of their lives on the Chatham Rise, which drives the use of a two-stock model rather than two separate single-stock assessments.

Hoki undergo complex migrations associated with spawning and recruitment of fish from the Chatham Rise to the Sub-Antarctic (Livingston and Schofield 1995). Spawning migrations are not straightforward. Hoki mature from ages 2 to 6 and not all mature fish spawn each year (Vignaux et al. 1995). It is not known whether fish have spawning ground fidelity (i.e., whether a fish returns to the ground in which it was spawned). Although it is considered unlikely, there is a possibility that some fish may spawn in different grounds in different years.

There is a substantial amount of data available for use in hoki stock assessments. Early trawl survey data which are not part of consistent time series are of limited use. However, some of the *Shinkai Maru* and *Amaltal Explorer* data were used in recent assessments. Consistent time series of trawl surveys are available in the 1990s from *Tangaroa* surveys of the Chatham Rise, Southland, and the Sub-Antarctic. Also, since the late 1980s, for the spawning grounds there are indices from CPUE analysis and acoustic surveys, and catch at age data from land-based catch sampling (for Cook Strait) and sea-based observer sampling (from WCSI). The catch at age data were originally quite limited, being produced by an analysis of length frequencies. However, NIWA now use a validated ageing method based on otolith readings (Horn and Sullivan 1994).

11. Methods

Two new hoki models, the 'simple' and 'intermediate' models, were designed and tested (the 'complex' model is as used in the 1999 hoki assessment (Cordue 2000)). Many sets of simulated observations were generated using the complex model, using several different sets of 'true values'. For each set of simulated observations, least squares estimates of B_0 and YCS were calculated for each of the three models. The results were compared to the original 'true values'.

In this section, we first reproduce material from Cordue (2000) about the complex model, then describe the modifications made to produce the simple and intermediate models, then the process of generating simulated observations and producing simulated estimates.

The complex model is age-structured and has two stocks, eastern and western. It has a multi-stage annual cycle incorporating a two-stage pre-spawning season and a two-stage spawning season. Six areas are defined: eastern and western spawning grounds (Cook Strait and WCSI, the west coast of the South Island); the western home ground (the Sub-Antarctic); the nursery (the Chatham Rise), and two "corridors" which are used to move fish between spawning grounds and the nursery. So as to model observations occurring during periods of migration, some migrations between areas are split into two waves, with observations placed between waves. Each stock is assumed to have a Beverton-Holt spawning-biomass to recruitment relationship. Stock fidelity parameters determine the proportion of larvae from each stock which join an "undecided" pool and the proportion of the undecided larvae which go on to become eastern stock fish. Cordue (2000) gives equations for the model. Estimated parameters include the virgin spawning biomass (B_0) of each spawning ground, the year class strengths of the cohorts spawned in each ground, stock fidelity parameters, and various migration parameters. Data inputs include various biological parameters (Ballara 1997), catch histories (Cordue 2000), and the following observations:

- acoustic survey data for WCSI and Cook Strait
- CPUE for WCSI
- commercial catch-at-age for WCSI, Cook Strait, Sub-Antarctic, and Chatham Rise
- proportions-mature-at-age for Sub-Antarctic
- trawl survey numbers-at-age for Sub-Antarctic, Chatham Rise, and Southland.

The Southland observations are assumed to relate to the southern corridor area.

Penalties are applied to the relativity coefficients q to encourage WCSI acoustic surveys to have similar q's to Cook Strait acoustic surveys, and multiple trawl surveys using the same vessel to have similar q's.

The intermediate model was conceived as a simpler version of the two-stock model. The changes from the complex model are as follows:

- Stock fidelity is complete.
- No stock-recruit relationship.
- Rather than keeping track of numbers of mature and immature fish, the model calculates the proportion of mature fish at any time using a constant, sex-specific maturity ogive.
- The migrations between Sub-Antarctic, WCSI, and Chatham Rise are no longer split into two waves.
- Fish appear first on the Chatham Rise at age 2, rather than appearing at WCSI and migrating to the Chatham Rise. As a consequence, the Southland trawl survey data and all observations of 1-year-olds are not used. Fish now cannot reach the Sub-Antarctic by age 2, so observations of 2-year olds are not used. Nor can 2-year olds reach the Chatham Rise in the time step corresponding to November / December, so some Amaltal Explorer observations of 2-year olds on the Chatham Rise are not used.

The simple model abandons the linkage between the two stocks. It consists of two totally separate single-stock models, modified from those used for NIWA assessments of other middle-depth species such as hake (Dunn 2001) and ling (Horn 2001). These models are similar to the complex model in terms of structure and time sequence, but include only three areas: a home ground, a spawning ground, and a corridor connecting the two. The other respects in which the simple model differs from the complex model are as follows:

- Stock fidelity is complete.
- No stock-recruit relationship.
- Rather than keeping track of numbers of mature and immature fish, the model calculates the proportion of mature fish at any time using a constant, sex-specific maturity ogive.
- The migrations between areas are no longer split into two waves.
- Fish always reach the home ground at age 2, as per the intermediate model.
- No penalties encouraging catchabilities from observations using similar methods to be similar.
- The catch on the Chatham Rise is partitioned between the western and eastern stocks. Following Sullivan et al. (1995), we assume that 25% of fish (by weight) under 70 cm length and 100% of fish over 70 cm length taken on the Chatham Rise are eastern stock. By using commercial catch length frequency data, we arrive at a catch breakdown (Appendix 1). This is a crude assumption, but it is hard to do much better if the two stock models are separated, given the available information.
- Numbers-at-age observations of 6+ and older fish from *Tangaroa* surveys on the Chatham Rise are used for the eastern stock, because most western stock fish are thought to migrate to the Sub-Antarctic before reaching that age. Numbers-at-age of 2+ fish from *Tangaroa* surveys on the Chatham Rise are used for the western stock, because only a small proportion of them are thought to be eastern fish, and most western stock fish are

thought to be on the Chatham Rise at this age. Various other data are removed because the model does not allow fish to reach the relevant areas at the relevant ages. Once this is done, the observations are as follows:

Eastern stock observations:
acoustic survey data for Cook Strait
commercial catch-at-age for Cook Strait
trawl survey numbers-at-age for Chatham Rise, *Tangaroa* January surveys, only including fish of age 6+ and over
proportions-spawning-at-age (from Sub-Antarctic survey, but used for the eastern stock anyway).

Western stock observations:
acoustic survey data for WCSI
commercial catch-at-age for WCSI, only including fish of age 5+ and over
commercial catch-at-age for Sub-Antarctic, only including fish of age 4+ and over
trawl survey numbers-at-age for Sub-Antarctic, only including fish of age 4+ and over
trawl survey numbers-at-age for Chatham Rise, *Tangaroa* January surveys, only including fish of age 2+
proportions-spawning-at-age from Sub-Antarctic survey.

Simulated observations and estimates

Nine simulation scenarios were considered: low (900 kt), medium (1 450 kt), and high (2000 kt) western stock B_0, crossed with low (250 kt), medium (425 kt), and high (600 kt) eastern stock B_0. (The MIAEL estimates from base-case run 3d of Cordue (2000) were 1 330 and 280 kt respectively.) All the other true parameter values were taken from base-case run 3d of Cordue (2000).

For each of the nine scenarios, the complex model was run, fits were calculated for all observations, and 500 sets of simulated observations were generated by parametric bootstrapping around the fitted values. Proportions-at-age observations were bootstrapped using the multinomial distribution with specified 'equivalent sample size' parameters: all other observations were bootstrapped using the lognormal distribution with specified c.v.s. The equivalent sample sizes and c.v.s were as used in the 1999 stock assessment (Cordue 2000) and are reproduced in Table 1.

For each set of simulated observations, B_0 and YCS were estimated under each of the three models, and compared with the true values. RMSRE (root-mean-squared relative error) was used as a measure of error. Where T is a true value and $E_1 ... E_n$ are estimates,

$$RMSRE = \sqrt{\sum_{i=1}^{n}\left(\left(\frac{E_i - T}{T}\right)^2\right)\Big/ n}\ .$$

So, a low RMSRE indicates good performance in terms of relative error.

12. Results

The distributions of simulated estimates of western stock B_0 from each of the three models, for low, medium, and high true values, are shown in Figure 1. There is considerable variability in estimates for all three models. The simple model is clearly performing poorly: estimates are usually at the upper bound of 3 350 kt, regardless of the true value. The complex and intermediate models yield similar results for the medium and high B_0 scenarios, but the intermediate model typically yields lower estimates for the low B_0 scenario, often returning the lower bound.

Distributions of simulated estimates of eastern stock B_0 are shown in Figure 2. Again, there is considerable variability in estimates for all three models. The simple model has less median bias than the intermediate and complex models, but more variability. The complex and intermediate models have very similar performance.

The errors in the estimates of B_0 are summarized in Table 2, in terms of RMSRE (root-mean-squared relative error). The performance of the intermediate model for estimation of B_0 is clearly very similar to that of the complex model. Both perform better for the western stock than for the eastern stock. The simple model has similar performance to the other two models for eastern stock B_0 but very poor performance for western stock B_0.

The mean western stock YCS estimates for 1987–1996 are plotted alongside the true western YCS in Figure 3, for each of the three models, averaged over all nine scenarios. (YCS after 1996 were poorly determined: YCS before 1987 were increasingly poorly determined and of relatively little interest to contemporary stock assessment.) The three models all produce similar YCS estimates, unbiased with regard to the 'true values', except that the simple and intermediate models somewhat underestimate the strong 1991-1994 year classes (though this is probably just a result of the parameterization rather than a genuine weakness: see the Conclusions). The equivalent results for the eastern stock are shown in Figure 4. All four models produce similar YCS estimates, unbiased with regard to the 'true values', except that the complex model tends to overestimate the relatively weak 1995 year class.

13. Conclusions

The intermediate model yielded similar estimates of B_0 to the complex model.

The simple model for the western stock failed to produce adequate estimates of B_0. Estimates were usually at the upper bound. Based on exploratory analysis of the complex model, removing model elements and redoing least squares estimates, this was probably a result of

(1) the removal of the bulk of the Chatham Rise *Tangaroa* trawl survey data, which have a strong downward trend over the 1990s,

(2) the removal of the penalties constraining western and eastern observations to have similar q's, which allow eastern stock acoustic and trawl survey observations to exert a restraining influence on western biomass.

YCS estimates were very similar for the three models. The simple and intermediate models underestimated the 1991 through 1994 western stock year classes, but this is most likely a result of their parameterization. The complex model includes a stock-recruit relationship, which the simple and intermediate models do not, and therefore needs a higher YCS to yield the same number of fish when spawning stock sizes are low. The YCS used in the simulations lead to relatively low western spawning stock biomass during 1991-1994 (as in the stock assessment: see Figure 24 of Cordue (2000)). Thus, lower 1991-1994 YCS are needed in the simple and intermediate models to produce the same number of fish.

The overestimation of the 1995 eastern YCS in the complex model is of some concern, and presumably relates to the inclusion of observations of 1+ juvenile hoki in the complex model which were not used by the intermediate or simple models. Presumably the strength of very recent year classes is relatively poorly determined: uncertainty in the estimation of recent YCS should be explored in the assessment, if they are found to influence the implications for management.

In summary, these partial results do not indicate that the intermediate model has worse estimation performance than the complex model in any respect. However, the simple model has been shown to have poor performance.

14. Publications

None.

15. Data Storage

None.

16. Acknowledgments

This work was conceived (in its original, more extensive form) and supervised by Patrick Cordue.

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Table 1: **Equivalent sample sizes for the multinomial distribution of proportions-at-age, and c.v.s for the lognormal distribution of other observations, used when generating simulated observations. These values are taken from the 1999 hoki assessment (Cordue 2000).**

Observation	Years	Equivalent sample sizes
WCSI catch-at-age	1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998	141, 111, 146, 172, 113, 88, 182, 107, 146, 114, 146
Cook Strait catch-at-age	1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998	50, 80, 65, 95, 165, 315, 220, 275, 255, 325, 355
Chatham Rise catch-at-age	1992, 1993, 1994, 1995, 1996, 1997, 1998	30, 8, 43, 23, 45, 26, 108
Southern Plateau catch-at-age	1992, 1993, 1994, 1995, 1996, 1997, 1998	267, 187, 100, 50, 114, 68, 175

Observation	Years	c.v.s
WCSI acoustics	1988, 1989, 1990, 1991, 1992, 1993, 1997	0.53, 0.40, 0.37, 0.46, 0.53, 0.37, 0.38
Cook Strait acoustics	1988, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998	0.79, 0.50, 0.61, 0.50, 0.54, 0.50, 0.47, 0.46, 0.47
Southland trawl survey	1993, 1994, 1995, 1996	1.49, 1.45, 1.39, 1.45
Sub-Antarctic *Tangaroa* summer trawl surveys	1991, 1992, 1993	1.20, 1.19, 1.23 (1-year-olds); 0.90, 0.89, 0.93 (older ages)
Sub-Antarctic *Tangaroa* spring trawl survey	1992	1.40
Sub-Antarctic *Tangaroa* autumn trawl surveys	1992, 1996, 1998	1.00, 0.97, 1.05 (1-year-olds); 0.90, 0.88, 0.94 (older ages)
Sub-Antarctic *Shinkai Maru* autumn trawl survey	1982	1.20
Sub-Antarctic *Shinkai Maru* spring trawl survey	1983	1.50
Sub-Antarctic *Amaltal Explorer* spring trawl survey	1989, 1990	1.00, 1.00
Sub-Antarctic *Amaltal Explorer* winter trawl surveys	1990	1.20
Chatham Rise *Tangaroa* summer trawl surveys	1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999	0.72, 0.71, 0.73, 0.78, 0.85, 0.82, 0.85, 0.82
Chatham Rise *Shinkai Maru* autumn trawl survey	1983	1.00
Chatham Rise *Shinkai Maru* winter trawl survey	1986	0.75
Chatham Rise *Amaltal Explorer* summer trawl survey	1989	0.55
Proportions-spawning-at-age	1992	0.25

Table 2: **Errors in the estimation of B_0 for the simple, intermediate, and complex models. Error is measured by the RMSRE (root-mean-squared relative error): a high RMSRE indicates poor performance. Results are shown for each stock, for the low, medium, and high B_0 scenarios and overall, aggregated over the three levels of B_0 for the other stock.**

(a) Western B_0

	Error (RMSRE) in estimates		
True B_0 (kt)	Complex	Intermediate	Simple
900	0.23	0.13	0.62
1 450	0.21	0.24	1.25
2 000	0.27	0.28	0.67
Overall	0.24	0.23	0.89

(b) Eastern B0

	Error (RMSRE) in estimates		
True B_0 (kt)	Complex	Intermediate	Simple
250	0.21	0.17	0.35
425	0.47	0.49	0.51
600	0.40	0.41	0.41
Overall	0.38	0.38	0.42

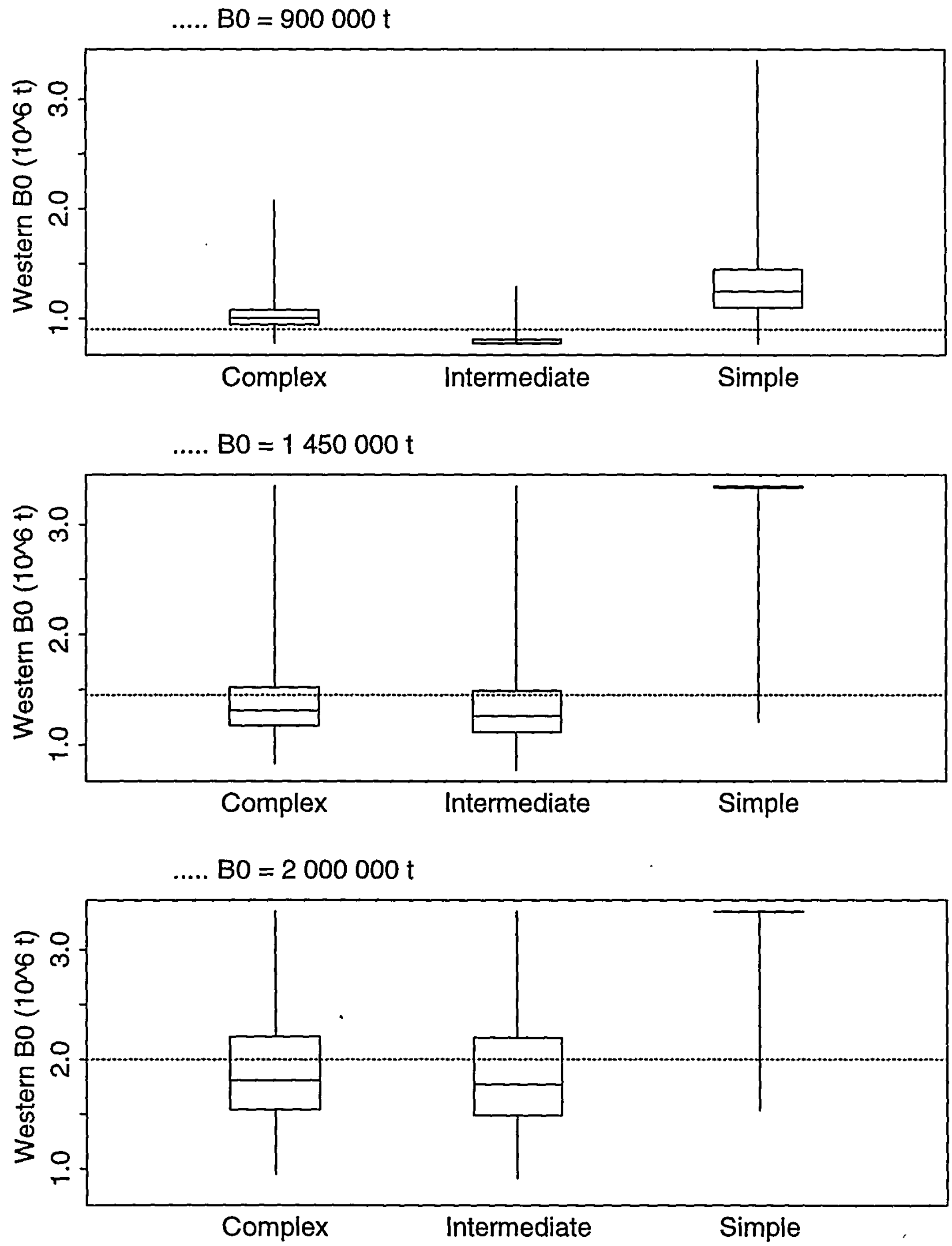

Figure 1: **Box-and-whisker plots of simulated estimates of western stock B_0, from the complex, intermediate, and simple models, for low, medium, and high western stock B_0 scenarios. The dotted lines indicate true western B_0. Results are aggregated over the three levels of eastern B_0. (Box indicates 25%, 50%, and 75% quartiles: whiskers indicate minimum and maximum.)**

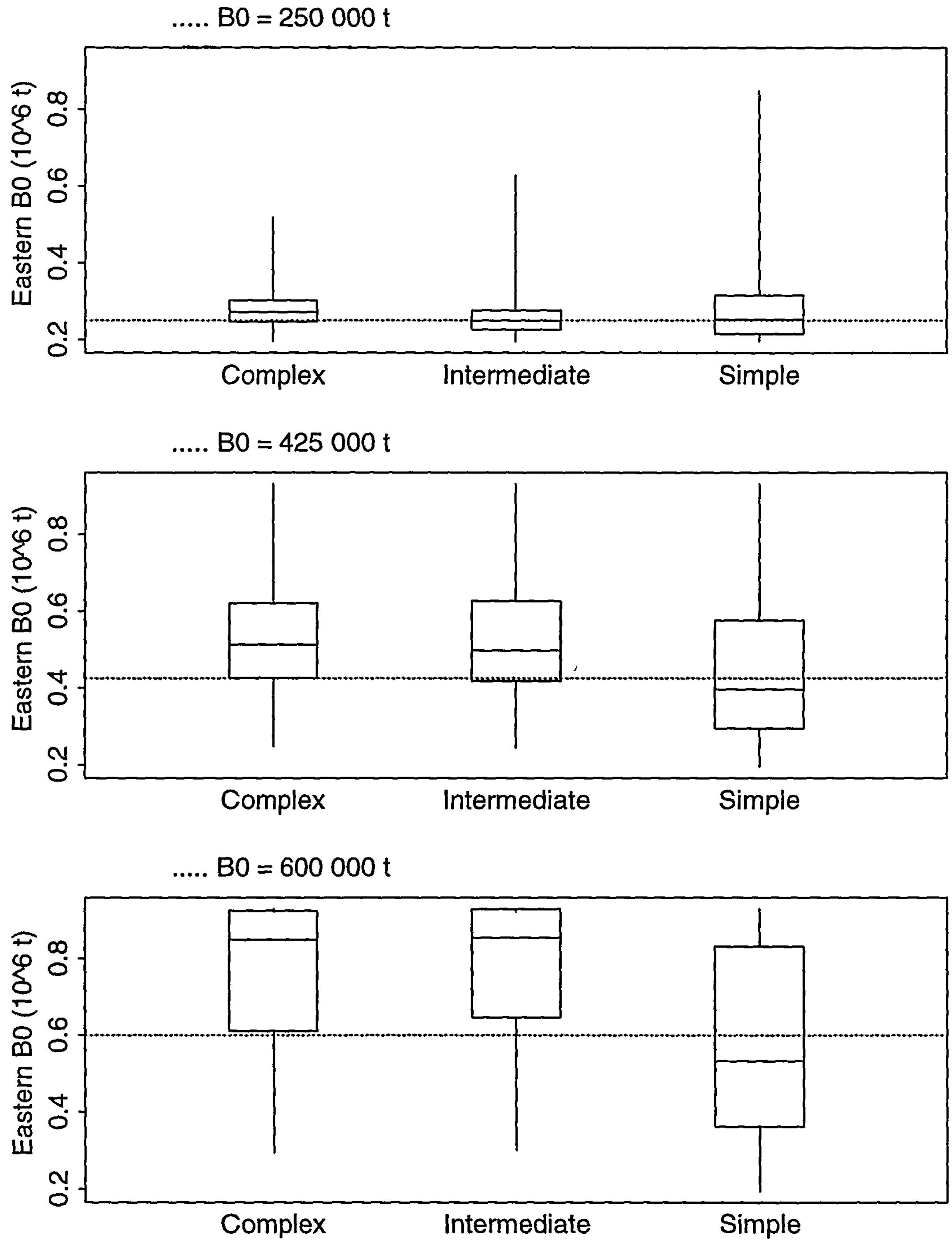

Figure 2: **Box-and-whisker plots of simulated estimates of eastern stock B_0, from the complex, intermediate, and simple models, for low, medium, and high eastern stock B_0 scenarios. The dotted lines indicate true eastern B_0. Results are aggregated over the three levels of western B_0. (Box indicates 25%, 50%, and 75% quartiles: whiskers indicate minimum and maximum.)**

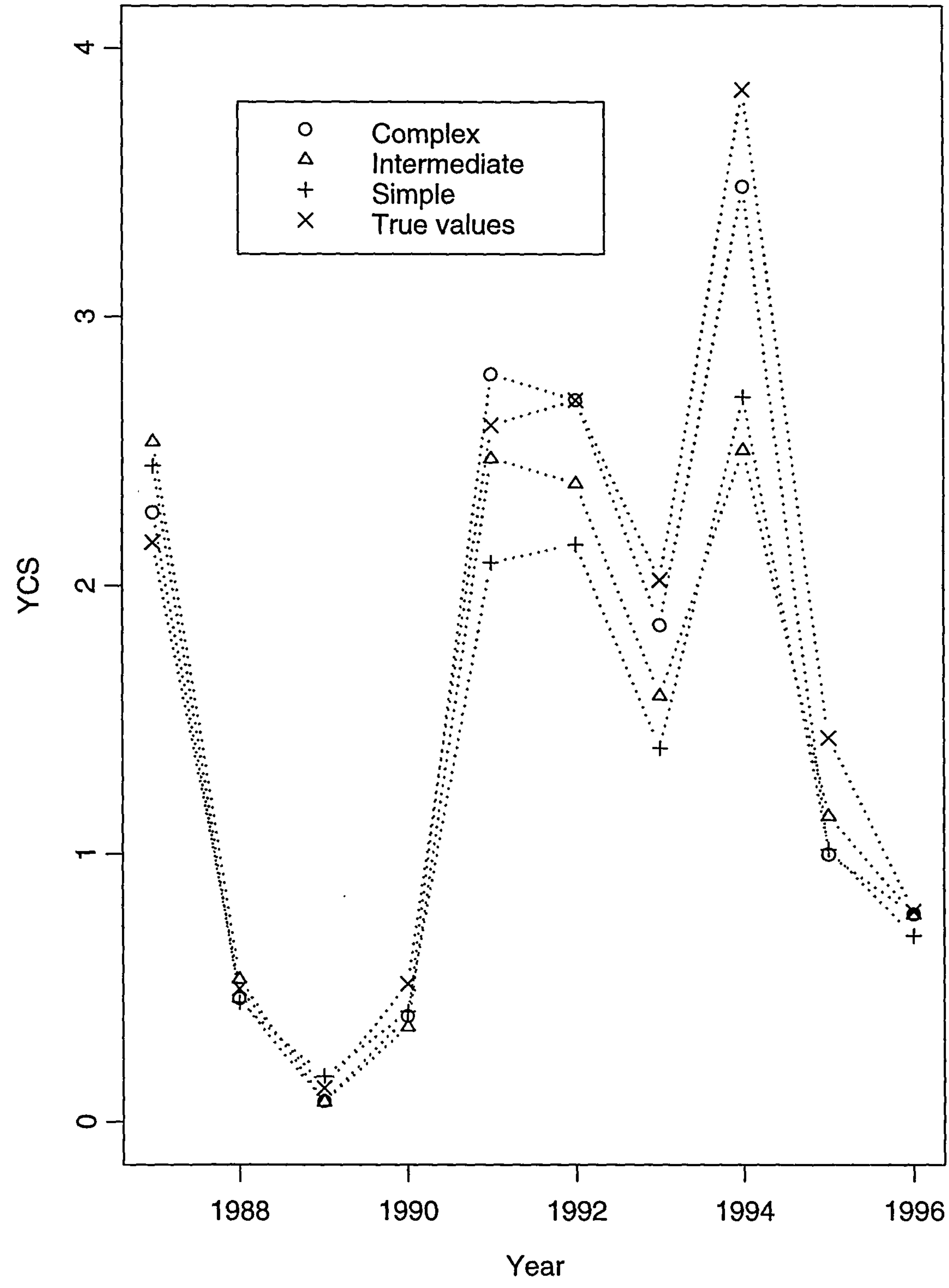

Figure 3: **Mean estimated western stock YCS for 1987–1996, for each of the three models, averaged over all nine scenarios, versus the true western stock YCS.**

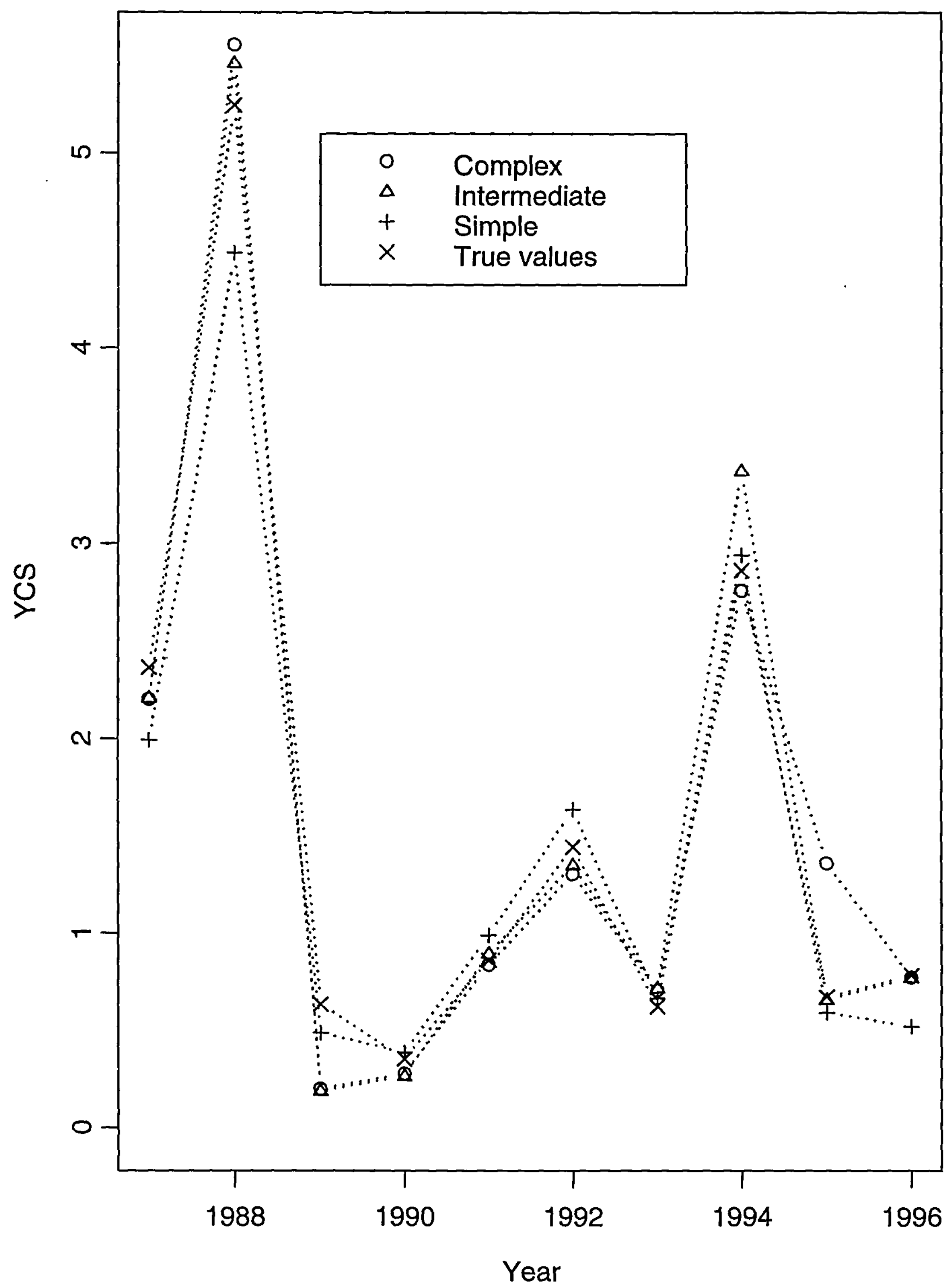

Figure 4: **Mean estimated eastern stock YCS for 1987–1996, for each of the three models, averaged over all nine scenarios, versus the true eastern stock YCS.**

Appendix 1: Breakdown of Chatham Rise hoki catch between the western and eastern stocks in the simple model.

When dividing Chatham Rise catch into western and eastern stock fish for the simple hoki model, we make the assumption that 25% of hoki under 70 cm and 100% of hoki over 70 cm taken on the Chatham Rise are eastern stock. Commercial catch length frequency data give the following results:

Year	Proportion over 70 cm	Proportion of western fish
1989/90	0.15	0.36
1990/91	0.81	0.86
1991/92	0.36	0.52
1992/93	0.69	0.77
1993/94	0.72	0.79
1994/95	0.50	0.63
1995/96	0.29	0.47
1996/97	0.40	0.55
1997/98	0.43	0.57
1998/99	0.44	0.58

For earlier years, for which commercial catch data were not available, we use the average of 61% western fish.

The catch breakdown is hence

Year	Catch (000 t)	Western catch	Eastern catch
90	13	4.7	8.3
91	13	11.1	1.9
92	49	25.5	23.5
93	46	35.3	10.7
94	27	21.3	5.7
95	41	25.6	15.4
96	53	24.8	28.2
97	64	35.2	28.8
98	82	46.9	35.1
99	82	47.6	34.4