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EXECUTIVE SUMMARY

Horn, P.L., Harley, S.J., Ballara, S.L., & Dean, H. 2000: Stock assessment of ling (*Genypterus blacodes*) around the South Island (Fishstocks LIN 3, 4, 5, 6, and 7).
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Ling in QMAs 3–7 were assessed as four biological stocks: Chatham Rise (LIN 3 and LIN 4), Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176° E), Bounty Platform (LIN 6 east of 176° E), and west coast South Island (LIN 7 west of Cape Farewell). These biological stocks are subsequently referred to as LIN 3&4, LIN 5&6, LIN 6B, and LIN 7WC, respectively.

Some biological parameters important to the stock assessments were updated. Estimates of timing and duration of spawning were derived for all stocks from gonad stage data collected by observers. Conclusions for LIN 6B and LIN 7WC are tentative because available data do not cover all months. Maturity ogives were derived for all except the LIN 6B stock, primarily from gonad stage data obtained during trawl surveys. Von Bertalanffy parameters for LIN 7WC, and length-weight parameters for LIN 3&4 and LIN 5&6, were updated using large quantities of data which have recently become available.

Fishing selectivity ogives were derived for the main fisheries in each of the four stocks, from length-frequency data collected by observers. Longline and trawl selectivity ogives clearly differ; the longline fisheries capture a relatively greater proportion of larger, older fish than the trawl operations.

An existing series of longline CPUE for LIN 7WC was updated to include data to the end of the 1998 calendar year. A CPUE series based on the trawl bycatch of ling in LIN 7WC was investigated, but does not appear to be useful because of changes in trawl fishing practice over time and perceived inaccuracies in the reporting of the trawl catch of ling.

The assessments of the four biological stocks incorporated all relevant biological parameters, the commercial catch histories, updated CPUE series, and new series of catch-at-age data into a population model using the MIAEL estimation technique. The model structure had been modified so that catch histories, selectivities, and relative abundance indices attributable to different fishing methods could be used separately. LIN 3&4 was also assessed using a Bayesian age-structured model.

The MIAEL assessments for LIN 3&4, LIN 5&6, and LIN 6B all appear to be reasonably reliable, based on their performance indices (i.e., about 40% for estimates of B_0, and 60% for estimates of stock status). The LIN 3&4 stock appears to have a current biomass level close to B_{MAY}, and it is likely that recent levels of catch are not sustainable. An annual catch level of about 4000 t is probably the maximum harvest that will not cause the stock to decline further (compared with annual landings of about 6000–7000 t since 1991–92). The LIN 5&6 stock is estimated to be at a level of about 65% B_0. There are currently no sustainability issues for this stock. However, there are some problems (relating to year class strengths and selectivity ogives) which indicate a high level of uncertainty in the assessment. The Bounty Platform stock (LIN 6B) is approaching the B_{MAY} level. There is no TACC exclusive to this stock; it forms part of administrative stock LIN 6. The LIN 6B fishery is almost exclusively target longline, so economic considerations may regulate catches from this area.

The LIN 7WC assessment is very unreliable; performance indices for all estimates of biomass are less than 4%. The next assessment of this stock will include four additional years of catch-at-age data, so the precision of the assessment should improve markedly.

An alternative Bayesian assessment of LIN 3&4 suggests that current stock size is about 41% B_0. The stock has been decreasing since 1990, and future annual catches in excess of 3000 t will cause the decline to continue.

1. INTRODUCTION

This document reports the results of Project MID9801, Objectives 6, 7, and 8, as they relate to ling. Objectives 7 and 8 were added as a variation to the originally accepted tender. The objectives are as follows:

6. To update the stock assessments of ling (LIN 3&4 and 5&6) including estimating biomass and yields.
7. To update the stock assessment of LIN 7.
8. To apply an alternative stock assessment model structure to the LIN 3&4 stock.

Ling are managed as eight Fishstocks, although five of these (LIN 3, 4, 5, 6, and 7; *see* Figure 1) currently produce over 95% of landings. Investigations have indicated that there are at least four major biological stocks of ling in New Zealand waters (*see* Horn & Cordue 1996), i.e., the Chatham Rise, the Campbell Plateau (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Platform, and the west coast of the South Island.

The four stocks assessed in this document are defined as follows: LIN 3&4, Chatham Rise; LIN 5&6, Campbell Plateau including Stewart-Snares shelf and Puysegur Bank; LIN 6B, Bounty Platform; LIN 7WC, west coast of the South Island.

Recent assessments of ling in LIN 3, 4, 5, and 6 (Horn & Cordue 1996, Horn 1997) examined the biological stocks on the Chatham Rise and Campbell Plateau, and excluded the Bounty Platform section of LIN 6. Horn & Cordue (1996) produced estimates of B_0 and MCY using the MIAEL estimation technique of Cordue (1993, 1995, 1998). For LIN 3&4 and LIN 5&6, estimates of B_0 were 137 000 t and 213 000 t respectively, but they were based on very little data (catch histories, and estimates of likely maximum and minimum levels of exploitation) and had performance indices of 16% and 8%, respectively. Horn (1997) updated the analyses by incorporating a series of relative biomass indices from trawl surveys, a CPUE series, and two sets of catch-at-age data, for each stock. For LIN 3&4 and LIN 5&6, respectively, estimates of B_0 (and performance indices) were 150 000 t (28%) and 147 000 t (23%).

Assessments of LIN 7 were reported by Horn & Cordue (1996) and Horn & Ballara (1999). Horn & Cordue (1996) estimated B_0 to be 52 300 t, but this value was based on scant data (a catch history, and estimates of likely maximum and minimum levels of exploitation) and had a performance index of 0%. Horn & Ballara (1999) added a longline CPUE series and three years of commercial trawl catch-at-age data, and estimated B_0 to be 39 300 t (with a performance index of 15%). However, the model structure used for this assessment (and recent assessments of LIN 3, 4, 5, and 6) was considered inappropriate for ling as it used a single catch history and single fishing selectivity ogive, whereas the stocks supported both trawl and longline fisheries with markedly different selectivities. Subsequently, the model structure was modified to allow inputs from two separate fishing methods (i.e., catch histories, fishing selectivities, abundance indices).

The current assessments use the new MIAEL model structure, and incorporate additional catch-at-age data, and updated CPUE series for LIN 3&4, LIN 5&6, and LIN 7WC. A first assessment of LIN 6B is presented. Also, LIN 3&4 was assessed using an alternative Bayesian age-structured model, Coleraine (Hilborn *et al.* unpublished results).

2. REVIEW OF THE FISHERY

Reported landings of ling are summarised in Tables 1 and 2. From 1975 to 1980 there was a substantial longline fishery on the Chatham Rise (and to a lesser extent in other areas), carried out by Japanese and Korean longliners. Reported landings by method from LIN 3, 4, 5, 6, and 7 are shown in Figure 2. During the 1980s, most ling were taken by trawl. In the early 1990s a longline fishery developed, with a resulting increase in landings from LIN 3, 4, 5, and 6. Landings on the Bounty

Platform are taken almost exclusively by longline. A small, but important, quantity of ling is also taken by set net in LIN 3 and LIN 7. In LIN 7, about two-thirds of ling landings are taken as a trawl bycatch.

Under the Adaptive Management Programme (AMP), TACCs for LIN 3 and 4 were increased by about 30% for the 1994–95 fishing year to a level that was expected to allow any decline in biomass to be detected by trawl surveys of the Chatham Rise (with *c.v.* 10% or less) over the 5 years following the increase. The TACCs were set at 2810 and 5720 t, respectively. These stocks were removed from the AMP from 1 October 1998, with TACCs maintained at the increased level. Recent anecdotal reports from the fishing sector suggest that longline catch rates have declined in recent years, particularly in LIN 3 and 4. Consequently, fishing companies have reduced the effort in this fishery.

The TACC for LIN 7 has been consistently exceeded throughout the 1990s, sometimes by as much as 50%.

3. RESEARCH RESULTS

3.1 Comparison of longline and trawl age-length keys

Catch at age data for ling were available from two commercial longline trips (in LIN 5&6 in April–May 1998, and in LIN 3&4 in January 1999) and two research trawl surveys conducted in similar areas at the same time (TAN9805 and TAN9901) (*from* Horn 2000). These four data sets indicate that, in both areas, the longline fishery catches a greater proportion of older fish than the trawl surveys (Figure 3). [These longline trips may not be representative of the overall longline catch, but summarised observer length-frequency data indicate that the trend of larger fish being taken by longline is real (*see* Figure 3a).] Mean lengths at age were calculated separately by sex for each of the four aged samples. Means were calculated only when there was a minimum of three fish at a particular age, and are shown in Figure 4. Pairs of mean lengths at age from the same area and sex, but different fishing methods, were compared using *t*-tests. There were no significantly different pairings for Campbell Plateau fish, or for females on the Chatham Rise. However, male ling on the Chatham Rise caught by longline appear to be consistently larger at a particular age than trawl-caught fish. Four individual pairings of means were statistically significant (i.e., ages 10, 11, 16, and 17), but for 15 of the 16 ages that could be compared, the mean length was smaller for the trawl survey fish. It should be noted that the sample sizes of aged male fish from the longline fishery were small in both areas. Also, while the trawl surveys comprehensively sampled the Chatham Rise and Campbell Plateau, the longline samples were from more restricted areas (i.e., longitude 176°–179° E on the north Chatham Rise, and the Pukaki Rise and southeast Campbell Plateau).

Age-length keys calculated for ling on the Campbell Plateau, and for female ling on the Chatham Rise, can probably be applied to length-frequency data from either the trawl or longline fisheries. But for male ling from the Chatham Rise, the age-length keys may be fishery dependent. This result either reflects an underlying reality or a systematic bias. A bias in otolith interpretation is considered unlikely, as the trawl and longline samples were read less than two months apart by the same reader. Fishing selectivity could influence mean length at age. Young fish taken by longline (i.e., those from only partially selected year classes) are likely to be the faster growing individuals of their year class, hence elevating their mean length at age relative to similar aged fish which would be fully selected by trawl. Very large fish may also have a better chance of avoiding the trawl, which could depress the mean length at age for older trawl-caught year classes relative to similar aged fish which would all be fully selected by the longline method. The combination of these two factors could result in the effect noted for Chatham Rise males. However, it is difficult to understand how the mean length at age of only one sex on one ground could be influenced in this way.

3.2 Time, duration, and areas of spawning

Scientific observers have classified female gonad stage using a 5-stage scale. Data were sorted by month, by biological stock, and the proportion of the total fish measured that were in spawning condition (i.e., stages 3–5, which comprised fish with hyaline eggs present, and those actively spawning or recently spent) was determined (Table 3). Most of the data are from the trawl fisheries.

On the Chatham Rise, peak spawning appears to occur during September and October. There are indications that the season could extend from June to November, although only small numbers of fish were sampled from July and August. A 3-month spawning season from September to November was used in subsequent stock modelling.

On the Campbell Plateau, peak spawning appears to occur during October and November. There are indications that some spawning could begin as early as June, but the sample size in that month is very low. A 3-month spawning season from September to November was used in subsequent stock modelling.

Data from the Bounty Platform did not comprehensively cover the full year, but there was a clear indication that some spawning occurred from August to December. A 3-month spawning season from October to December was used in subsequent stock modelling.

Significant quantities of data from ling off the west coast of the South Island were available only from July to September. It is apparent that the fish are actively spawning in these three months. As a 3-month spawning season had been defined for other ling stocks, a similar period (July to September) was chosen for LIN 7WC.

The distribution of recorded running ripe female ling (Figure 5) indicates that significant spawning activity occurs on the Chatham Rise to the west of Chatham Island and around the Mernoo Bank, off the northern west coast of the South Island, on Puysegur Bank, and around Bounty Island. Spawning fish were also recorded in Cook Strait, on the central north Chatham Rise, and at three sites on the Southern Plateau (the Pukaki Rise, the Auckland Islands Shelf, and the southwestern margin of the Stewart-Snares shelf).

3.3 Estimation of maturity ogives

The maturity ogives used in the current assessment were based on data collected during trawl surveys of the Chatham Rise and Campbell Plateau, or by scientific observers off WCSI. These ogives are presented for each stock in Table 9, but note that they are not the cumulative ogive values, but are the change in ogive over the previous value.

On the Chatham Rise (Figure 6), the data indicated that the youngest mature fish were 57 cm (age 5 years) for males and 67 cm (aged 6) for females, and that immature fish of either sex older than 10 years (lengths of 84 and 91 cm for males and females, respectively) were rare. Lengths at 50% maturity were about 74 cm for males and 88 cm for females, corresponding to ages of 8 and 9 years, respectively. Hence, ogives were estimated which, at ages 5, 6, 7, 8, 9, and 10, had 10, 20, 35, 50, 80, and 100% of males mature, and 0, 10, 20, 35, 50, 100% of females mature.

On the Campbell Plateau (Figure 7), the data indicated that the youngest mature fish of both sexes were age 5 years (57 and 60 cm for males and females, respectively), and that immature males older than 9 years (79 cm) and immature females older than 10 years (87 cm) were rare. Lengths at 50% maturity were about 70 cm for males and 85 cm for females, corresponding to ages of 7 and 8 years, respectively. Hence, ogives were estimated which, at ages 5, 6, 7, 8, 9, and 10, had 10, 30, 50, 80, 100, and 100% of males mature, and 5, 10, 30, 50, 80, and 100% of females mature.

Insufficient gonad stage data are available from ling on the Bounty Platform to estimate maturity ogives for this stock. The growth rates of ling on the Bounty Platform are comparable to those of Chatham Rise fish, so the maturity ogives calculated for LIN 3&4 were also applied to the LIN 6B stock.

Most of the ling catch from LIN 7WC is taken as a bycatch of the trawl fishery for hoki and hake off WCSI. This fishery is concentrated in what appears to be the ling spawning season in this area, but it is assumed that at least some of the younger fish caught are not mature. Consequently, the maturity ogive for LIN 7WC is based on the trawl fishing selectivity ogive, modified assuming that 50% of ling in the trawl catch aged 3 to 5, and 90% of ling aged 6 to 10, are mature.

3.4 CPUE analyses

Full details of the analyses of CPUE data from longline fisheries in LIN 3&4, LIN 5&6, and LIN 6B were given by Harley (1999). An update of the existing longline series from LIN 7WC is presented in Appendix A. An examination of a possible series derived from trawl bycatch of ling off WCSI is also reported in Appendix A. The trawl bycatch fishery does not appear to provide a useful series of relative abundance indices.

CPUE indices used in current stock assessments are listed in Table 4.

3.5 Updated productivity parameters

Von Bertalanffy parameters for ling from LIN 7WC were calculated from a sample of only 371 fish collected in 1991 (Horn 1993). A considerable quantity of additional age data are now available (samples from 1994 to 1998), so the growth parameters for this stock were updated using all available data (Table 5). All aged fish were taken as bycatch in trawl fisheries off the west coast of the South Island. No length or age data are available from line-caught ling, or from ling in the Cook Strait section of LIN 7.

Length-weight parameters were updated using the extensive data sets now available from research trawl surveys of the Chatham Rise (LIN 3&4), and the Campbell Plateau including the Stewart-Snares shelf and Puysegur Bank (LIN 5&6). The new parameters, by stock and sex, are presented in Table 6. Sample sizes were over 2500 per sex in LIN 3&4, and over 4500 per sex in LIN 5&6.

There are insufficient data to calculate a length-weight relationship for Bounty Platform or WCSI ling. Consequently, parameters for LIN 6B and LIN 7WC were assumed to be the same as those for LIN 3&4, as ling from these three areas have comparable maximum sizes and growth rates (*see* Horn 1993).

3.6 Estimation of fishing selectivity ogives

It has been shown above that significant quantities of the commercial landings from LIN 3&4 and LIN 5&6 are taken by both longline and trawl (*see* Figure 2). It is also apparent (*see* Section 3.1) that the selectivity of these two fishing methods differs (although catches from trawl surveys are likely to contain a greater proportion of smaller fish than commercial trawl landings because of the use of a 60 mm mesh codend).

The Middle Depth Species Fisheries Assessment Working Group considered that the use of a single selectivity ogive for a dual fishery was inappropriate. Subsequently, the MIAEL estimation procedure was modified so that catch histories and selectivities attributable to different fishing methods could be used separately. Hence, selectivity ogives (by sex) were derived, where possible, for each major fishing method from each stock to be modelled.

This was done for each stock as follows.

1. All raw length-frequency data collected by observers were extracted and sorted by method and sex into percent frequency distributions. It was assumed that the distribution of measured fish approximated the distribution of the entire commercial catch (for that sex and method).
2. For each sex and method, length at 100% selectivity (generally the length at the peak of the distribution) was identified.
3. For each sex and method, a cumulative frequency curve was created up to the length of 100% selectivity.
4. Based on known length-at-age (from the von Bertalanffy equations), the selectivity at each age was read off the cumulative frequency curve.
5. The proportions of fish of each sex taken by a particular method were obtained from the observer data. The calculated selectivities for females were then scaled by the ratio of the total number of female fish caught per male. This standardised the selectivity of males to 1 at the estimated length (age) at 100% selectivity, but allowed the maximum selectivity for females to be greater or less than 1 at the estimated 100% selectivity length for females. (This scaling assumes that the numbers of male and female recruits in the population are equal.)

Plots of estimated selectivity at age for various areas and fisheries are shown in Figure 8. The ogives used as model inputs (i.e., following scaling of the selectivity estimates for females) are listed in Table 7.

Alternative selectivity ogives were derived for the LIN 3&4 longline fishery from length-frequency data collected by the industry-run logbook scheme. The ogives were calculated as described above, and are shown in Figure 8 and Table 7.

4. STOCK ASSESSMENT

4.1 Model input data

Estimated catch histories for the four stocks are listed in Table 8. The split between the pre-spawning and spawning seasons from 1983 to 1999, by method, was based on reported estimated landings per month, pro-rated to equal total reported landings. Landings before 1983 were split into method and season based on perceived fishing patterns at the time. Any inaccuracies in the allocation of pre-1983 catches to method or season could influence the assessment, particularly if catches from these early years define the B_{min} or B_{max} bounds. This occurs only for LIN 3&4, where the 1977 catch defines B_{min}.

Estimates of biological parameters and of model parameters used in the assessments are given in Tables 6 and 9 respectively. Note that the maturity ogives listed in Table 9 are not the cumulative ogive values (*see* Section 3.3), but are the change in ogive over the previous value.

A series of longline CPUE indices was available for each modelled stock (*see* Table 4). A. series of trawl survey indices were available for LIN 3&4 and LIN 5&6 (Table 10). Two of the trawl survey series (the January Chatham Rise series, and the autumn Southern Plateau series) were available as numbers-at-age. For LIN 7WC, three years of commercial trawl proportion-at-age data were available. The *c.v.*s assigned in the model to each relative abundance series are listed in Table 11.

4.2 Model procedure

Each ling stock was modelled using the least squares and single-stock MIAEL estimation techniques of Cordue (1993, 1995, 1998). The model year for each stock was set to begin at the start of the pre-spawning season (*see* Section 3.2 for season details). The MIAEL model uses a two-stage process. All input data are used in the first stage to obtain least squares estimates of year class strength (YCS), trawl survey vulnerability ogives, and fits to the series of relative abundance indices. The second stage of the procedure produces the least squares and MIAEL estimates of biomass.

Base case model runs were conducted for each stock. The only sensitivity tested was an alternative fishing selectivity ogive for the longline fishery in LIN 3&4 (*see* Section 3.6 above). The LIN 3&4 stock was also assessed using an alternative approach (*see* Section 4.7 below).

A series of sensitivity tests was carried out (and reported) when the LIN 3&4 and LIN 5&6 stocks were initially assessed using the single fishery MIAEL model. The additional work requested under a project variation was primarily aimed at comparing results from base case runs of two different modelling methods.

4.3 Year class strengths and ogives

Year class strengths were able to be estimated for three of the assessed stocks (Table 12). In general, the differences between extreme values for any stock are about one order of magnitude. YCS for LIN 3&4 are likely to be the best estimated of the three series as they are based on data from eight trawl surveys. For LIN 5&6, data were available from four trawl surveys, but only three years of commercial proportion-at-age data were used to estimate LIN 7WC year class strengths.

For LIN 3&4, a series of relatively strong year classes was spawned in the mid to late 1970s. Recruitment success was then below average for about 13 years. Recent trawl surveys indicate that some relatively strong year classes were spawned in the early to mid 1990s. For LIN 5&6, recruitment appeared to be relatively constant throughout the 1970s and 1980s, but a series of relatively strong year classes were spawned in the early 1990s.

Trawl survey selectivity ogives, derived from the number-at-age data, are available from two of the survey series (Figure 9). There are marked differences in ogive shape between the two areas.

4.4 MIAEL estimates of biomass

Estimates of mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 1999–2000 ($B_{mid2000}$), and 2000–01 ($B_{mid2001}$), and estimates of 2001 beginning of year total biomass ($B_{beg2001}$) were obtained for all stocks (Table 13).

LIN 3&4

The B_{min} bound for this stock is defined by catches in 1977, which are not well known. However, the least squares estimate of B_0 is not near the lower bound, so this uncertainty is likely to have little effect on the assessment.

The best estimate of B_0 (89 060 t) is lower than estimates from previous assessments (Horn & Cordue 1996, Horn 1997). The estimate has a reasonable performance index. Current biomass ($B_{mid2000}$) is estimated to be only 25% of B_0 with a performance index of 58%. The biomass trajectory is shown in Figure 10.

The base case model fit to the CPUE indices is good (Figure 11). The model fit to the numbers-at-age data from the trawl survey series is generally good (Figure 12), although the year class strengths since 1994 are not estimated, so the relatively high number of young fish caught in the 1999 survey is not well predicted.

The use of an alternative fishing selectivity ogive for the longline fishery made only slight changes to all the biomass estimates (*see* Table 13). None of the point estimates changed by more than 3%.

LIN 5&6

The best estimate of B_0 (121 160 t) is slightly lower than estimates from previous assessments (Horn & Cordue 1996, Horn 1997). Current biomass ($B_{mid2000}$) is estimated to be 62% of B_0 with a performance index of 66%. The biomass trajectory is shown in Figure 10.

The base case model fit to the CPUE indices is reasonable, although this series does not exhibit a clear trend (*see* Figure 11). The model fit to the numbers-at-age data from the autumn trawl survey series is only mediocre, and the trawl q is very high (*see* Figure 13). The reduction in the size of the plus group is very dramatic over the 6 years covered by the survey series.

The worst fits to the numbers-at-age data appear to be associated with fish aged 6 to 9 years. The distributions in Figure 13 suggest that fish are fully selected by about age 8, yet the estimated survey selectivity ogives have 8 year old fish only about 30% selected (*see* Figure 9). This problem is linked to the "broken stick" nature of the catch curve for ling caught in trawl surveys, described by Horn (2000). On the Southern Plateau, the "mean" catch curve declined only slightly from ages 6 to 12, but quite steeply from age 13 (which is where the model estimates full selectivity). Also, the commercial trawl selectivity ogive for females (based on length-frequency data) is quite different to the female trawl survey selectivity ogive.

So despite the relatively high performance indices for the biomass estimates, inconsistencies in the model fits to some data sets and uncertainties in the selectivity ogives emphasise the overall uncertainty of this assessment.

LIN 6B

This is the first estimate of B_0 for LIN 6B, and is 8370 t. Current biomass ($B_{mid2000}$) is estimated to be 35% of B_0 with a performance index of 68%. The biomass trajectory is shown in Figure 10.

The base case model fit to the CPUE indices is generally good, although it is unable to fit the steep early decline (*see* Figure 11). This is the only index of relative abundance available for this stock.

LIN 7WC

The best estimate of B_0 (42 910 t) is slightly higher than the estimate by Horn & Ballara (1999). The estimate has wide bounds and a low performance index, so should be considered as highly uncertain. Current biomass ($B_{mid2000}$) is estimated to be 28% of B_0. The performance index is low (4%), and the bounds around the estimated biomass are wide (range 13–91%), so the uncertainty associated with this assessment is high. The biomass trajectory is shown in Figure 10.

The model fit to the longline CPUE indices is good (*see* Figure 11). Most fits to the commercial trawl proportion-at-age data (Figure 14) are good. Differences between observed and expected values from the 1997 sample are caused by the model predicting that about 53% of the trawl catch will be male fish, compared with an observed level that year of 71%. The trawl selectivity ogive was based on a substantial quantity of length frequency data from 1989 to 1998 that indicates the ratio of males to females in the catch is about 1:1. The next assessment of LIN 7WC will have trawl catch-at-age data available from 7 years (1991, 1994–1999). This should enable a more precise estimation of year class strengths. Also, the trawl selectivity will be estimated in the model from the catch-at-age data, rather than outside the model from length frequency data.

4.5 Yield estimates

MCY was estimated from MCY = p.B_0, where p is determined for each stock using the method of Francis (1992) such that the biomass does not drop below 20% B_0 more than 10% of the time. CAY was estimated from the MIAEL estimates of current projected total biomass ($B_{beg2001}$) using the method of Francis (1992). Estimates of MCY and CAY for each stock are given in Table 14. CAY was not estimated for LIN 7WC because of the high uncertainty surrounding the estimate of current biomass for this stock.

4.6 Biomass projections for LIN 3&4

For LIN 3&4, projections were carried out to determine what level of catch would be required to allow the stock to stabilise or rebuild. Catch in 2000 was assumed to be 7200 t, caught in the proportions shown in Table 8. In 2001 and 2002, a range of catch levels from 3000 t to 8500 t (in 500 t intervals) was explored, with proportions by season and method as for 2000.

MIAEL estimates of $B_{mid2002}/B_0$ under the various scenarios are listed in Table 15. The results indicate that an annual catch level of about 4000 t is necessary to ensure that the stock does not decline any further in the short term (i.e., current biomass does not decline below the $B_{mid2000}$ level of 25% B_0).

4.7 Alternative assessment of LIN 3&4

As an alternative to the MIAEL procedure, a Bayesian age-structured model was fitted to the LIN3&4 stock. The model was fitted to CPUE, trawl survey catch-at-age, and survey biomass. Mean recruitment, year class strength, survey selectivity at age, and q for the survey and CPUE series were estimated. Methods and results of this analysis are described in Appendix B. Estimated year class strengths are listed in Table 12. Above-average recruitment in the mid to late 1970s and below-average recruitment throughout the 1980s was indicated, which is similar to the conclusions from the MIAEL analysis. The main difference between the Bayesian and MIAEL assessments is in the estimated trawl survey selectivity. The Bayesian model has all fish fully selected by age 5, compared with age 13 for the MIAEL model. However, the overall results of the two assessments are similar.

The posterior mode point estimate (PME) from the base case model for B_0 was 79 900 t, and the ratio of B_{2000}/B_0 was 0.34. The posterior mean estimate of B_{2000}/B_0 was 0.41. A sensitivity run using the alternative longline selectivity ogive from industry logbook data (*see* Table 7) resulted in a slightly more optimistic assessment, i.e., the PME ratio of B_{2000}/B_0 was 0.39.

Projections to 2002 were performed using the base case model, and assuming constant annual catches in 2000–2002 of 3000 to 8500 t (in 500 t steps). The mean point estimates of B_{2002} are lower than B_{2000} at all tested future catch levels. The probability that the stock would be below 30% B_0 by 2002 ranged from 0.12 at the 3000 t catch level, to 0.39 when 8500 t was taken annually.

4.8 Management implications

LIN 3&4

Current stock size from the MIAEL model is estimated at 25%B_0 (range 6–68%) which is just below the B_{MAY} of 27%. The Bayesian model estimated current stock size at 41%B_0 (90% confidence interval 28–57%). The stock has been decreasing since 1990 when catch levels increased. Both models indicate that catches at recent levels (7000–8000 t), or at the current TACC level (8530 t), will cause the stock to decline further. Current TACCs and recent catch levels for LIN 3 and 4 are higher than the point estimate of CAY (6260 t). The MIAEL modelling indicated that an annual catch of about 4000 t appears to be the highest catch level that will not cause the biomass to decline further. The Bayesian model indicated that the stock would continue to decline at all tested future catch levels.

LIN 5&6

Fishstocks LIN 5 and 6 (but excluding fish on the Bounty Platform) are probably only moderately fished and current stock sizes are estimated to be well above B_{MAY}. Recent catch levels and current TACCs are probably sustainable in the medium term; a comparison of biomass estimates for 2000 and 2001 indicates that stock size is increasing. The stock declined during the early 1990s as the older part of the population was fished down, but has been rebuilding since about 1997 as a series of relatively strong year classes spawned in 1990–92 appear to have been recruiting into the fishery. However, the strengths of the recent year classes are uncertain as they do not fit well in the model and would be correlated with any inaccuracies in the commercial trawl and survey selectivities.

Catches at current levels, or at the TACCs, should allow the stock to move towards a size that will support the MSY. Current catch levels for LIN 5&6 are about at the level of the MCY. There is much uncertainty in this assessment.

LIN 6B

The ling fishery on the Bounty Platform (part of the LIN 6 Fishstock) is probably fully developed and current stock sizes are estimated to be just above B_{MAY}. Catch levels over the past 5 years have averaged about 500 t. Catches at this level appear to be sustainable, at least in the short term. There is no separate TACC for this stock, but current catch levels are slightly lower than the point estimate of CAY. The assessment presented here is largely driven by the longline CPUE indices, which constitutes the only estimate of relative abundance for this stock.

LIN 7WC

This assessment relates only to the WCSI section of Fishstock LIN 7. The assessment presented here is largely driven by the longline CPUE indices, which constitutes the only estimate of relative abundance for this stock.

Model results suggest that the LIN 7WC stock may be below the level that would support the MSY, and could decline further at the current catch level or at a catch level equal to the current TAC. However, the wide bounds around the estimates and poor performance indices highlight the high level of uncertainty about this assessment.

It is not known if recent landings and the current TACCs are sustainable in the long term, or are at levels which will allow the stocks to move towards a size that will support the MSY. The TACC for LIN 7 has been significantly over-caught since 1988–89. Overruns have often been in the order of 30–

50% of the TACC. In all but one of the years since 1988–89, reported landings have been higher than the estimate of MCY (2620 t).

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Table 1: Reported landings (t) from 1975 to 1987–88. Data from 1975 to 1983 from MAF; data from 1983–84 to 1985–86 from FSU; data from 1986–87 to 1987–88 from QMS

	New Zealand			Foreign licensed					Grand
				Longline	Trawl				
Fishing Year	Domestic	Chartered	Total	(Japan + Korea)	Japan	Korea	USSR	Total	total
1975*	486	0	486	9 269	2 180	0	0	11 499	11 935
1976*	447	0	447	19 381	5 108	0	1 300	25 789	26 236
1977*	549	0	549	28 633	5 014	200	700	34 547	35 096
1978–79#	657*	24	681	8 904	3 151	133	452	12 640	13 321
1979–80#	915*	2 598	3 513	3 501	3 856	226	245	7 828	11 341
1980–81#	1 028*	–	–	–	–	–	–	–	–
1981–82#	1 581*	2 423	4 004	0	2 087	56	247	2 391	6 395
1982–83#	2 135*	2 501	4 636	0	1 256	27	40	1 322	5 958
1983†	2 695*	1 523	4 218	0	982	33	48	1 063	5 281
1983–84§	2 705	2 500	5 205	0	2 145	173	174	2 491	7 696
1984–85§	2 646	2 166	4 812	0	1 934	77	130	2 141	6 953
1985–86§	2 126	2 948	5 074	0	2 050	48	33	2 131	7 205
1986–87§	2 469	3 177	5 646	0	1 261	13	21	1 294	6 940
1987–88§	2 212	5 030	7 242	0	624	27	8	659	7 901

* Calendar years (1978 to 1983 for domestic vessels only).
\# April 1 to March 31.
† April 1 to Sept 30.
§ Oct 1 to Sept 30.

Table 2: Reported landings (t) of ling by Fishstock from 1983–84 to 1998–99 and actual TACs (t) from 1986–87 to 1998–99. Estimated landings for LIN 7 from 1987–88 to 1992–93 include an adjustment for ling bycatch of hoki trawlers, based on records from vessels carrying observers

Fishstock	LIN 1		LIN 2		LIN 3		LIN 4		LIN 5	
QMA (s)	1 & 9		2		3		4		5	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1983–84*	141	–	594	–	1 306	–	352	–	2 605	–
1984–85*	94	–	391	–	1 067	–	356	–	1 824	–
1985–86*	88	–	316	–	1 243	–	280	–	2 089	–
1986–87#	77	200	254	910	1 311	1 850	465	4 300	1 859	2 500
1987–88#	68	237	124	918	1 562	1 909	280	4 400	2 213	2 506
1988–89#	216	237	570	955	1 665	1 917	232	4 400	2 375	2 506
1989–90#	121	265	736	977	1 876	2 137	587	4 401	2 277	2 706
1990–91#	210	265	951	977	2 419	2 160	2 372	4 401	2 285	2 706
1991–92#	241	265	818	977	2 430	2 160	4 716	4 401	3 863	2 706
1992–93#	253	265	944	980	2 246	2 162	4 100	4 401	2 546	2 706
1993–94#	241	265	779	980	2 171	2 167	3 920	4 401	2 460	2 706
1994–95#	261	265	848	980	2 679	2 810	5 072	5 720	2 557	3 001
1995–96#	245	265	1 042	980	2 956	2 810	4 632	5 720	3 137	3 001
1996–97#	313	265	1 187	982	2 963	2 810	4 087	5 720	3 438	3 001
1997–98#	300	265	1 031	982	2 745	2 810	5 188	5 720	3 312	3 001
1998–99#	208	265	1 070	982	2 705	2 810	4 396	5 720	2 942	3 001

Fishstock	LIN 6		LIN 7			LIN 10		Total	
QMA (s)	6		7 & 8			10			
	Landings	TAC	Reported Landings	Estimated Landings	TAC	Landings	TAC	Landings§	TAC
1983–84*	869	–	1 552	–	–	0	–	7 696	–
1984–85*	1 283	–	1 705	–	–	0	–	6 953	–
1985–86*	1 489	–	1 458	–	–	0	–	7 205	–
1986–87#	956	7 000	1 851	–	1 960	0	10	6 940	18 730
1987–88#	1 710	7 000	1 853	1 777	2 008	0	10	7 901	18 988
1988–89#	340	7 000	2 956	2 844	2 150	0	10	8 404	19 175
1989–90#	935	7 000	2 452	3 171	2 176	0	10	9 028	19 672
1990–91#	2 738	7 000	2 531	3 149	2 192	<1	10	13 506	19 711
1991–92#	3 459	7 000	2 251	2 728	2 192	0	10	17 778	19 711
1992–93#	6 501	7 000	2 475	2 817	2 212	<1	10	19 065	19 737
1993–94#	4 249	7 000	2 142	–	2 213	0	10	15 961	19 741
1994–95#	5 477	7 100	2 946	–	2 225	0	10	19 841	22 111
1995–96#	6 314	7 100	3 102	–	2 225	0	10	21 428	22 111
1996–97#	7 510	7 100	3 024	–	2 225	0	10	22 522	22 113
1997–98#	7 327	7 100	2 980	–	2 225	0	10	22 884	22 113
1998–99#	6 112	7 100	3 345	–	2 225	0	10	20 793	22 113

* FSU data.
\# QMS data.
§ Includes landings from unknown areas before 1986–87, and areas outside the EEZ since 1995–96.

Table 3: Proportions of all female ling measured by observers that were in spawning condition (i.e., had some hyaline eggs present, were running ripe, or spent), by biological stock and month. *N*, number measured; %, percentage in spawning condition; –, no data available

	LIN 3&4		LIN 5&6		LIN 6B		LIN 7	
Month	*N*	%	*N*	%	*N*	%	*N*	%
January	2 067	0.1	413	0.0	8	100.0	5	0.0
February	2 057	0.1	782	0.8	–		7	0.0
March	1 536	0.4	1 858	0.3	–		–	
April	1 752	0.0	2 735	0.0	–		–	
May	1 255	0.6	269	0.0	–		–	
June	1 554	3.3	46	47.8	–		–	
July	314	4.8	534	3.0	3	0.0	2 267	9.3
August	25	4.0	249	8.0	352	5.4	2 093	23.0
September	1 060	43.8	2 331	6.2	114	16.7	538	32.3
October	2 036	24.9	1 001	19.2	–		–	
November	1 886	5.3	1 692	28.1	307	27.7	–	
December	894	0.3	911	1.6	429	77.6	–	

Table 4: Standardised CPUE indices for ling longline fisheries

Fishstock	LIN 3&4	LIN 5&6	LIN 6B	LIN 7WC
Area	Chatham Rise	Southern Plateau	Bounty Platform	WCSI
Year				
1990	1.000	–	–	1.000
1991	0.758	1.000	–	1.078
1992	0.845	1.259	1.000	1.194
1993	0.694	1.283	0.839	0.894
1994	0.687	0.980	0.524	0.921
1995	0.661	1.323	0.380	0.888
1996	0.428	1.052	0.538	0.590
1997	0.326	1.168	0.434	0.756
1998	0.318	1.008	0.460	0.793

Table 5: Von Bertalanffy parameters (with 95% confidence intervals), by sex, for ling from the west coast of the South Island (LIN 7WC)

Sex	n	L_∞		k		t_0	
Male	1 612	155.7	(150.3–161.0)	0.071	(0.064–0.077)	–1.95	(–2.41 to –1.49)
Female	1 561	170.5	(165.4–175.7)	0.076	(0.070–0.083)	–0.83	(–1.19 to –0.47)

Table 6: Biological parameters used in the ling assessments

Fishstock	Estimate	
1. Natural mortality (M)		
All	Female	Male
	0.18	0.18

2. Weight = a (length)^b (Weight in g, length in cm total length)

	Female		Male	
	a	*b*	*a*	*b*
LIN 3&4	0.00114	3.318	0.00100	3.354
LIN 5&6	0.00128	3.303	0.00208	3.190
LIN 6B	0.00114	3.318	0.00100	3.354
LIN 7	0.00114	3.318	0.00100	3.354

3. von Bertalanffy growth parameters

	Female			Male		
	k	t_0	L_∞	k	t_0	L_∞
LIN 3&4	0.076	–1.05	160.1	0.108	–1.24	119.0
LIN 5&6	0.113	–0.67	125.7	0.194	0.16	95.1
LIN 6B	0.079	–0.70	158.4	0.128	0.28	123.2
LIN 7WC	0.076	–0.83	170.5	0.071	–1.95	155.7

Table 7: Estimated fishing selectivities at age, by sex, for ling from various stocks and fishing methods. All ogives were derived from scientific observer data, except for one of the LIN 3&4 longline ogives which was derived from industry logbook data. M, male selectivity; F, female selectivity; F.sca, selectivity for females scaled by the ratio of females to males caught. Data in the M and F.sca columns were incorporated in the stock assessment model as home ground selectivities for the specific fishing method

Age	M	F	F.sca	M	F	F.sca	M	F	F.sca
	LIN 3&4 (Trawl)			LIN 3&4 (Longline)			LIN 3&4 (Line: Logbook)		
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0.01	0.01	0.01	0	0	0	0	0	0
4	0.04	0.05	0.05	0	0	0	0	0	0
5	0.11	0.15	0.15	0	0	0	0.007	0.005	0.006
6	0.23	0.28	0.28	0.003	0.01	0.01	0.017	0.008	0.01
7	0.36	0.48	0.48	0.01	0.03	0.04	0.04	0.018	0.02
8	0.54	0.72	0.72	0.02	0.10	0.14	0.09	0.05	0.06
9	0.74	0.95	0.95	0.09	0.20	0.27	0.20	0.10	0.12
10	0.91	1	1	0.19	0.48	0.68	0.30	0.23	0.27
11	1	1	1	0.32	0.82	1.14	0.47	0.45	0.54
12	1	1	1	0.52	1	1.38	0.70	0.74	0.88
13	1	1	1	0.74	1	1.38	1	1	1.19
14	1	1	1	1	1	1.38	1	1	1.19
	LIN 5&6 (Trawl)			LIN 5&6 (Longline)					
1	0	0	0	0	0	0			
2	0	0	0	0	0	0			
3	0.03	0.07	0.08	0	0	0			
4	0.13	0.19	0.21	0.001	0.0006	0.002			
5	0.20	0.30	0.34	0.009	0.0096	0.03			
6	0.27	0.41	0.46	0.07	0.056	0.15			
7	0.36	0.51	0.58	0.21	0.13	0.36			
8	0.45	0.68	0.77	0.34	0.27	0.70			
9	0.60	0.90	1.01	0.50	0.45	1.21			
10	0.75	1	1.13	0.65	0.67	1.82			
11	0.84	1	1.13	0.76	0.92	2.51			
12	0.95	1	1.13	0.88	1	2.72			
13	1	1	1.13	1	1	2.72			
14	1	1	1.13	1	1	2.72			
	LIN 7 (Trawl)			LIN 6B (Longline)					
1	0	0	0	0	0	0			
2	0	0	0	0	0	0			
3	0.003	0.005	0.004	0	0	0			
4	0.01	0.02	0.019	0	0	0			
5	0.07	0.08	0.07	0	0	0			
6	0.17	0.24	0.20	0.01	0.004	0.007			
7	0.30	0.41	0.35	0.02	0.01	0.017			
8	0.49	0.58	0.50	0.11	0.06	0.10			
9	0.74	0.79	0.67	0.21	0.16	0.27			
10	1	1	0.85	0.38	0.25	0.42			
11	1	1	0.85	0.51	0.47	0.78			
12	1	1	0.85	0.68	0.73	1.21			
13	1	1	0.85	0.79	1	1.66			
14	1	1	0.85	1	1	1.66			

Table 8: Catch histories (t) for LIN 3&4 (Chatham Rise), LIN 5&6 (Southern Plateau excluding the Bounty Platform), LIN 6B (Bounty Platform), and LIN 7WC (WCSI section of LIN 7). Landings have been separated by fishing method, and by pre-spawning (Pre) and spawning (Spn) season. The last two values in each column are assumed, and were allocated to method and season based on mean proportions over the years 1995 to 1999. For LIN 6B, all landings up to 1990 were taken by trawl, and over 98% of all landings after 1990 were taken by line

Year	LIN 3&4				LIN 5&6				LIN 6B		LIN 7WC			
	Trawl		Line		Trawl		Line		Line		Trawl		Line	
	Pre	Spn	Pre	Spn	Pre	Spn	Pre	Spn	Pre	Spn	Pre	Spn	Pre	Spn
1972	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1973	188	62	0	0	313	187	0	0	0	0	20	65	10	10
1974	287	95	0	0	700	420	0	0	0	0	44	100	20	20
1975	610	343	5148	3291	468	432	118	192	0	0	101	300	250	550
1976	1344	756	10636	6800	1769	1633	190	309	0	0	115	450	800	1300
1977	1315	740	14636	9358	1612	1488	301	490	0	0	115	600	1700	2600
1978	896	504	4622	2955	1011	934	494	806	10	0	60	240	123	200
1979	1523	857	501	320	1928	1779	1022	1668	0	0	89	450	100	260
1980	1020	320	259	101	3250	1950	0	0	0	0	90	450	80	225
1981	520	153	107	53	2767	1660	0	0	10	0	80	412	100	200
1982	905	278	240	99	1501	901	0	0	0	0	125	550	200	200
1983	799	411	254	72	1905	873	5	1	10	0	170	870	360	350
1984	963	403	307	99	2549	654	2	0	6	0	76	848	302	293
1985	830	521	296	105	2629	1851	25	3	2	0	185	971	111	191
1986	859	635	256	119	1310	1872	2	0	0	0	112	970	172	190
1987	857	456	209	97	1192	2770	0	0	0	0	147	958	178	192
1988	1107	529	234	56	961	1104	6	0	0	0	183	1245	164	127
1989	856	541	371	117	1250	1673	10	2	2	7	245	1714	187	183
1990	1056	878	362	167	1556	1643	9	4	11	0	328	1877	206	193
1991	1613	950	1153	1075	2055	2479	392	97	22	150	271	1892	202	162
1992	2580	871	3100	595	3709	2528	566	518	1009	421	127	1504	366	295
1993	1744	631	2233	1738	5099	2236	1238	474	828	747	163	1446	355	361
1994	1113	820	2894	1265	2331	3125	770	486	714	161	116	1104	418	290
1995	1259	963	3303	2227	1949	3399	2355	338	338	49	243	1540	536	278
1996	1673	1052	3047	1816	2518	4251	2153	531	358	230	216	1605	509	234
1997	1661	1342	2223	1824	2706	4217	3412	614	202	131	276	1453	542	236
1998	2682	2025	1292	1935	3172	2860	4032	581	358	211	382	1459	527	200
1999	1892	1390	2064	1754	2381	3212	2721	489	425	346	310	1775	557	198
2000	1900	1400	2100	1800	2400	3200	2700	500	330	200	300	1700	550	200
2001	1900	1400	2100	1800	2400	3200	2700	500	330	200	300	1700	550	200

Table 9: Model input parameters for the ling assessments. For fishing selectivity ogives, *see* Table 7

Parameter	Estimate
Steepness	0.9
Recruitment variability	0.6
Proportion spawning	0.9
Spawning season length	0.25
Ageing error	± 15% for ages ≥ 3

Stock	3&4	5&6	6B	7
Maximum exploitation on home ground ($r_{hm\text{-}max}$)	0.6	0.6	0.6	0.5
Maximum exploitation on spawning ground ($r_{sp\text{-}max}$)	0.6	0.6	0.6	0.5
Minimum exploitation at highest catch on home ground ($r_{hm\text{-}mmx}$)	0.05	0.02	0.02	0.01
Minimum exploitation at highest catch on spawning ground ($r_{hm\text{-}mmx}$)	0.05	0.02	0.02	0.01

Maturity ogive	Age	3	4	5	6	7	8	9	10	11
LIN 3&4, 6B	Male	0.0	0.0	0.100	0.11	0.19	0.23	0.60	1.00	1.00
	Female	0.0	0.0	0.001	0.10	0.11	0.19	0.23	1.00	1.00
LIN 5&6	Male	0.0	0.0	0.10	0.22	0.29	0.60	1.00	1.00	1.00
	Female	0.0	0.0	0.05	0.05	0.22	0.29	0.60	1.00	1.00
LIN 7	Male	0.002	0.004	0.03	0.10	0.14	0.24	0.44	0.90	1.00
	Female	0.003	0.009	0.03	0.15	0.21	0.26	0.46	0.90	1.00

Table 10: Biomass indices (t) from trawl surveys, and estimated coefficients of variation (*c.v.*)

Fishstock	Area	Vessel	Trip code	Date	Biomass	*c.v.* (%)
LIN 3&4	Chatham Rise	*Tangaroa*	TAN9106	Jan-Feb 1992	8 930	5.8
			TAN9212	Jan-Feb 1993	9 360	7.9
			TAN9401	Jan 1994	10 130	6.5
			TAN9501	Jan 1995	7 360	7.9
			TAN9601	Jan 1996	8 430	8.2
			TAN9701	Jan 1997	8 540	9.8
			TAN9801	Jan 1998	7 313	8.0
			TAN9901	Jan 1999	10 310	16.1
			TAN0001	Jan 2000	8 350	7.8
LIN 5&6	Southern Plateau	*Amaltal Explorer*	AEX8902	Oct–Nov 1989	17 490	14.2
			AEX9002	Nov–Dec 1990	15 850	7.5
LIN 5&6	Southern Plateau	*Tangaroa*	TAN9105	Nov-Dec 1991	24 100	6.8
			TAN9211	Nov-Dec 1992	21 950	6.2
			TAN9310	Nov-Dec 1993	29 910	11.5
LIN 5&6	Southern Plateau	*Tangaroa*	TAN9204	Mar-Apr 1992	42 330	5.8
			TAN9304	Apr-May 1993	37 540	5.4
			TAN9605	Mar-Apr 1996	32 520	7.8
			TAN9805	Apr-May 1998	30 950	8.8

Table 11: Coefficients of variation (*c.v.*) applied in the model to the series of relative abundance indices

Fishstock	Data series	*c.v.* (%)
LIN 3&4	Trawl survey (*Tangaroa*, Jan)	25
	CPUE (longline)	35
LIN 5&6	Trawl survey (*Amaltal Explorer*, Nov)	35
	Trawl survey (*Tangaroa*, Nov–Dec)	25
	Trawl survey (*Tangaroa*, Apr)	25
	CPUE (longline)	35
LIN 6B	CPUE (longline)	35
LIN 7WC	CPUE (longline)	35
	Proportion-at-age (commercial trawl)	35

Table 12: Estimated year class strengths for LIN 3&4 from the Bayesian model, and for three ling stocks from MIAEL base case runs. YCS is assumed to be 1 in all years without estimates

	Bayesian			MIAEL
Year	LIN 3&4	LIN 3&4	LIN 5&6	LIN 7WC
1968	–	–	–	1.65
1969	–	2.85	0.13	1.28
1970	–	0.01	0.01	0.42
1971	–	0.67	1.42	0.71
1972	–	1.06	0.29	0.52
1973	0.91	0.87	0.56	0.66
1974	1.16	2.07	0.77	0.31
1975	1.11	0.88	0.75	0.35
1976	2.04	1.79	0.50	0.81
1977	1.68	1.27	0.78	0.79
1978	1.76	1.11	0.82	2.20
1979	1.58	1.22	0.62	1.52
1980	1.44	0.60	1.02	0.56
1981	1.32	0.60	1.06	1.18
1982	0.87	0.78	0.89	0.65
1983	0.69	0.81	0.94	0.96
1984	0.73	0.69	0.66	0.67
1985	0.83	0.55	0.92	1.41
1986	0.63	0.72	0.78	1.06
1987	0.52	0.86	0.76	0.74
1988	0.57	1.41	0.93	1.57
1989	0.75	0.67	1.05	1.65
1990	0.86	0.94	1.41	1.32
1991	0.44	0.61	1.72	–
1992	0.65	0.51	5.25	–
1993	0.39	1.42	–	–
1994	0.38	–	–	–
1995	0.29	–	–	–
1996	0.44	–	–	–
1997	3.44	–	–	–

Table 13: Least squares (LSQ) and best k estimates of biomass, and MIAEL estimates of p, biomass (MIAEL) and performance indices (Perf.) All model runs are base case, except for runs using an alternative longline fishing selectivity for LIN 3&4 (Alt LL sel). Biomass estimates and bounds are in tonnes for B_0 and B_{beg}, and expressed as a percentage of virgin biomass for B_{mid}

Estimate	Model run	Bounds ($B_{min} - B_{max}$)	LSQ	best k	p	MIAEL	Perf. (%)
LIN 3 & 4							
B_0	Base case	57 110 – 194 870	77 630	99 150	0.469	89 060	38.5
	Alt LL sel	56 890 – 194 870	78 380	99 130	0.473	89 310	39.0
$B_{mid2000}/B_0$	Base case	5.8 – 67.6	30.9	15.6	0.644	25.4	57.6
	Alt LL sel	5.9 – 67.4	31.6	15.7	0.653	26.1	58.6
$B_{mid2001}/B_0$	Base case	5.5 – 66.3	28.2	14.9	0.599	22.9	52.4
	Alt LL sel	5.7 – 66.1	29.0	15.3	0.575	23.2	49.9
$B_{beg2001}$	Base case	28 330 – 249 800	64 820	69 560	0.508	67 150	47.9
	Alt LL sel	28 330 – 249 170	66 150	69 500	0.512	67 780	48.4
LIN 5 & 6							
B_0	Base case	60 380 – 243 840	132 190	112 020	0.453	121 160	37.9
$B_{mid2000}/B_0$	Base case	19.2 – 90.5	71.7	37.8	0.719	62.2	66.0
$B_{mid2001}/B_0$	Base case	24.6 – 103.3	83.4	46.3	0.718	72.9	67.1
$B_{beg2001}$	Base case	53 590 – 474 980	225 600	131 800	0.489	177 670	46.4
LIN 6B							
B_0	Base case	4 250 – 31 160	6 250	9 800	0.403	8 370	35.9
$B_{mid2000}/B_0$	Base case	8.2 – 88.3	39.6	21.5	0.748	35.0	68.1
$B_{mid2001}/B_0$	Base case	5.6 – 88.1	38.5	16.5	0.728	32.5	65.0
$B_{beg2001}$	Base case	2 140 – 46 230	5 700	6 900	0.444	6 360	44.9
LIN 7WC							
B_0	Base case	21 940 – 114 440	21 940	44 830	0.084	42 910	2.8
$B_{mid2000}/B_0$	Base case	13.2 – 90.7	13.2	29.7	0.096	28.2	3.6
$B_{mid2001}/B_0$	Base case	14.4 – 92.4	14.4	31.7	0.089	30.2	3.1
$B_{beg2001}$	Base case	12 790 – 177 740	12 790	36 270	0.049	35 120	1.6

Table 14: MIAEL estimates and performance indices (Perf.) of B_{MCY} (as % of B_0), MCY (as % of B_0) and MCY (t), and B_{MAY} (as % of B_0), MAY (as % of B_0) and CAY (t)

Fishstock	B_{MCY} (%B_0)	MCY (% B_0)	MCY (t)	Range (t)	Perf. (%)
LIN 3&4	41.9	6.2	5 520	3 540 – 12 080	38.5
LIN 5&6	42.3	6.8	8 240	4 110 – 16 580	37.9
LIN 6B	42.1	6.3	530	270 – 1 960	35.9
LIN 7WC	42.0	6.1	2 620	1 340 – 6 980	2.8

Fishstock	B_{MAY} (%B_0)	MAY (% B_0)	CAY (t)	Range (t)	Perf. (%)
LIN 3&4	27.4	7.3	6 260	2 710 – 23 210	47.9
LIN 5&6	27.1	8.1	18 030	5 430 – 48 340	46.4
LIN6B	27.8	7.5	640	220 – 4 670	44.9

Table 15: Projected estimates of mid season spawning biomass in 2002 ($B_{mid2002}$) under a variety of catch history scenarios. Catch history to 2000 is as in Table 8. Annual catch (t) in each of years 2001 and 2002 is as listed under "Catch". Parameters listed are least squares (LSQ) and best k estimates of biomass, and MIAEL estimates of *p*, biomass (MIAEL) and performance indices (Perf.). Biomass estimates and bounds are in tonnes for B_0, and expressed as a percentage of virgin biomass for $B_{mid2002}$

	B_0		$B_{mid2002}$					
Catch	Bounds (B_{min}–B_{max})	LSQ	Bounds (B_{min}–B_{max})	LSQ	best k	*p*	MIAEL	Perf.
3 000	57 110 – 194 870	77 580	8.3 – 67.9	33.3	19.9	0.657	28.7	58.4
3 500	57 110 – 194 870	77 580	7.5 – 67.6	32.6	18.5	0.661	27.8	59.0
4 000	57 110 – 194 870	77 580	6.1 – 67.1	31.4	16.1	0.647	25.0	57.3
4 500	57 110 – 194 870	77 580	4.9 – 66.8	30.5	13.8	0.635	24.4	56.1
5 000	57 260 – 194 870	77 580	4.2 – 66.4	29.5	12.4	0.612	22.9	53.9
5 500	58 010 – 194 870	77 600	4.4 – 66.0	28.6	12.8	0.593	22.2	52.4
6 000	58 910 – 194 870	77 600	4.8 – 65.6	27.7	13.5	0.565	21.5	49.3
6 500	59 820 – 194 870	77 590	5.2 – 65.3	26.8	14.3	0.534	21.0	46.0
7 000	60 720 – 194 870	77 590	5.5 – 64.9	25.9	14.8	0.509	20.5	43.1
7 500	61 620 – 194 870	77 620	5.8 – 64.5	25.0	15.4	0.477	20.0	39.1
8 000	62 520 – 194 870	77 550	6.1 – 64.2	24.0	15.9	0.451	19.5	36.4
8 500	63 430 – 194 870	77 600	6.3 – 63.8	23.1	16.2	0.433	19.2	34.6

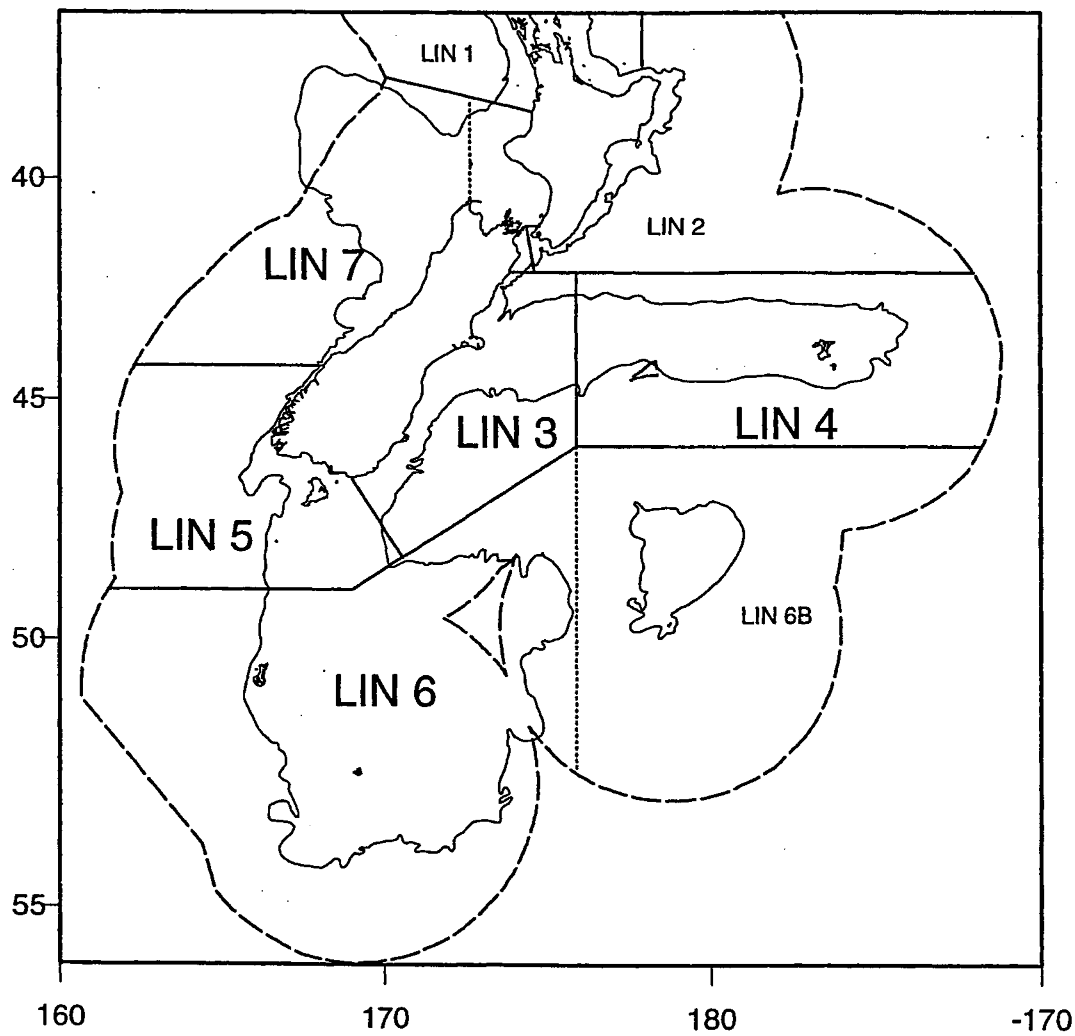

Figure 1: Area of Fishstocks LIN 3, 4, 5, 6, and 7. Adjacent ling fishstock areas are also labelled. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the Cook Strait section, are shown as a broken lines.

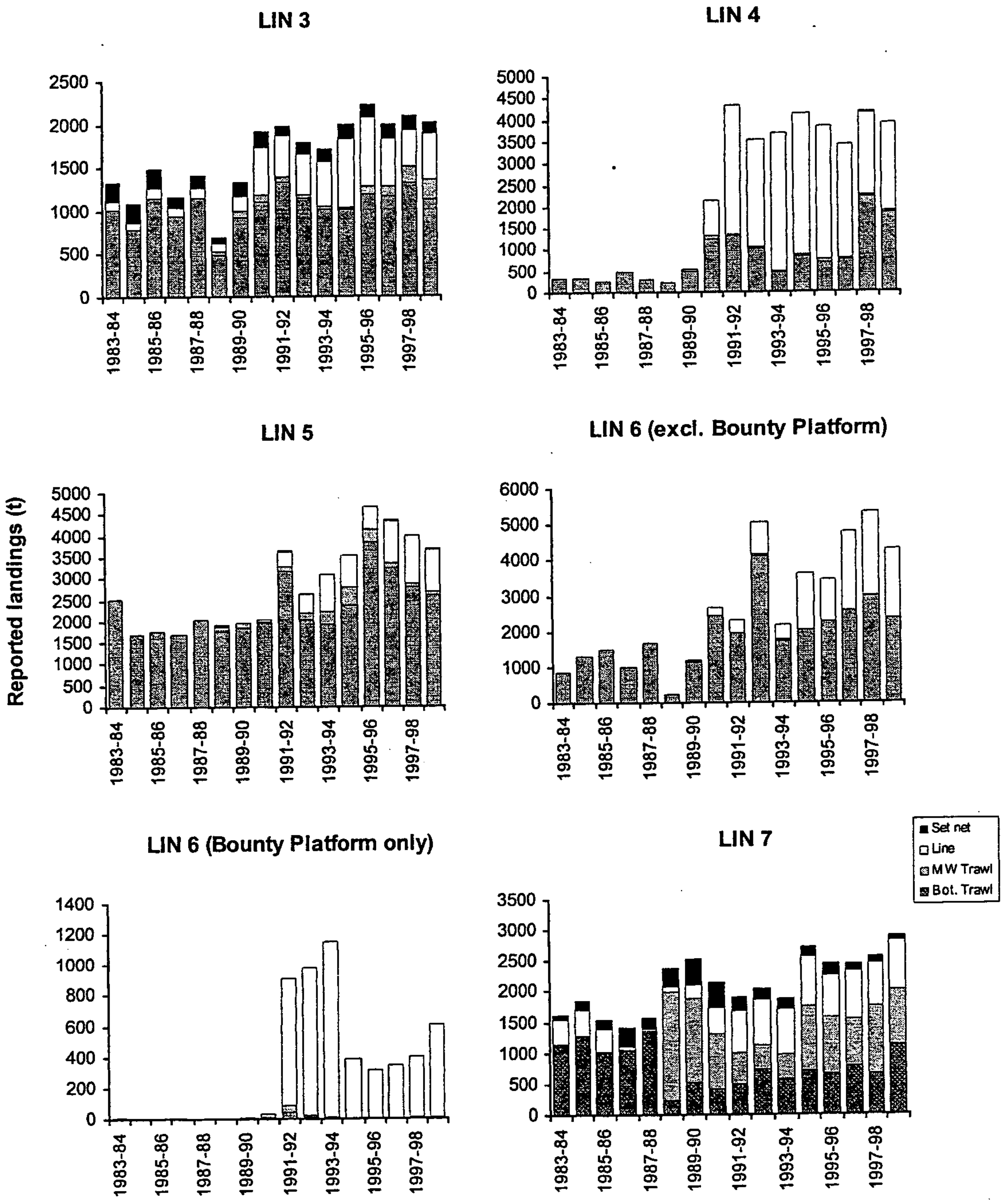

Figure 2: Reported estimated landings of ling in LIN 3, 4, 5, and 6, by fishing year and method. (MW, midwater; Bot., bottom)

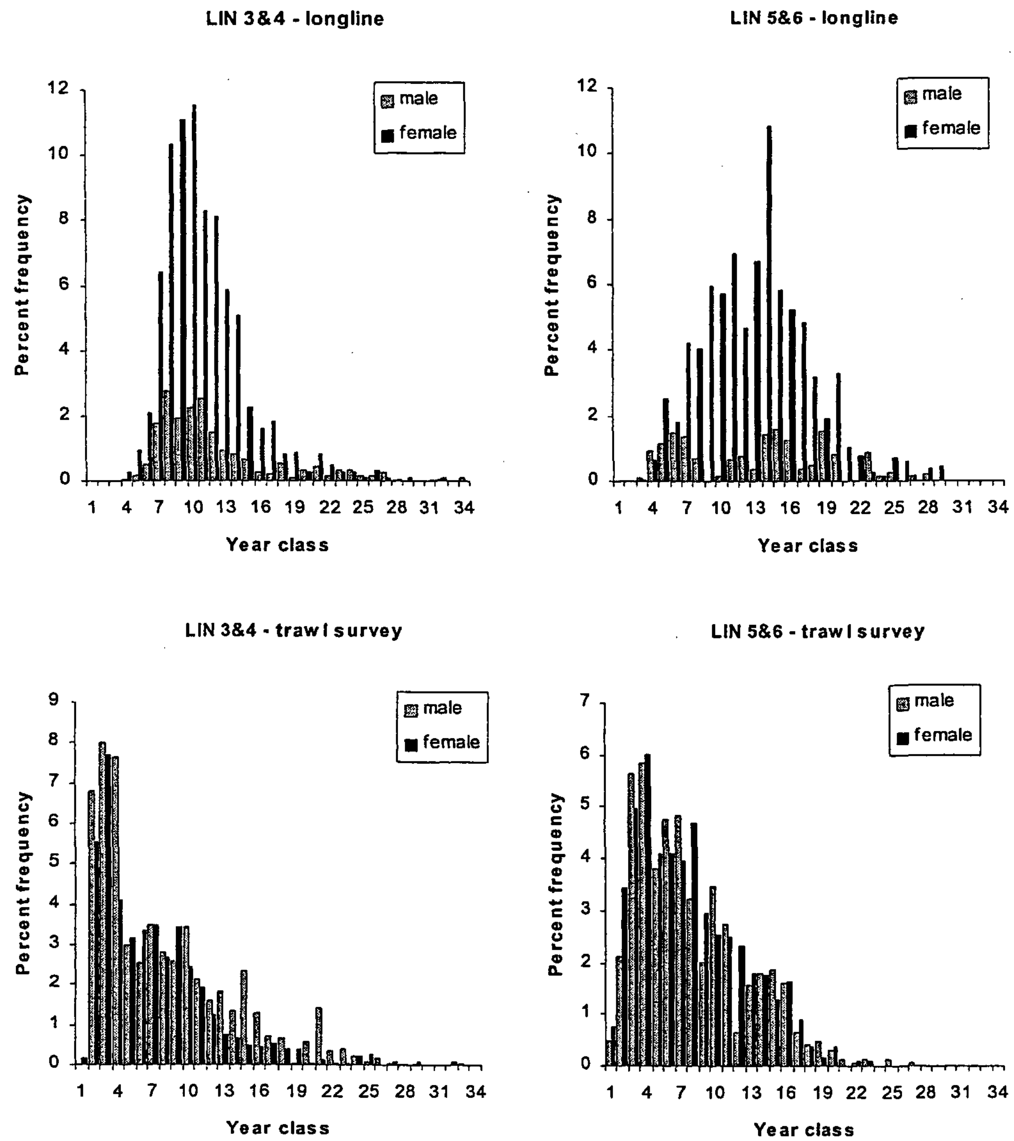

Figure 3: Calculated proportion-at-age, by sex, for comparable samples of ling caught by commercial longline and research trawl in LIN 5&6 (April–May 1998) and LIN 3&4 (January 1999).

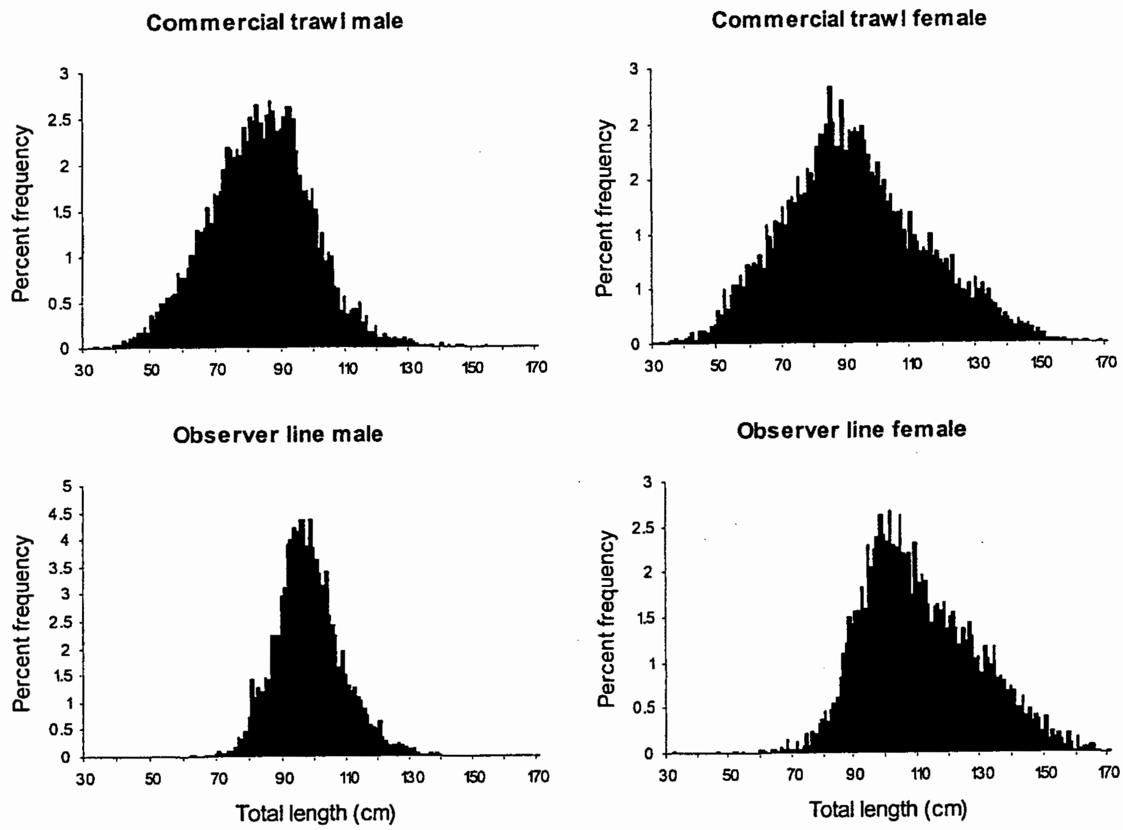

Figure 3a: Unscaled length-frequency data, by sex, for ling caught on the Chatham Rise by commercial trawl or commercial longline, as measured by scientific observers from 1990 to 1999.

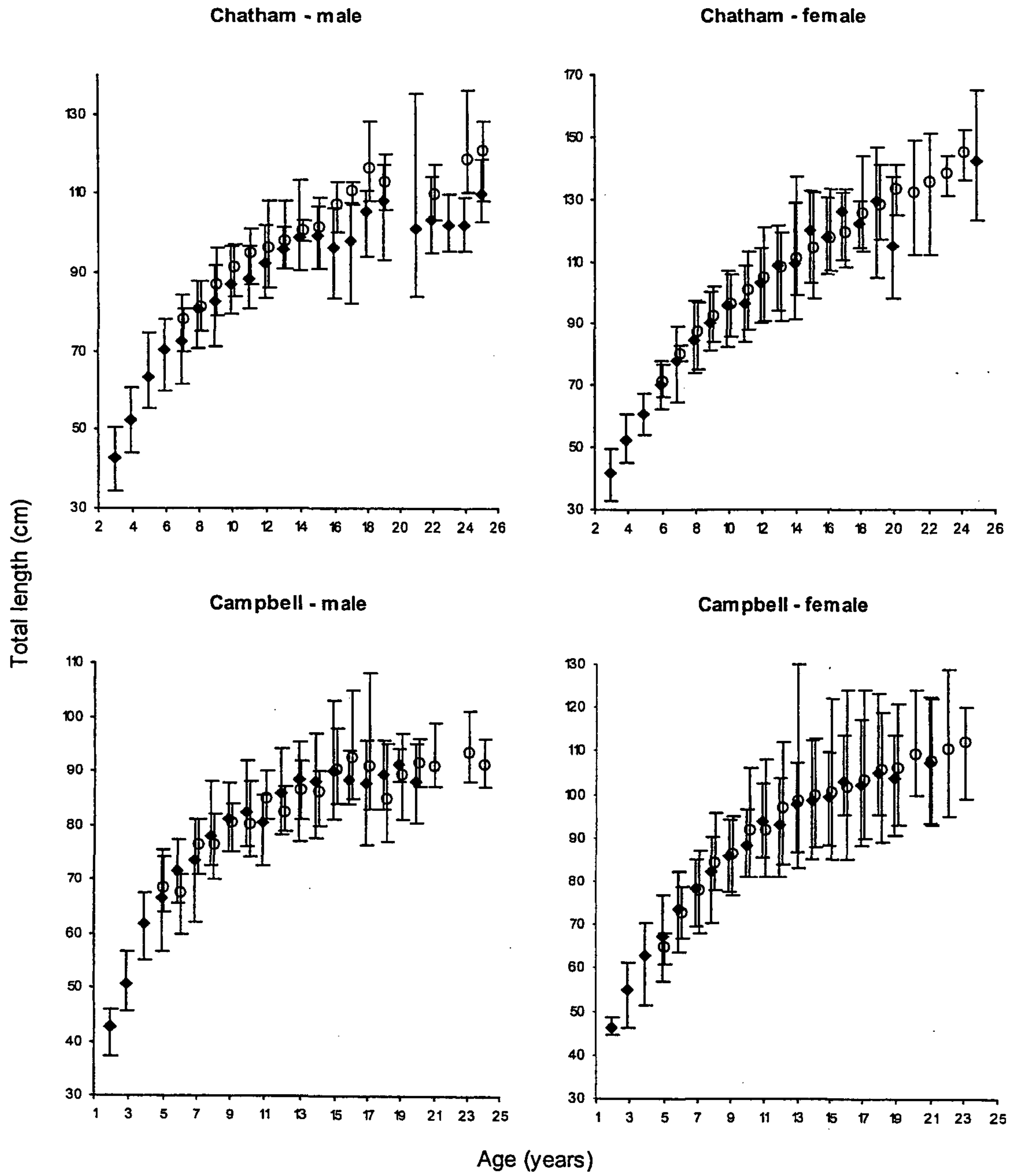

Figure 4: Mean lengths at age, separately by sex, for ling caught by commercial longline (open circles) and by research trawl (closed diamonds), on the Chatham Rise in January 1999 and the Campbell Plateau in April-May 1998. Means were calculated only where $n \geq 3$. Bars show range of size at age.

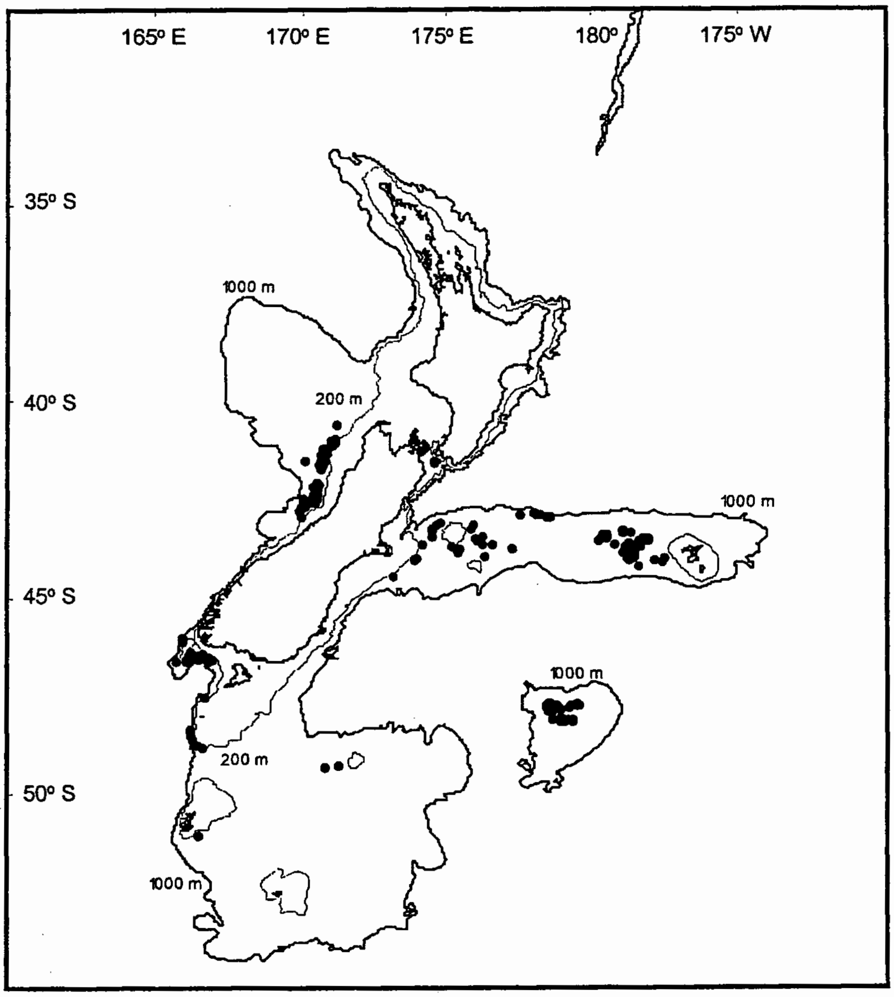

Figure 5: Capture positions of running ripe female ling recorded on the New Zealand continental shelf by scientific observers on commercial vessels, and on research trawl surveys. The 200 m and 1000 m isobaths are also shown.

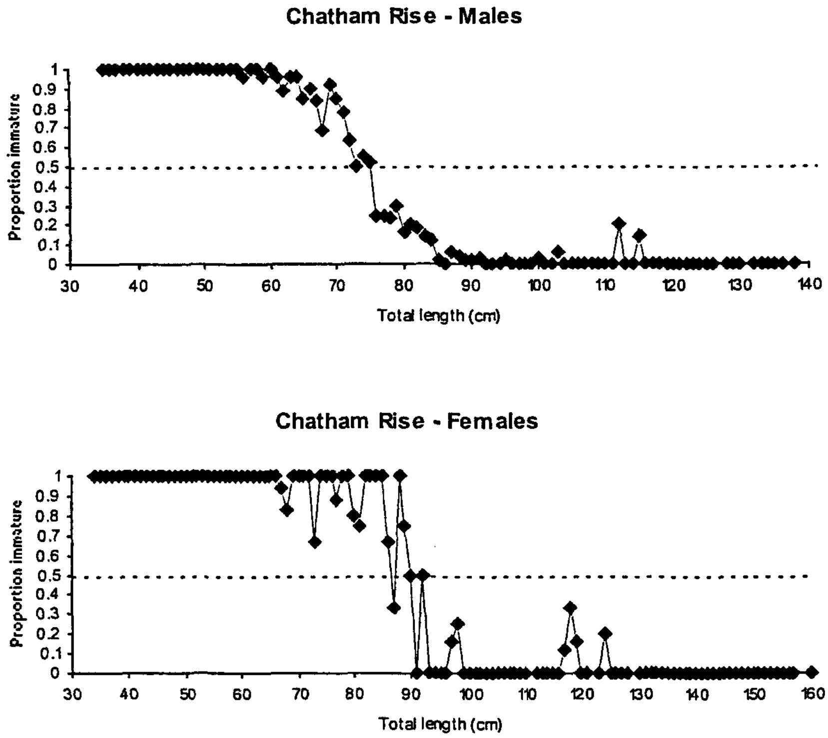

Figure 6: Proportion of immature ling by length class from trawl surveys of the Chatham Rise conducted in January 1992 to 1998.

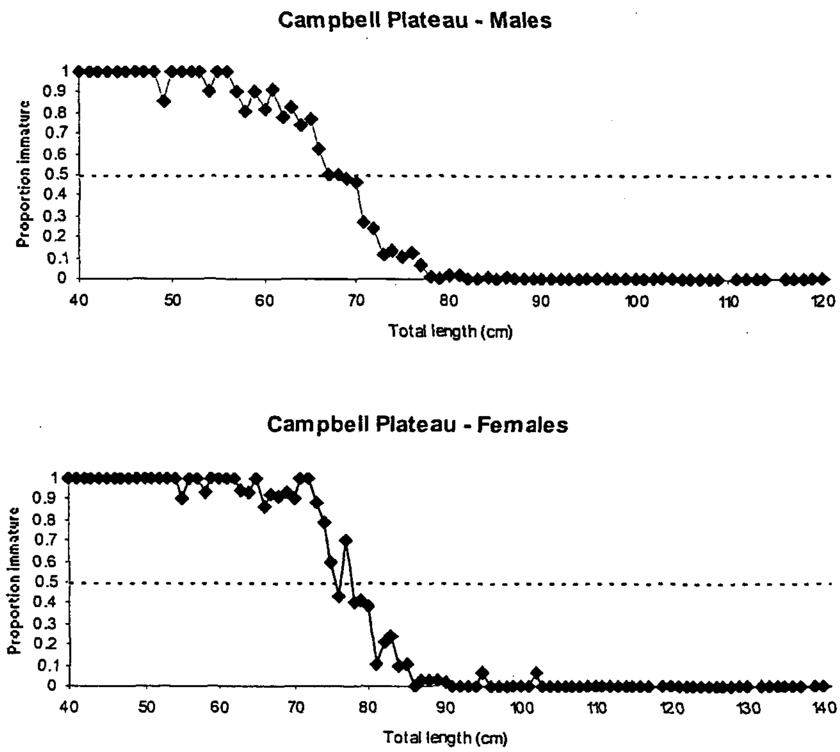

Figure 7: Proportion of immature ling by length class from trawl surveys of the Campbell Plateau conducted in various months from 1991 to 1998.

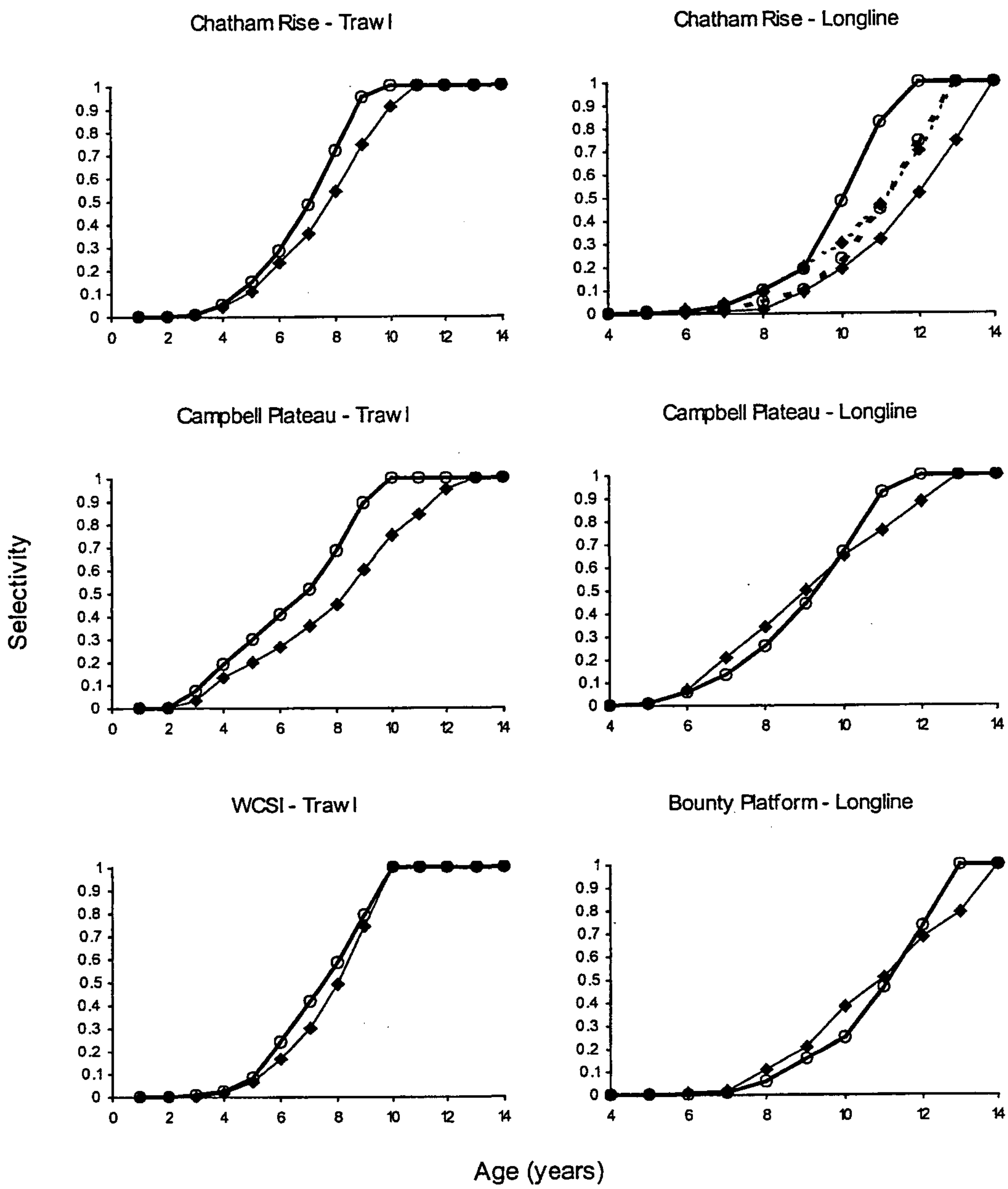

Figure 8: Calculated values of selectivity at age (by sex) for commercial trawl and longline fisheries in various areas. Open circle, female; diamond, male. All ogives were derived from Observer length-frequency data, except for the broken line ogives for Chatham Rise longline which were derived from industry logbook data.

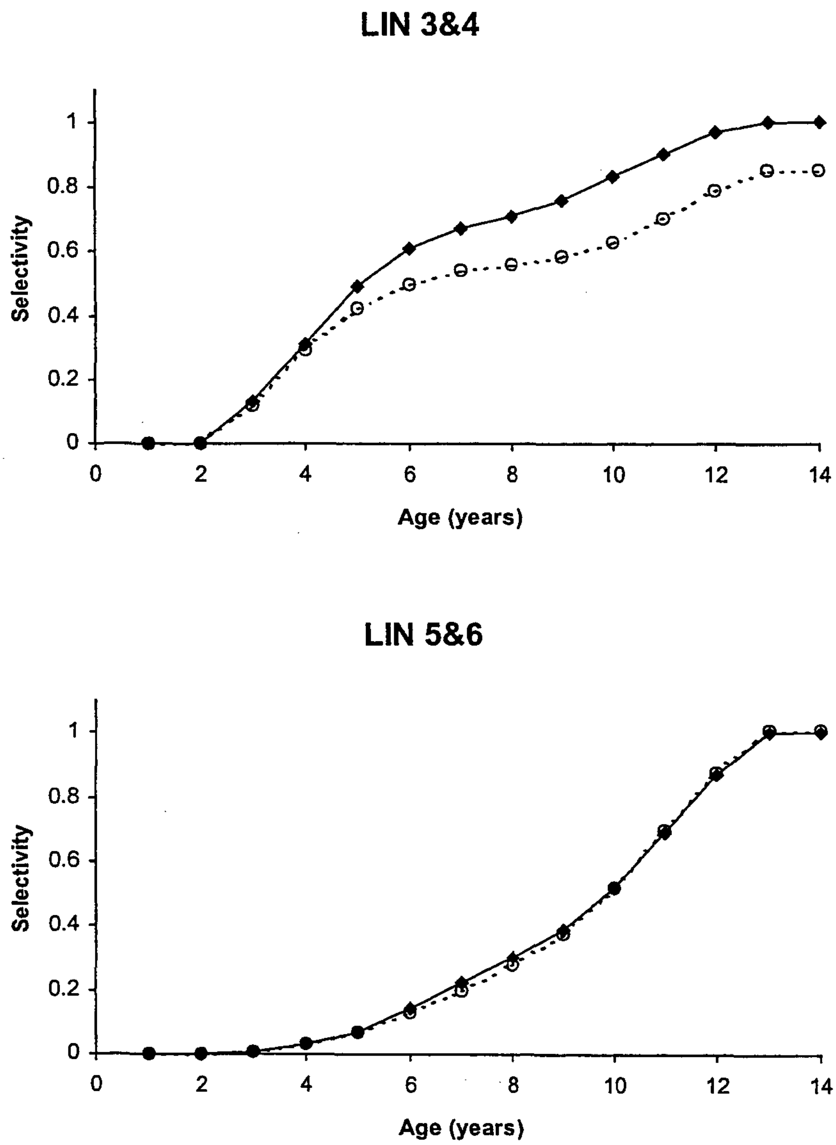

Figure 9: Trawl survey selectivity ogives (by sex) for the Chatham Rise (LIN 3&4) and Campbell Plateau (LIN 5&6), estimated within the model. Open circle, female; diamond, male.

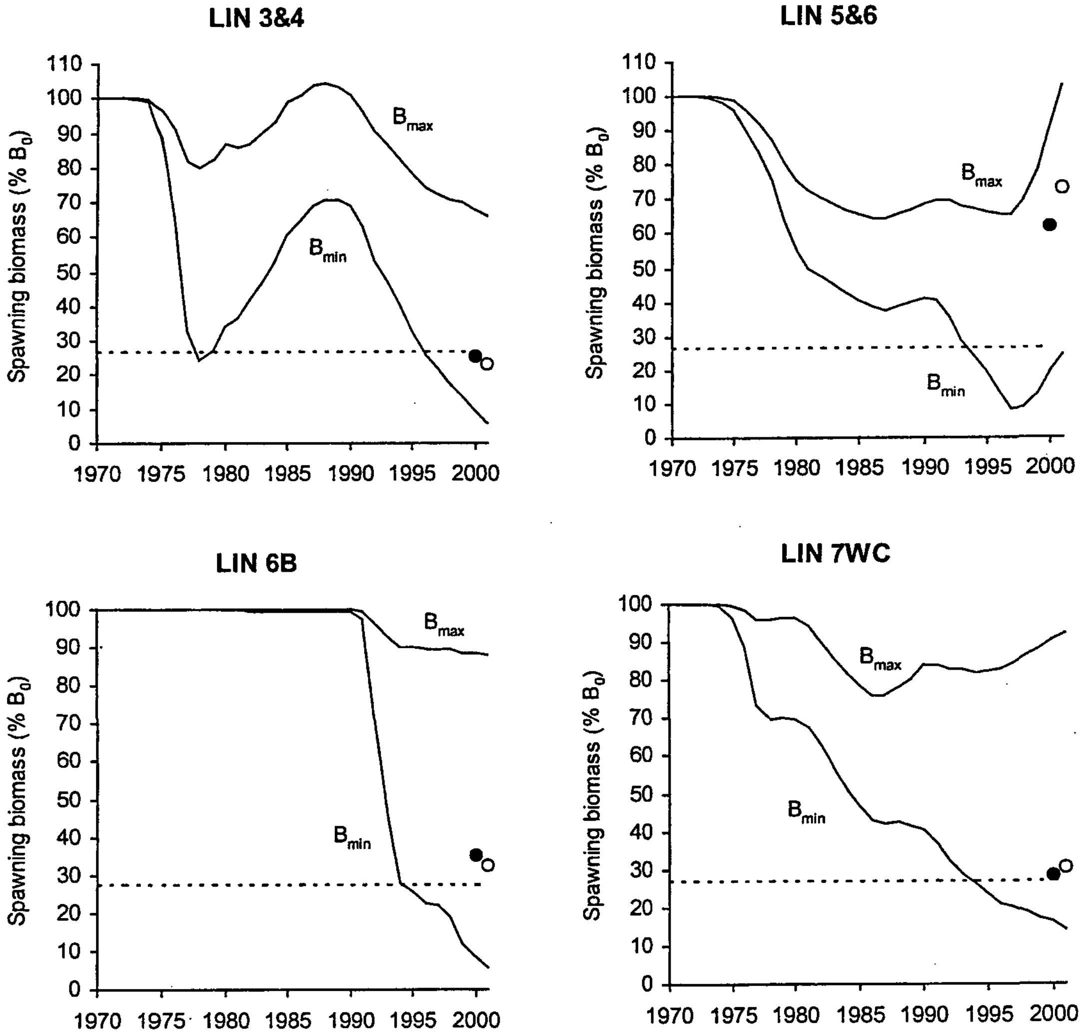

Figure 10: Biomass trajectories for minimum (B_{min}) and maximum (B_{max}) estimates of virgin biomass, for MIAEL base case assessments of LIN 3&4, LIN 5&6, LIN 6B, and LIN 7WC. MIAEL estimates of $B_{mid2000}$ and $B_{mid2001}$ are indicated by filled and open circles, respectively. Horizontal broken lines indicate B_{MAY}.

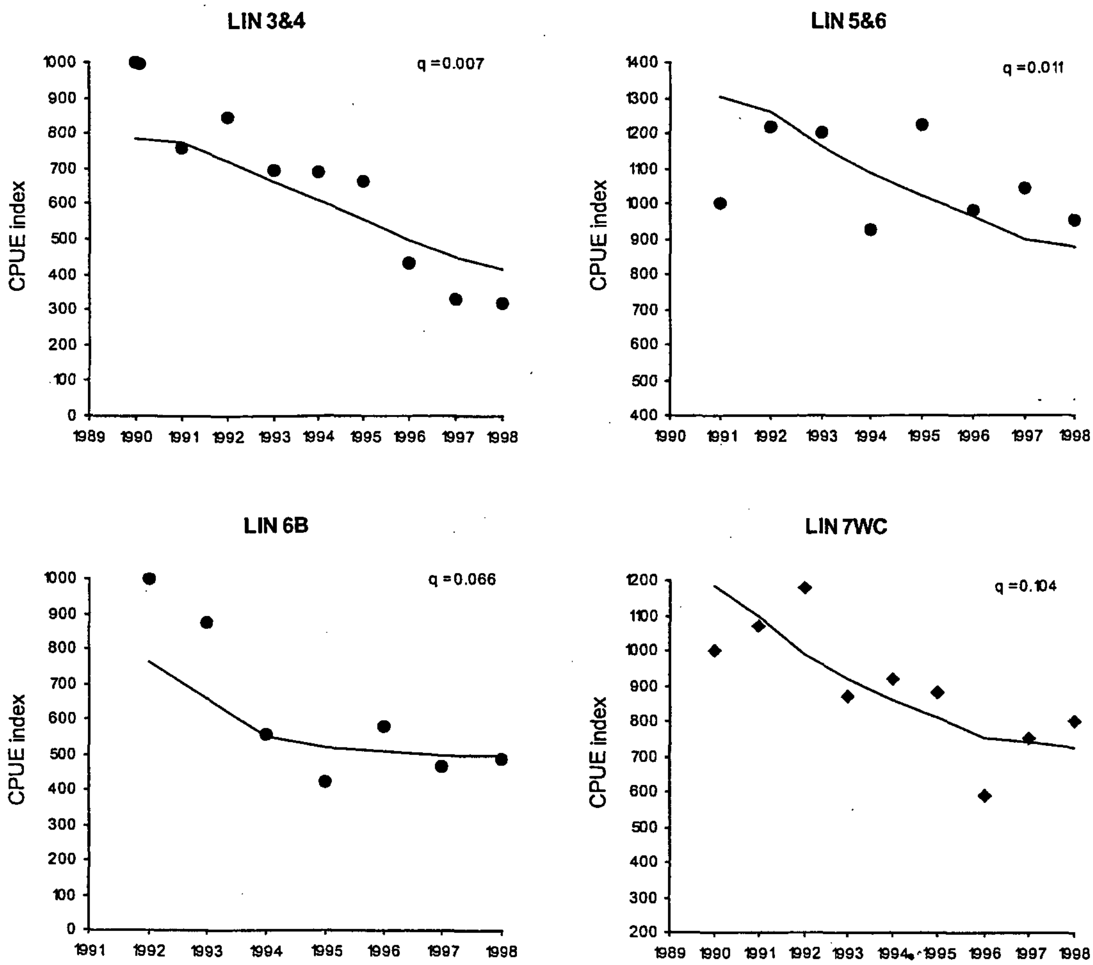

Figure 11: Model fits (solid lines) to the series of observed longline CPUE indices (diamonds) from the four assessed ling stocks. Estimates of q for each series are shown on the plots.

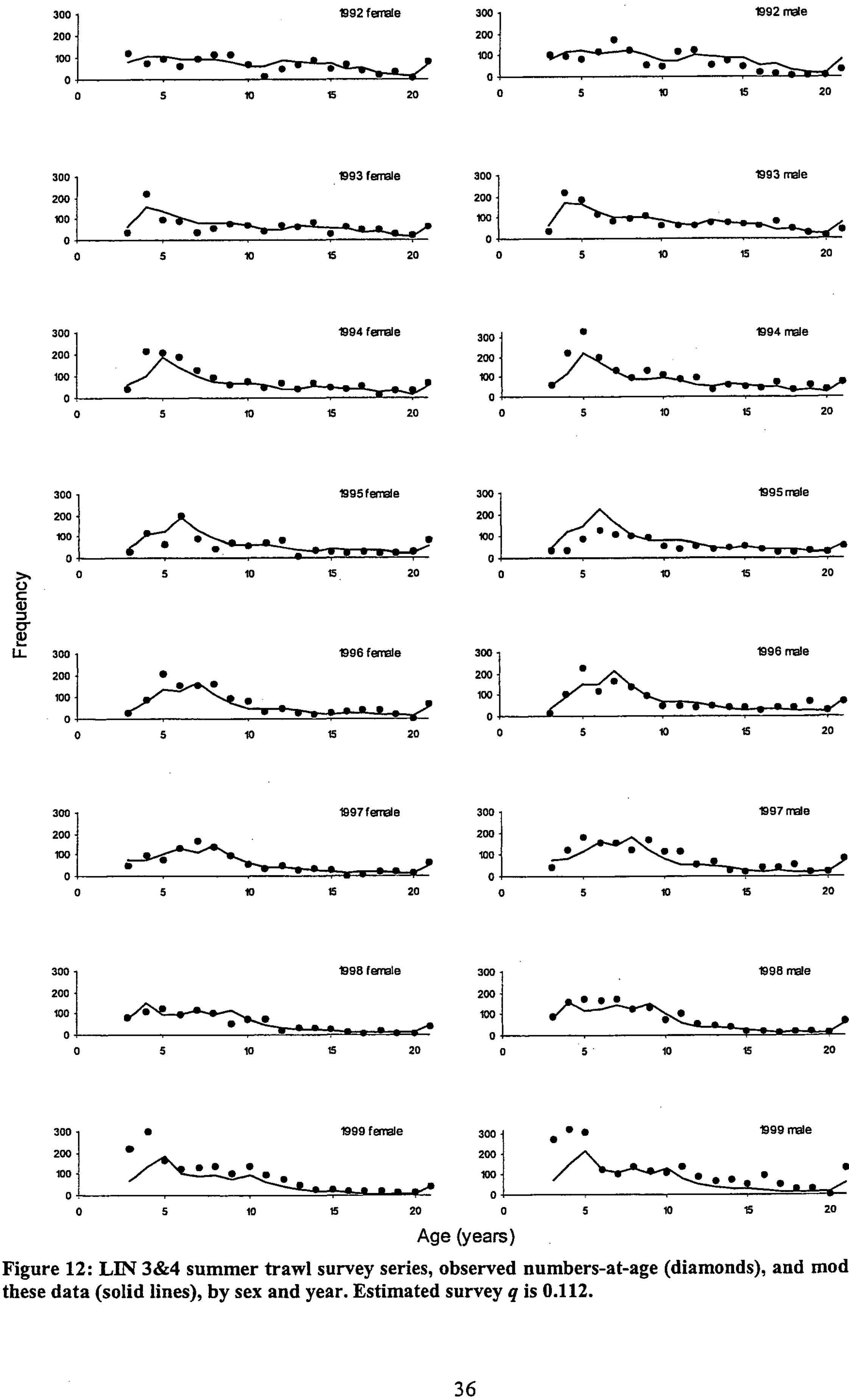

Figure 12: LIN 3&4 summer trawl survey series, observed numbers-at-age (diamonds), and model fits to these data (solid lines), by sex and year. Estimated survey q is 0.112.

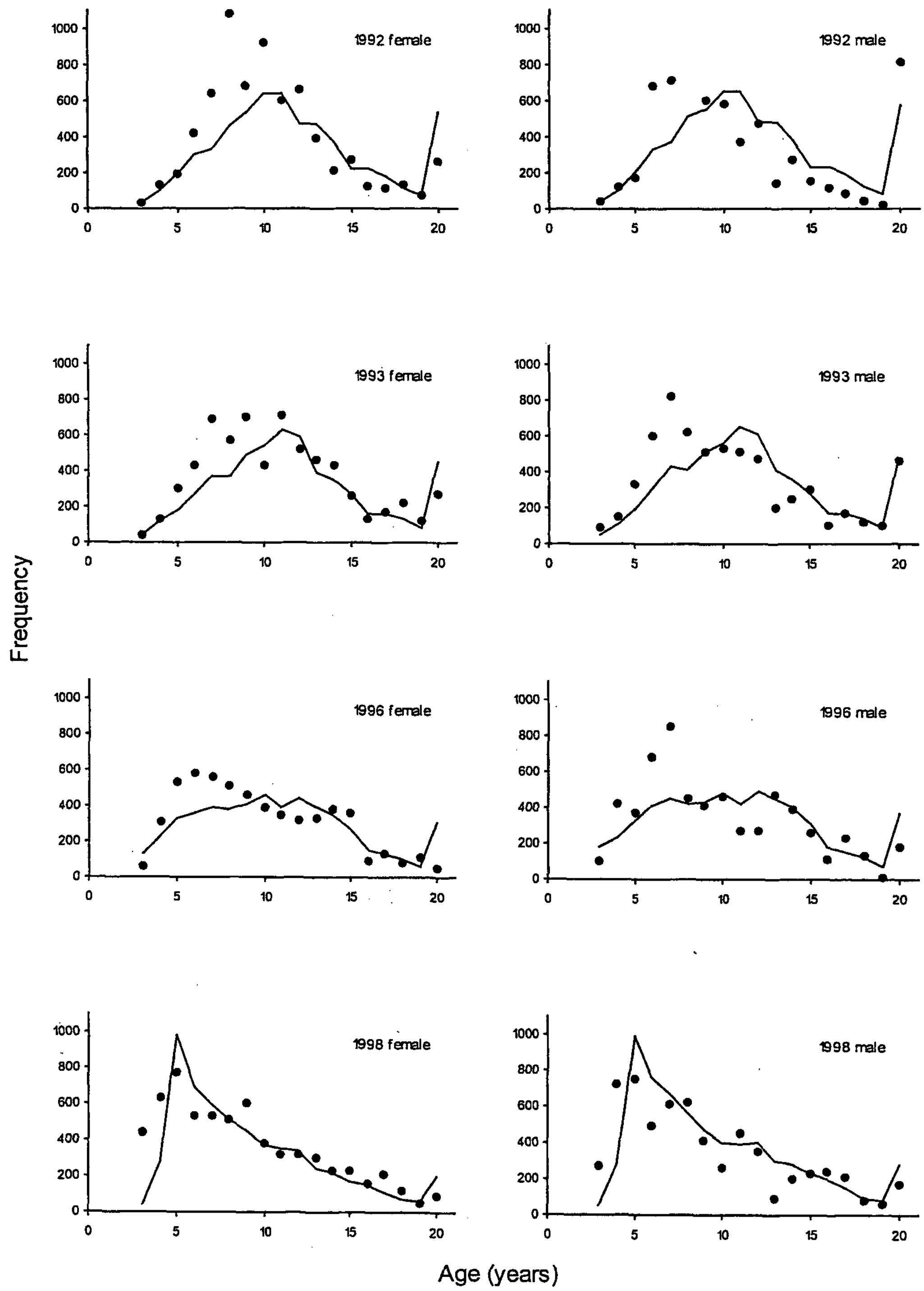

Figure 13: LIN 5&6 autumn trawl survey series, observed numbers-at-age (diamonds), and model fits to these data (solid lines), by sex and year. Estimated survey q is 0.75

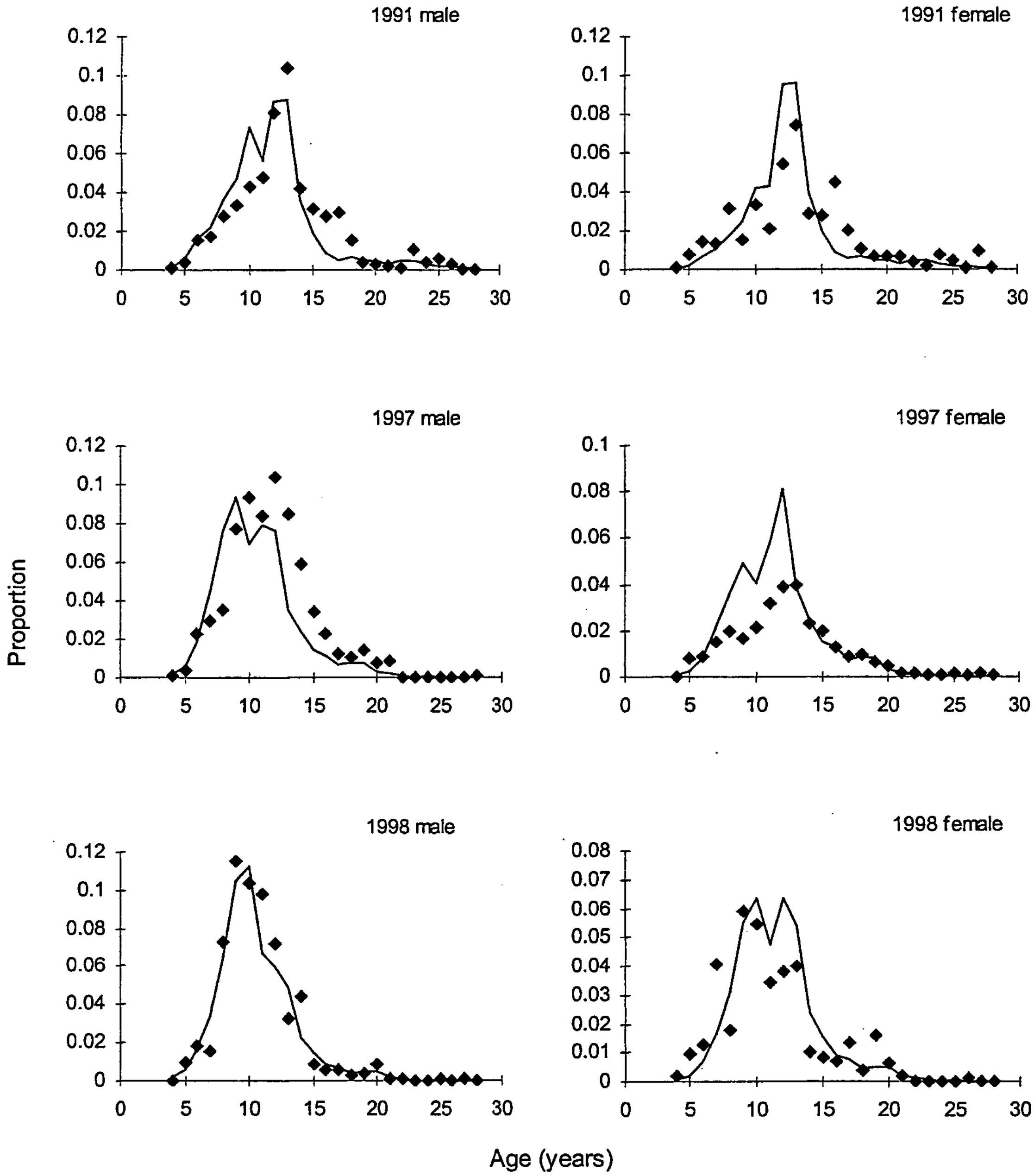

Figure 14: LIN 7WC winter commercial trawl bycatch, observed proportions-at-age (diamonds), and model fits to these data (solid lines), by sex and year.

APPENDIX A: CPUE ANALYSIS OF LING IN LIN 7

Summary

Ling in area LIN 7 are taken primarily as a bycatch of other target species trawl fisheries, but also by small domestic longline vessels. Approximately one-third of the LIN 7 catch is taken by bottom longline (BLL), with virtually all the rest being trawled. The primary trawl fishery in the area is the hoki fishery. A catch per unit effort (CPUE) series derived from the BLL fishery is considered a useful index of relative abundance for this stock, and has been used in previous stock modelling. The CPUE series is updated in this report to the end of 1998, using a lognormal linear model as used previously. The chosen data series used target bottom longline landings, excluding zero catches and auto-longline sets.

A CPUE analysis of ling bycatch in trawl fisheries targeting other species in LIN 7 is also presented here. This series is considered unlikely to accurately index abundance because of changes in fishing practice over time and perceived inaccuracies in the reporting of the ling catch.

Update the previous bottom longline CPUE series, targeting ling

A previous analysis of longline fishing targeting ling CPUE in LIN 7 provided a series of abundance indices (Horn & Ballara 1999). BLL was considered to provide the most reliable CPUE series for area LIN 7. A complication to CPUE analysis in LIN 7 was the two distinct areas of abundance in QMA 7, the west coast of the South Island (WCSI), and Cook Strait, with most of the landings from the WCSI. The stock affinity of Cook Strait is unknown, so data from the two areas were analysed separately. Data from the WCSI were applied to the lognormal linear (LNL) model of Vignaux (1993) which had previously been accepted by the Middle Depth Species Working Group as the most suitable model for this series.

This new analysis extended the "CELR data, which targeted ling in the BLL fishery" in Horn & Ballara (1999) to the end of the 1998 calendar year. The catch and effort data were extracted from the fishery statistics database managed by the Ministry of Fisheries (MFish). All catch effort landing returns (CELR) for the LIN7, BLL fishery targeting ling were extracted for the WCSI. Data were accepted according to Horn & Ballara (1999), and outliers were altered if the cause of the anomaly was apparent for that set, or removed.

Catch per unit effort was calculated from the catch of ling (kg) per hook set per vessel per day. The groomed data were used in a standardised multivariate CPUE model which attempted to minimise residual deviance, using a lognormal linear model (Vignaux 1993). Variables were added to the models using a stepwise procedure until less than 0.5% change in residual deviance was seen following the inclusion of an additional variable.

A first order interaction model was also run on the data set. The approach taken was described by Dunn & Harley (1999), and used a simultaneous forwards/backwards stepwise multiple regression, with variables being added or removed based on changes in residual deviance. At each step, first order interactions between variables already selected were considered for entry to the model. Variables were added or removed until there was less than 0.5% change in residual deviance.

A summary of data available by year is given in Table A1. The amount of effort remained relatively constant from 1992 to 1997, with 13–17 vessels each year placing on average 570 sets, and catching an average of 1.17 t of ling per set. There was a slight drop off in ling catch and number of sets in 1998. The overall number of zero catches was very low at about 1% of the data, but this varied from 0.3% in 1994 to

4.0% in 1996. There were 31 vessels in the whole data set after error checking, with only 4 vessels in the fishery in all years. There was only one autolongline vessel in the data set after data checking.

Variables used were the same as those used by Horn & Ballara (1999). These data were analysed by calendar year as in Horn & Ballara (1999), instead of fishing year, due to a weak seasonal trend running through the data, particularly from June to December for the WCSI data (Figure A1).

The data set was a target ling BLL, but this data set included zero catches and auto-longline data. Three CPUE analyses were undertaken on this data set. One included all the data (1), another excluded zeros (2), and the last excluded zeros and auto-longline vessels (3).

Variables entering the models are listed in Tables A2. As shown previously (Horn & Ballara 1999), 'Month' and 'Year' were important variables, as they both entered the model in all runs first. Next, one or more of 'Vessel power', 'Vessel tonnage' and/or 'Vessel breadth' vessel characteristics entered the model, explaining in some way the efficiency of vessels. This was followed by 'Statistical area'. Higher catch rates were generally seen from August to October, and in statistical areas 032, 033, and 034. The interaction effects entered the model after all the single variables. The most important interaction effect was month combined with a vessel characteristic or statistical area. 'Southern Oscillation Index' (SOI) did not enter any of the models but featured in most of the model runs in Horn & Ballara (1999).

The relative year effects for each analysis are given in Table A3, and plotted in Figure A2. In all runs, the indices showed a slight decline in CPUE over most years from 1992 to 1996, with an increase in 1997 and 1998. Running the model without zeros, or excluding zeros and auto-longline data changed the indices slightly, but did not change the trend. A comparison of interaction and non-interaction runs showed similar trends but the interaction indices tended to be lower.

Fitted residuals for the two models showed an apparent trend through the bulk of the data (Figures A3–A5), in the three cases, and poor correlation for zero catches for the LNL model. The plots of observed CPUE values versus fitted values, showed some correlation between observed CPUE and fitted values for all models.

There was little difference shown using the LNL model between each of the series. All three showed quite similar trends, so the "exclude zeros and exclude auto-longline interaction (3)" series was chosen. Running the LNL model without zeros did not produce a marked change in the relative year effects (*see* Figure A2, excluded zeros), which might be explained by the very low number of zero tows in the data set. Horn & Ballara (1999) also suggested "that analyses of CELR target ling BLL data should exclude auto-longline data, unless this fishing method substantially increased in importance off WCSI", and the auto-longline method is still a small component on the WCSI.

The WCSI CPUE data set for area LIN 7 is considered useful as an abundance index for stock assessment, as it shows a consistent trend, and for each data set and model, yearly indices were very similar.

Ling bycatch in the WCSI trawl fishery

All catch and effort data from the Trawling Catch and Effort Processing Returns (TCEPR) showing ling caught or targeted in area LIN 7, (off WCSI, west of 172.5° E, south of 40° S), were extracted from the MFish catch and effort database. These records were checked for errors as described above.

Catch per unit effort was calculated to be catch (kg) per nautical mile. The checked data was applied to a standardised multivariate log normal linear model (Vignaux 1993) using interaction and non-interactions as for the BLL data set. Variables used in this model were determined following data extraction, and included those used in the model for trawl data from LIN 5 (Ballara 1997) and the 'Time-depth' variable as in Sullivan *et al.* (in prep.). The data was analysed using calendar year as the 'Year' variable, and day of year as the 'Season' variable, as in other ling CPUE analyses (Ballara 1997, Horn & Ballara 1999). The seasonal trend decreased slightly during the main hoki-spawning fishery (Figure A6). The data set was analysed including and excluding zero tows.

A summary of data available by year is given in Tables A4 and A5. Most trawl ling is caught as bycatch of the hoki spawning fishery. The catch of ling, when ling is the reported target species, was a small proportion of the total catch and number of tows. Ling is also caught as bycatch in a range of other species on the WCSI. The total catches will also be low for the years 1990 to 1993 as ling catch was believed to be under-reported (Annala *et al.* 1999). After data checking, a total of 205 vessels had caught ling in the trawl fisheries on the WCSI from 1990 to 1998, with 64–93 vessels in each year. Only 5 vessels were in the fishery in all years. There were very few zero tows in the data set.

Variables entering the models are listed in Table A6. The 'Vessel length' and 'Nation' vessel characteristics were the first variables to enter all runs implying that vessel efficiency and fishing patterns are important. 'Month of year' entered the model next, explaining some of the seasonality of the data. In all runs the first six variables were the same. The same variables entered the model for both non-interaction runs. The same variables also entered the interaction runs, although in a slightly different order.

Relative year effects are given in Table A7, and plotted in Figure A7. In general, CPUE increased from 1990 to 1996, with a small decrease in 1994. In 1997 there was a decrease in CPUE, which leveled off in 1998. There was very little difference between running the model without zero catches or with interaction effects.

Fitted value plots against the residuals for the two models are shown in Figure A8. There is an absence of pattern among the residuals. The plots of observed CPUE against fitted value showed some correlation between observed CPUE and fitted values for both models.

There was very little difference between the indices from each of the data sets or between interaction and non-interaction runs. This series is considered unlikely to index abundance because of changes in fishing practices over time and the perceived inaccuracies in the reporting of ling catch.

Table A1: Number of data rows for BLL catch (t) and number of vessels associated with them after data grooming. Source CELR data

Year	Number of sets	Ling catch (t)	Number of vessels	Number of auto-longliners	Number of zero catches
1990	294	216	11	0	5
1991	421	412	14	0	5
1992	623	735	15	1	3
1993	481	625	13	0	4
1994	581	779	16	1	2
1995	533	710	17	1	2
1996	612	733	16	1	25
1997	593	764	14	0	21
1998	465	619	10	0	3

Table A2: Comparison of non-interaction and interaction variables used in the BLL target ling models for the showing the order in which they entered the models

Variable	All data, auto-longline and zero sets include		
	Previous*	Non-interaction	Interaction
1	Month	Month	Month
2	Year	Year	Year
3	Breadth	Tonnage	Tonnage
4	Tonnage	Breadth	Breadth
5	Stat area	Stat area	Stat area
6	SOI	Length	Number of sets
7	–	Power	Catch date
8	–	–	Month: Tonnage
9	–	–	Month: Breadth
10	–	–	Stat area: Tonnage
11	–	–	Month: Stat area
12	–	–	Month: Number of sets
13	–	–	Month: Catch date
14	–	–	Catch date: Tonnage
15	–	–	Stat area: Catch Date
16	–	–	Catch date: Breadth

* Previous non-interaction model (Horn & Ballara, 1999)

Variable	BLL Excluding zeros		BLL Excluding zeros and auto-longline	
	Non-interaction	Interaction	Non-interaction	Interaction
1	Month	Month	Month	Month
2	Year	Year	Year	Year
3	Power	Power	Power	Power
4	Stat area	Breadth	Breadth	Breadth
5	Length	Stat area	Stat area	Stat area
6	Breadth	Month: power	Number of sets	Month: breadth
7	Draft	Month: breadth	Length	Month: power
8	Number of sets	Month: statarea	Draft	Month: statarea
9	–	Statarea: power	–	Statarea: power
10	–	Power: breadth	–	Power: breadth
11	–	Statarea: breadth	–	Statarea: breadth

Table A3: Relative year effects from the Log normal model for years 1990 to 1998 for the ling target BLL data sets

Year	All BLL ling target data			Zero catches excluded		Zero catches and auto-longline excluded	
	Previous*	Non-interaction	Interaction	Non-interaction	Interaction	Non-interaction	Interaction
1990	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1991	1.42	1.36	1.16	1.26	1.08	1.26	1.08
1992	1.42	1.44	1.30	1.27	1.19	1.26	1.19
1993	1.18	1.23	0.97	1.09	0.90	1.08	0.89
1994	1.29	1.27	1.22	1.02	0.92	1.01	0.92
1995	1.00	1.16	1.05	0.97	0.88	0.98	0.89
1996	0.53	0.56	0.55	0.67	0.59	0.67	0.59
1997	0.75	0.68	0.61	0.80	0.76	0.80	0.76
1998	–	0.97	0.79	0.84	0.79	0.84	0.79

* Previous non-interaction model (Horn & Ballara, 1999)

Table A4: WCSI ling catches (kg) by target species for groomed reported data for the years 1990–1998. Source TCEPR data

Year	Ling	Hoki	Hake	Other	Total
1990	51 781	1 529 614	1 310	63 519	1 646 224
1991	13 060	965 752	–	36 159	1 014 971
1992	24 600	616 383	17 160	84 205	742 348
1993	85 700	665 169	41 839	70 147	862 855
1994	11 078	664 838	35 438	52 705	764 059
1995	12 010	1 095 999	18 919	52 952	1 179 880
1996	16 750	1 094 074	10 630	42 061	1 163 515
1997	38 770	1 130 145	30 816	82 980	1 282 711
1998	9 860	1 394 217	37 410	63 908	1 505 395

Table A5: Number of tows for the ling trawl bycatch data set by target species, the number of zero tows when either ling, hake or hoki were targeted, and number of vessels associated with them after data grooming. Source TCEPR data

Year	Number of tows					Number of vessels
	Ling	Hoki	Hake	Zeros	Total	
1990	32	3 437	20	2	3 589	75
1991	8	2 066	0	0	2 131	75
1992	22	1 473	79	0	1 717	69
1993	41	1 448	66	1	1 654	73
1994	10	1 649	86	0	1 794	75
1995	16	2 151	52	1	2 332	66
1996	15	2 425	30	0	2 549	64
1997	22	2 445	67	1	2 713	88
1998	8	2 898	72	2	3 199	93

Table A6: Comparison of interaction and non-interaction variables used in the trawl bycatch LNL models, in the order in which they entered the model

Variable	All data		Zero catches excluded	
	Non-interaction	Interaction	Non-interaction	Interaction
1	Vessel length	Vessel length	Vessel length	Vessel length
2	Nation	Nation	Nation	Nation
3	Month	Month	Month	Month
4	Depth net	Depth net	Depth net	Depth net
5	Head line height	Headline height	Head line height	Headline height
6	Latitude	Latitude	Latitude	Latitude
7	Longitude	Year	Longitude	Longitude
8	Breadth	Longitude	Breadth	Breadth
9	Year	Breadth	Year	Year
10	Stat area	Time depth	Stat area	Time depth
11	Time depth	Latitude: Headline height	Time depth	Latitude: Headline height
12		Month: Longitude		Vessel length: Month
13		Vessel length: Month		Month: Longitude
14		Vessel length: Breadth		Vessel length: Breadth

Table A7: Relative year effects from the LNL model for years 1990 to 1999 for the ling trawl bycatch data sets

Year	All ling data		Zero catches excluded	
	Non-interaction	Interaction	Non-interaction	Interaction
1990	1.00	1.00	1.00	1.00
1991	1.12	1.10	1.12	1.12
1992	1.11	1.10	1.10	1.10
1993	1.37	1.38	1.36	1.36
1994	1.25	1.35	1.24	1.25
1995	1.37	1.44	1.37	1.37
1996	1.46	1.50	1.46	1.46
1997	1.24	1.29	1.24	1.24
1998	1.26	1.30	1.26	1.26

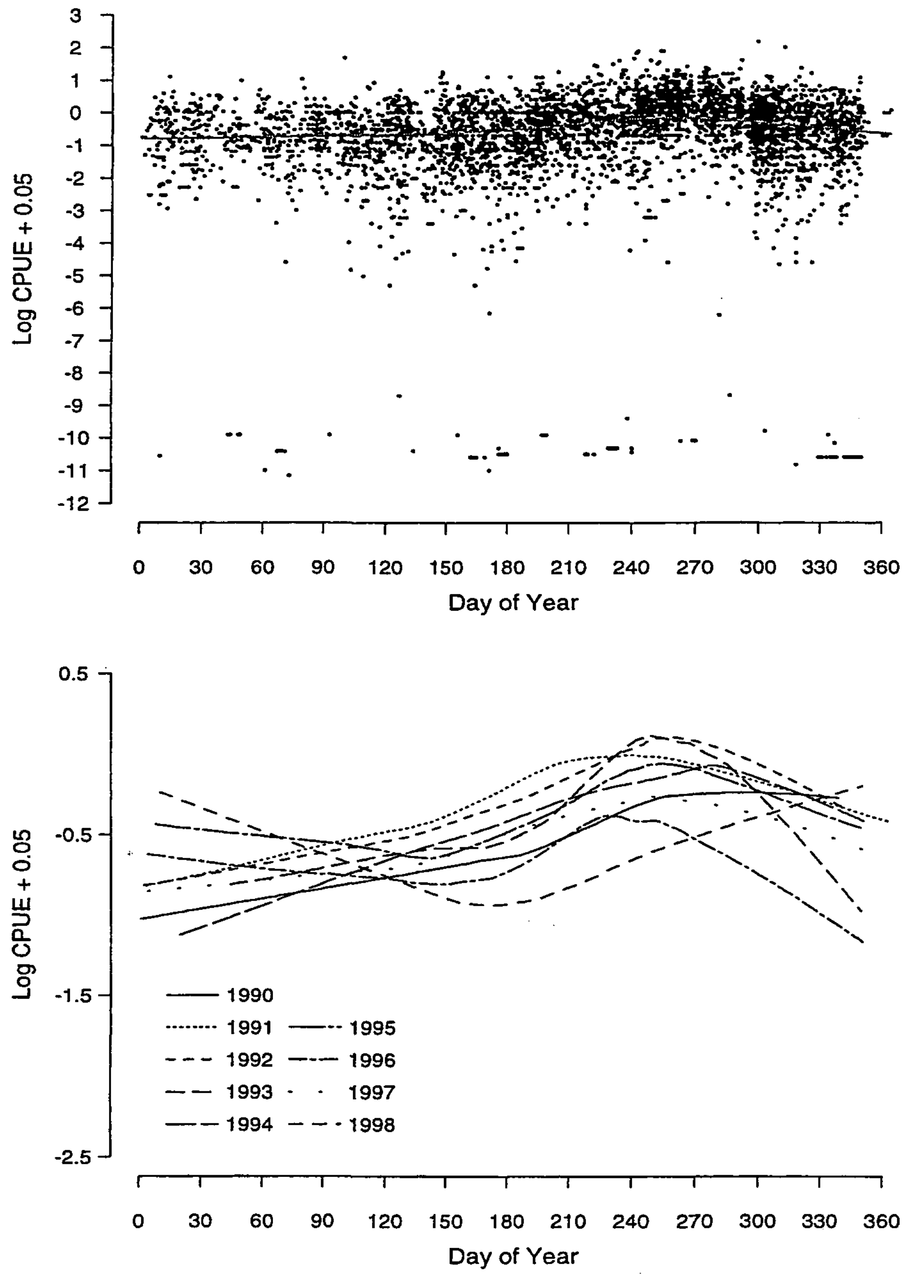

Figure A1: Plots of log (CPUE+0.05) against day of year showing individual points with a LOWESS fit through all data, and LOWESS fits for each year, 1990 to 1998, for the WCSI BLL data set.

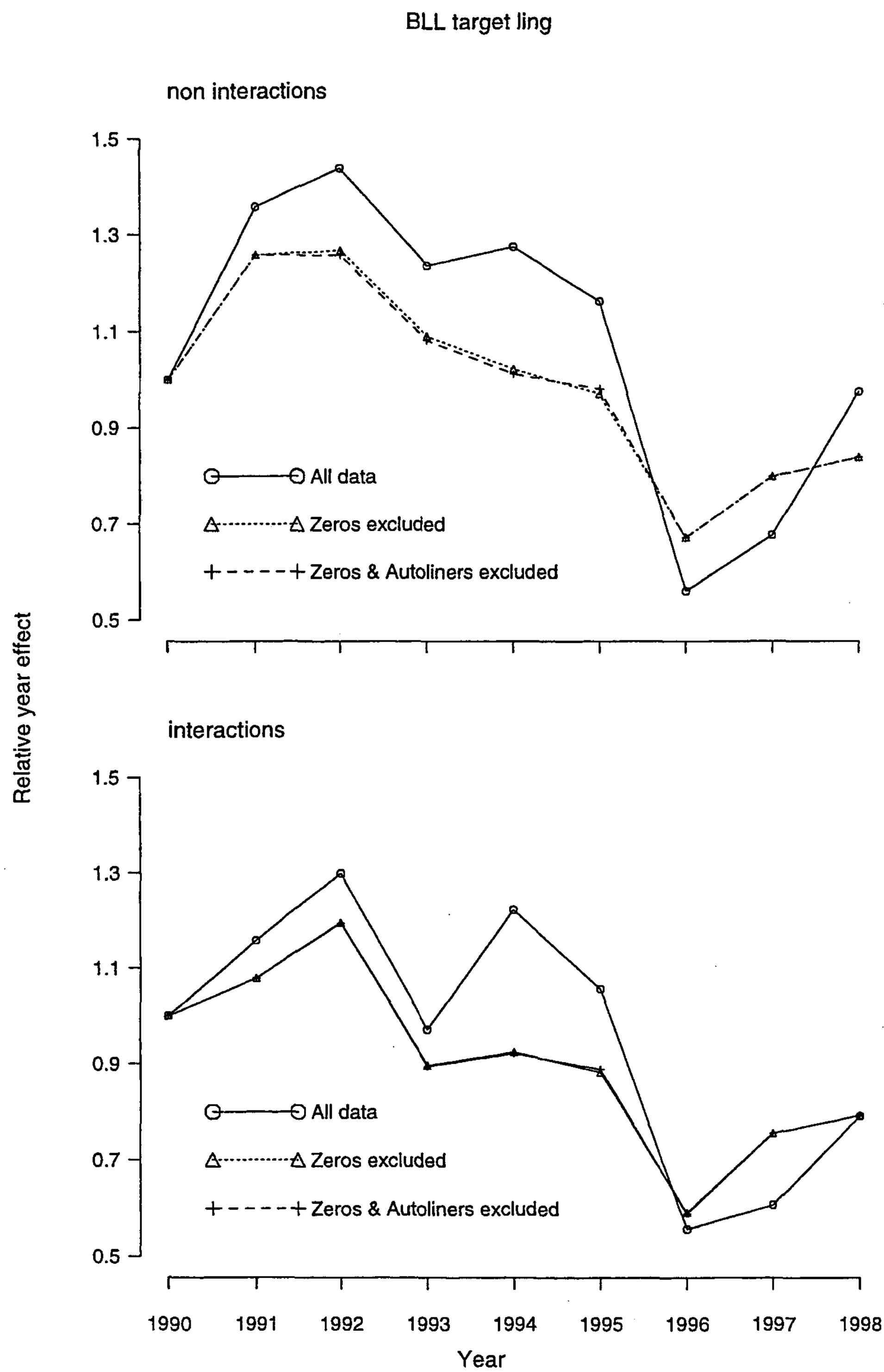

Figure A2: Comparison of interaction and non-interaction relative year effects estimated for the lognormal linear model for WCSI ling BLL data sets.

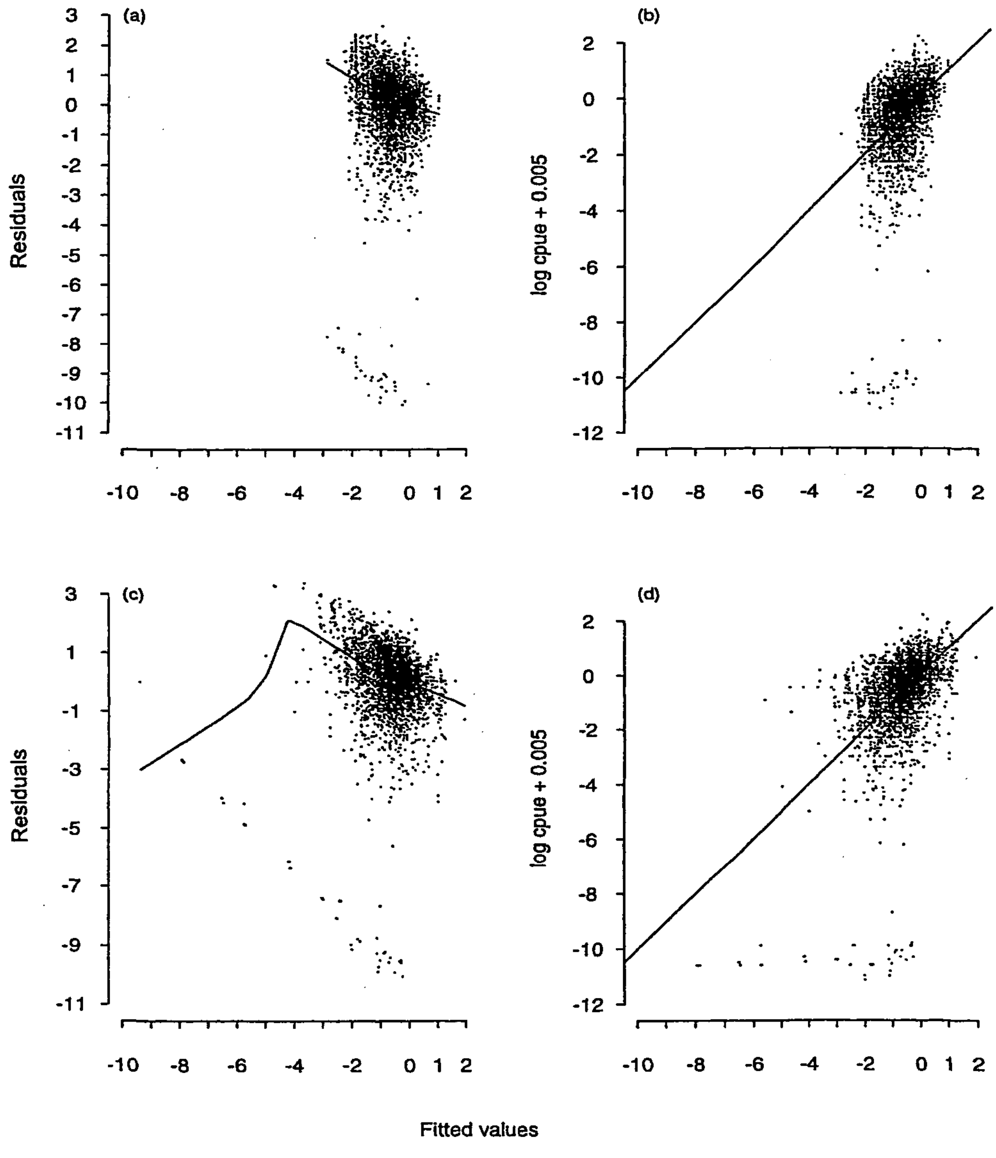

Figure A3: Plots for the BLL WCSI all data set non-interaction log normal linear model, (a) fitted values versus residuals, and (b) fitted versus observed CPUE values; and for the interaction log normal linear model (c) fitted values versus residuals, and (d) fitted values versus observed CPUE values. Residual plots show LOWESS curve fitted, and observed CPUE plots show y = x line fitted.

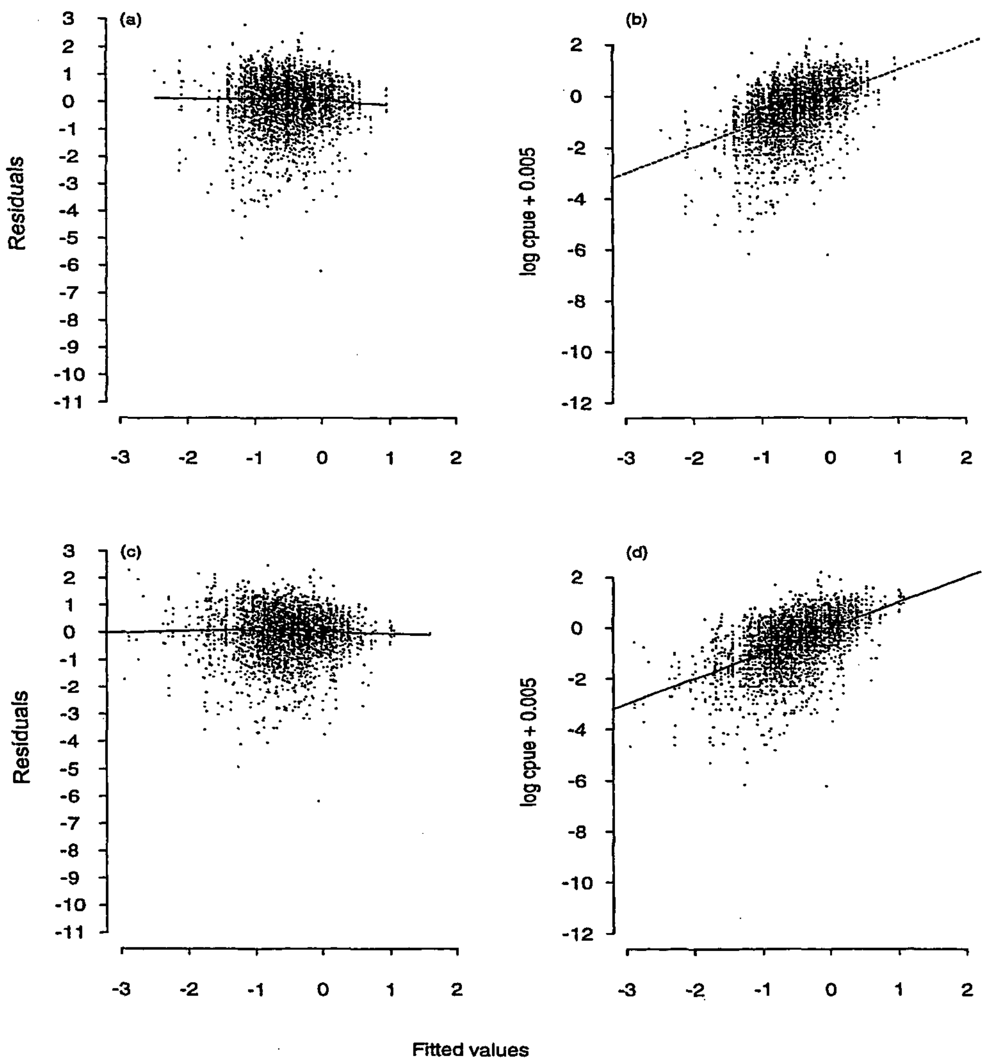

Figure A4: Plots for the BLL WCSI exclude zero data set non-interaction log normal linear model, (a) fitted values versus residuals, and (b) fitted versus observed CPUE values; and for the interaction log normal linear model (c) fitted values versus residuals, and (d) fitted values versus observed CPUE values. Residual plots show LOWESS curve fitted, and observed CPUE plots show y = x line fitted.

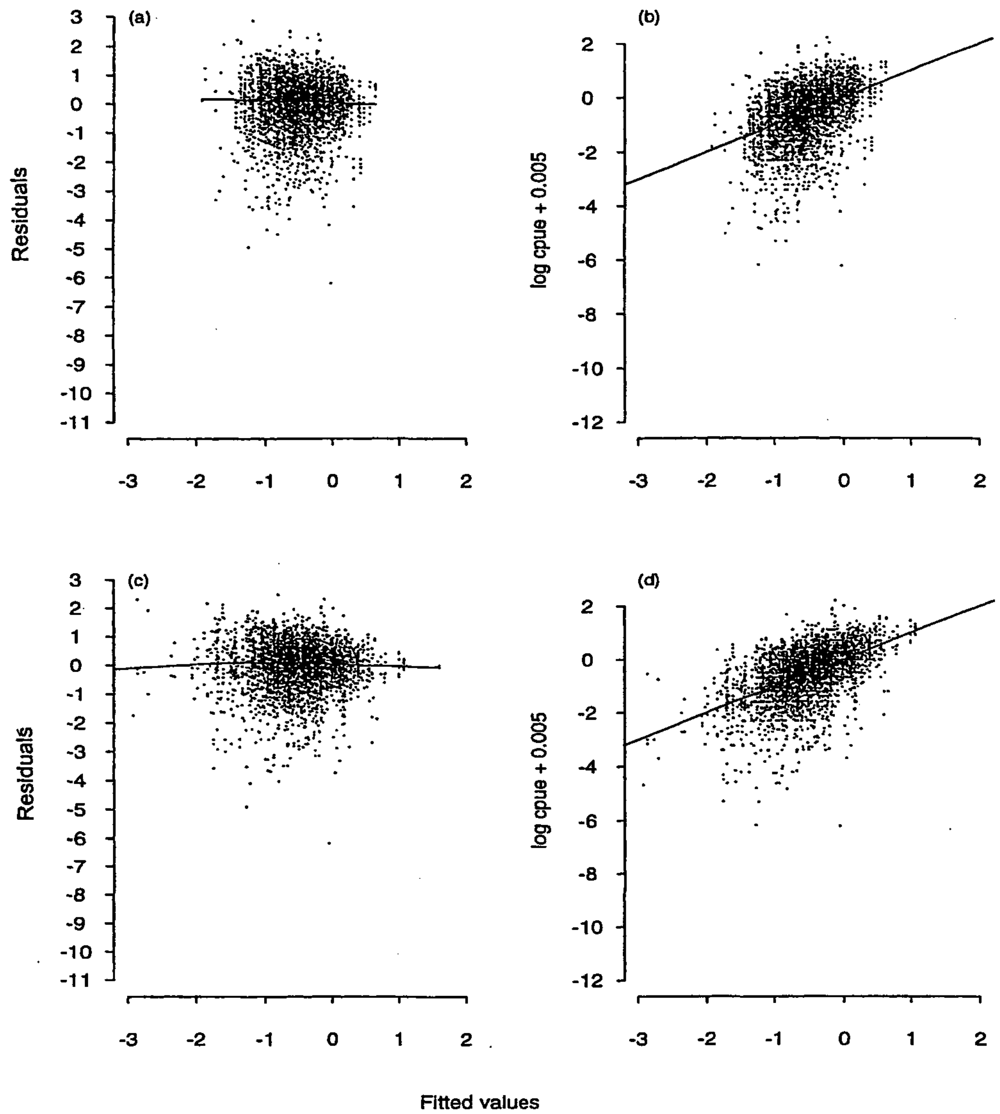

Figure A5: Plots for the BLL WCSI exclude zero and auto-lòngliner data set non-interaction log normal linear model, (a) fitted values versus residuals, and (b) fitted versus observed CPUE values; and for the interaction log normal linear model (c) fitted values versus residuals, and (d) fitted values versus observed CPUE values. Residual plots show LOWESS curve fitted, and observed CPUE plots show y = x line fitted.

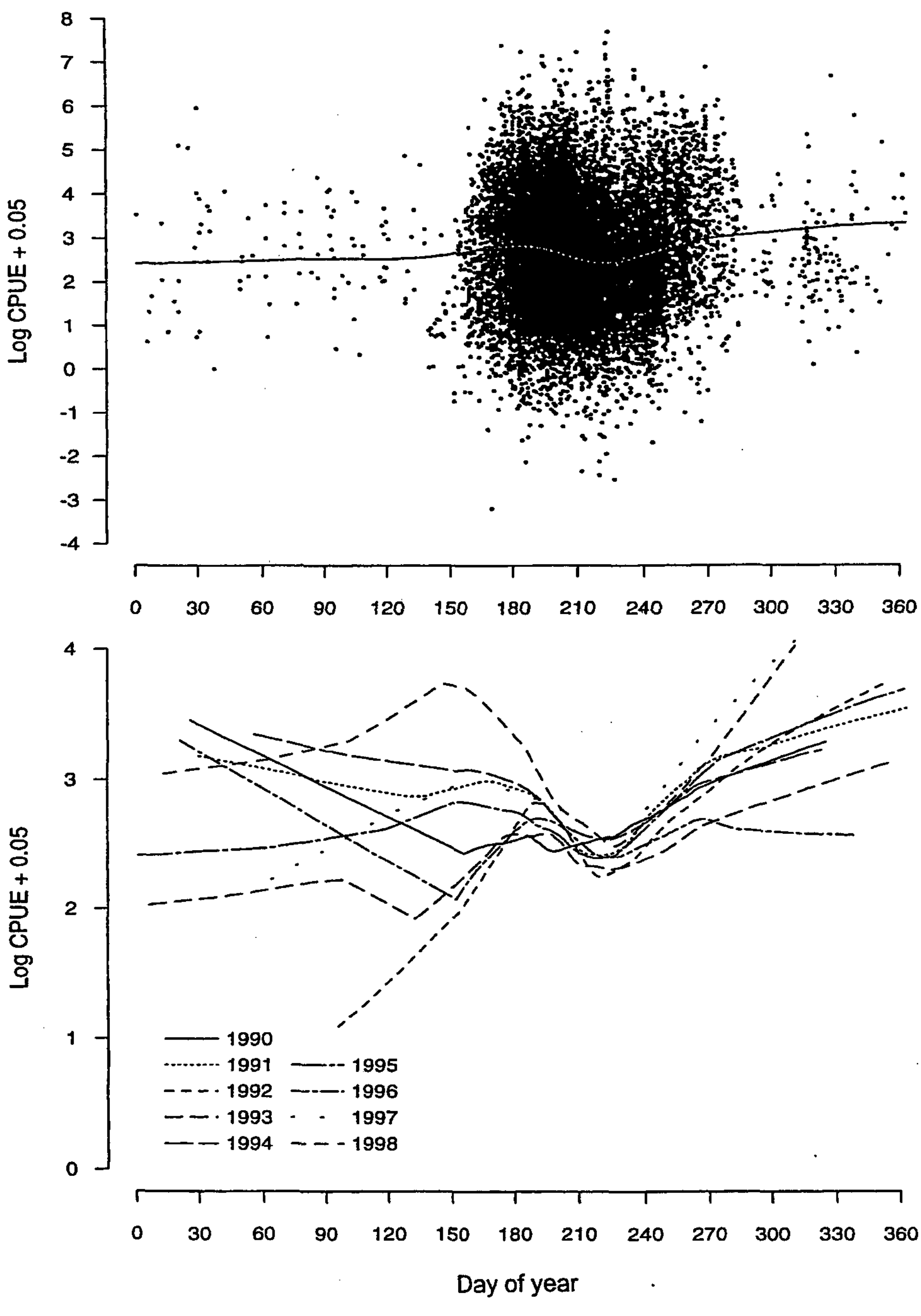

Figure A6: Plots of log(CPUE+0.05) against day of year showing individual points with a LOWESS fit through all data, and LOWESS fits for each year, 1990 to 1998, for the WCSI trawl bycatch data set.

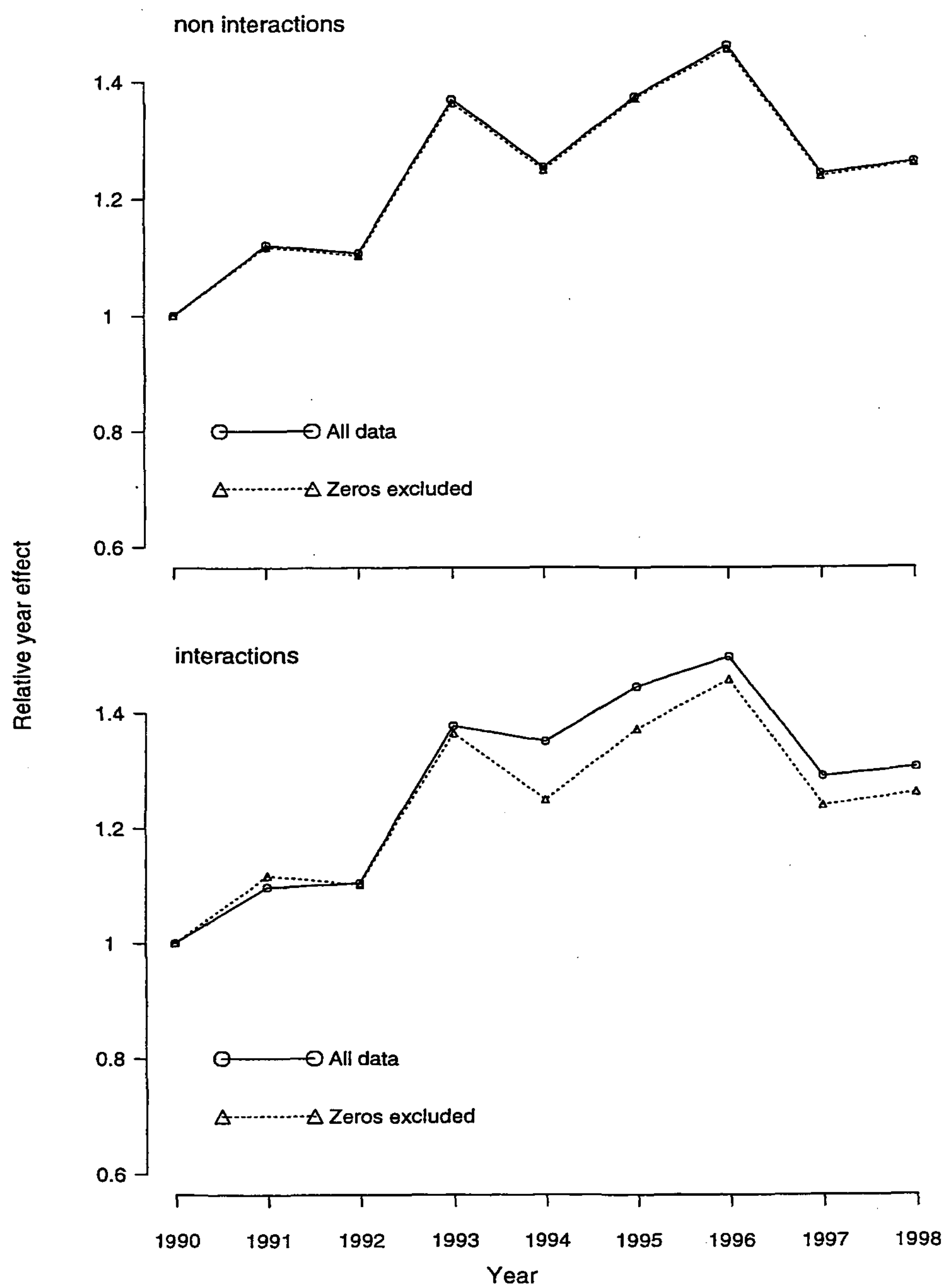

Figure A7: Comparison of interaction and non-interaction relative year effects estimated for the lognormal linear model for WCSI ling trawl bycatch data set.

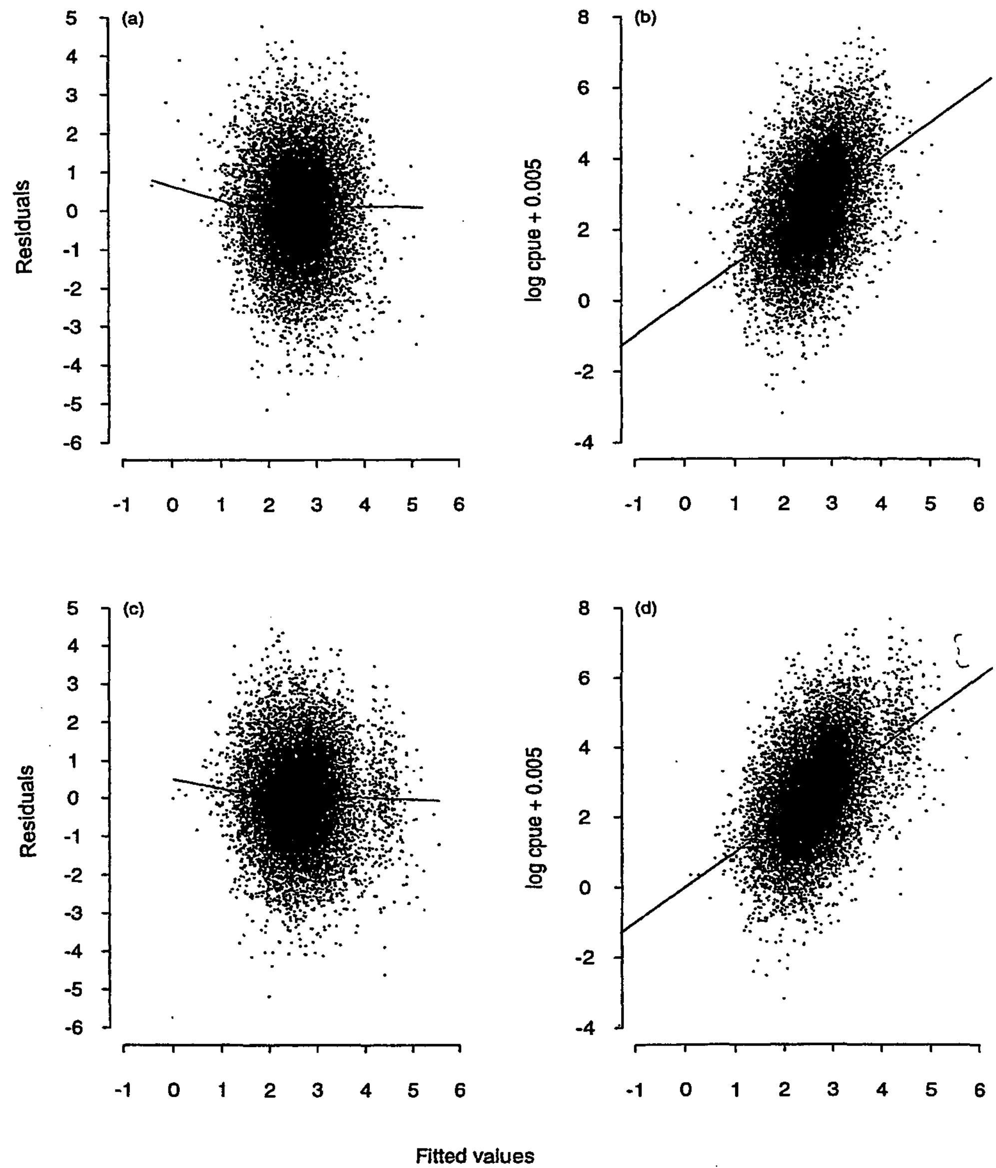

Figure A8: Plots for the ling bycatch including zero data set non-interaction log normal linear model, (a) fitted values versus residuals, and (b) fitted versus observed CPUE values; and for the interaction log normal linear model (c) fitted values versus residuals, and (d) fitted values versus observed CPUE values. Residual plots show LOWESS curve fitted, and observed CPUE plots show y=x line fitted.

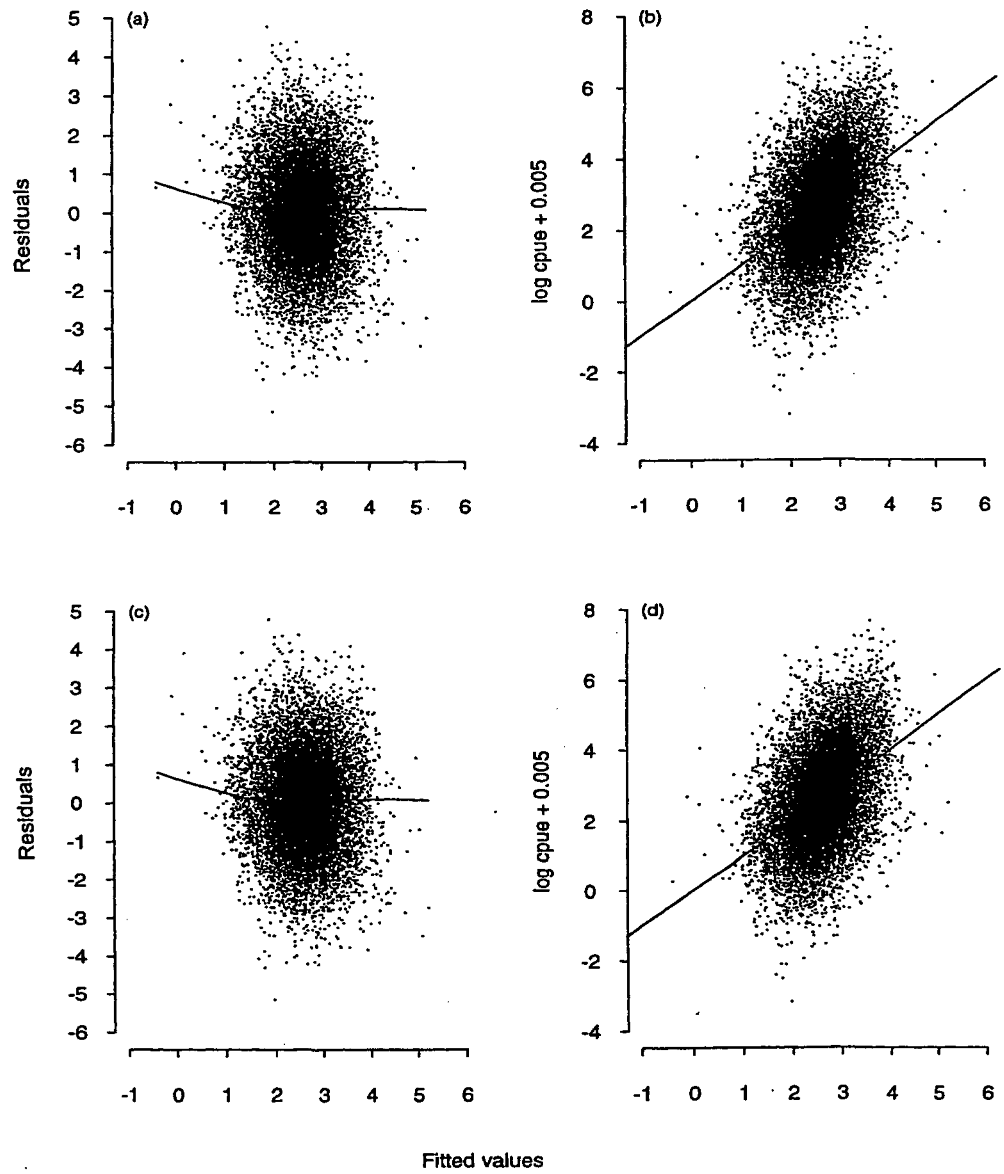

Figure A9: Plots for the ling bycatch excluding zero data set non-interaction log normal linear model, (a) fitted values versus residuals, and (b) fitted versus observed CPUE values; and for the interaction log normal linear model (c) fitted values versus residuals, and (d) fitted values versus observed CPUE values. Residual plots show LOWESS curve fitted, and observed CPUE plots show y = x line fitted.

APPENDIX B: BAYESIAN ASSESSMENT OF LIN 3 & 4

Summary

A Bayesian age-structured model was fitted to the LIN 3&4 stock. The model was fitted to CPUE, survey catch-at-age, and survey biomass data. Mean recruitment, year class strength, survey selectivity at age, and catchability for the survey and CPUE series were estimated.

In the base case model, B_0 was estimated to be 79 900 t with the ratio of B_{2000}/B_0 at 0.34. For sensitivity, an alternative longline selectivity curve based on logbook data was used. The estimated stock status was higher (0.39), however, the overall model fit was worse than the base case.

Projections to 2002 were performed with the base case model assuming catches of 3000 t to 8500 t in 500 t steps. With the catch of 4500 t the probability that the stock would be below 30% B_0 was 0.2 and below 20% was 0.01. When the catch was increased to 8500 t these probabilities increased to 0.39 and 0.06 respectively. Projections further into the future were not considered due to high uncertainty in recent year class strength estimates.

Model structure

A two-sex, age structured population dynamics model was used to model assess the LIN3&4 stock. The assessment was performed with the fishery assessment package Coleraine (Hilborn *et al.* unpublished results [version Colera20.exe]) that has the capability to produce maximum likelihood estimates as well as perform a full Bayesian analysis. Specific details of the model structure are given at the end of this Appendix.

The model was started from 1973 where the population was assumed to be unexploited. The commercial fleet was separated into longline and trawl components with selectivity varying by age, sex, and fleet. Research survey selectivity was described by four parameters, with three of these estimated in the model (the parameter describing the difference between male and female selectivity was assumed fixed).

Recruitment followed a Beverton and Holt spawner recruitment relationship and steepness was assumed known. The standard deviation of the log recruitment residual was also assumed known. CPUE and survey indices were fitted to mid-season vulnerable biomass using selectivity-at-age. A robust lognormal likelihood function was used for the survey catch-at-age data, and a lognormal likelihood function used for the CPUE and survey biomass indices. Ageing error was assumed in the fitting of the survey catch-at-age data.

Biological and fishery parameters

All biological parameters were the same as those used in the MIAEL assessment (i.e., growth parameters, M, steepness, ageing error, and the standard deviation of recruitment residuals) and are given along with a summary of assumed model structure in Tables B1–3. No attempt was made to estimate natural mortality and steepness within the model. A uniform prior with very wide bounds was assumed for R_0.

Selectivity at age was implemented using a double-half Gaussian function. Parameters estimated are the age at full selectivity and the variances of the half Gaussian functions on the left and right sides. For the commercial fishing methods these parameters were fixed to provide estimates of selectivity very similar to those used in the MIAEL assessment. For sensitivity, an alternative longline selectivity ogive based on logbook data was used. Commercial and survey selectivity-at-age curves are given in Figure B1.

Log recruitment residuals were assumed to be drawn from a normal distribution and uniform priors were assumed for all estimated parameters (Table B3). Log-uniform priors were assumed for the CPUE and survey catchability, and the selectivity variance parameters. Examination of the marginal posterior distributions did not indicate that the priors restricted estimation of key parameters.

Input data

Catch history: Catches by fishing method – longline and trawl (1973–99)
Trawl survey: RV *Tangaroa* survey on the Chatham Rise – total biomass (1992–99) [c.v. = 25%]
CPUE: Standardized CPUE from the longline fleet (1991–98) [c.v. = 35%]
Survey catch-at-age: Estimated catch-at-age (by sex) from the Chatham Rise survey (1992–99)

Estimation procedure

Coleraine has two distinct estimation procedures. The first stage involves the minimisation of the global objective function that is equal to the total negative log-likelihood plus any prior penalties. Estimates obtained in this phase are referred to as the mode of the joint posterior distribution as they are the estimates that give the highest joint posterior probability. These estimates are presented here as the point estimates.

The second estimation procedure uses the Metropolis Hastings (MH) algorithm to generate samples from the joint posterior distribution through a Markov Chain Monte Carlo (MCMC) process. By integrating over other parameters it is possible to obtain estimates of the marginal posterior distribution of parameters of interest. It is possible to obtain other Bayesian point estimates (e.g., posterior mean and median) and Bayesian confidence intervals from these marginal posterior distributions. The Bayesian confidence intervals as used here are the "equal tail" intervals rather than the regions of "highest posterior density" (Carlin & Louis 1996).

An important consideration when using this method is to test if the MH algorithm converged to the stationary distribution (assumed to represent the joint posterior distribution). There is a large body of literature on MCMC chain diagnostics with Cowles & Carlin (1996) providing a review of 13 diagnostic tests.

The method of Raftery & Lewis (1992) is intended to detect convergence to the stationary distribution and provide bounds for the accuracy of estimated quantiles for variables of interest using two-state Markov chain theory and the standard sample size formulas for binomial variance (Cowles & Carlin 1996). The user specifies the quantile to be estimated (e.g., 0.025), the desired accuracy (e.g., ± 0.005), and the required probability of attaining the specified accuracy (usually given as 0.001). Based on these values a minimum sample size can be determined based on the binomial variance assumptions.

Diagnostics were examined within the Bayesian Output Analysis (BOA) set of Splus functions (Brian Smith, www.public-health.uiowa.edu/boa). For the Raftery & Lewis test, BOA returns estimates of the length of burn-in and amount of thinning required to obtain a Markov chain with first order stationarity. This allows one to determine if the MH algorithm is likely to have converged to the posterior distribution.

Model runs

Mean recruitment, year class strengths, trawl survey selectivity, and CPUE and survey biomass catchability were estimated. An attempt was made to estimate initial age structure rather than assume that the stock was at an equilibrium virgin state. However, there are only observations for a couple of initial year classes in the survey catch-at-age data so this was not successful and the results are not reported here.

Model projections

The model was projected into the future using catches of 3000 t to 8500 t in 500 t steps. The catch was split between the two commercial methods: trawl (55%) and longline (45%) (*see* Table 8). The population was only projected two years into the future so future year class strength estimates were not important. Coleraine generates future recruitments by randomly sampling from the year class strengths estimated in the model.

Model results

The posterior mode estimates of virgin spawning biomass (B_0) and current spawning biomass were 79 900 t and 26 855 t respectively. The ratio of B_{2000}/B_0 was 0.34 (Table B4). Spawning biomass decreased over 4000 t since 1999. The fit to the CPUE was good while the model had difficulty fitting the survey biomass estimates (Figure B2). The fit to the survey catch-at-age data was generally good, but the model had some difficulty fitting the 1999 data (Figure B3).

The sensitivity analysis performed using the logbook longline selectivity estimated a higher B_0 and R_0 (Table B4). Current stock status was also more optimistic (0.39), however, the overall fit of the model to the data was worse (Table B5). Both models showed a large (about 5000 t) reduction in biomass from 1999 to 2000. The reductions in vulnerable biomass were similar to that observed in spawning biomass.

Recent estimates of year class strength are uncertain due to the small number of observations of them. It is also likely that the catchability of these younger fish is quite variable. Of particular interest is the extremely high estimate for the 1997 year class. This is the highest year class strength estimated, but the model had only one observation for it. There is evidence of a long period of relatively low recruitment from about 1982 to 1996, while recruitment was quite strong from 1976 to 1981 (Figure B4).

Bayesian estimates

The Metropolis Hastings algorithm was used to obtain estimates of the marginal posterior distributions for the parameters of interest. For the base case model, many iterations and high rate of thinning (sub-sampling) was required to obtain samples from the marginal posterior distributions that were suitable for Bayesian inference. After performing diagnostic tests on chains from short runs, a single long run of 10 000 000 iterations with every 1000^{th} iteration kept was used for inference. Properties of the chains were still not ideal so while estimates of the posterior mean should be accurate, the credible intervals may not be as reliable.

Point estimates based on the posterior mean and 90% Bayesian credible intervals are given in Table B6. The credible region for current stock status was 0.28–0.57, with 0.1 probability of being below 0.3. Spawning biomass trajectories are given in Figure B5. Estimates based on the posterior mode and mean are given as well as 90% credible intervals. The biomass declines due to the large longline catches in 1974 and 1975 and recovers by 1990. Since 1990 there is a steady decline.

Density plots of the marginal posterior distributions for four key parameters are presented in Figure B6. None of the posterior density functions show any undesirable features. The distributions for B_0 and R_0 have long right hand tails that are responsible for the asymmetry observed in the biomass trajectories.

Model projections and risk analysis

Projections to 2002 were performed using the base case model assuming annual catches of 3000 to 8500 t, in 500 t intervals. The probability that the stock was below 30% B_0 increased significantly as harvest increased (Table B7). With the catch of 4500 t the probability that the stock would be below 30% B_0 was 0.20 and below 20% was 0.01. When the catch was increased to 8500 t these probabilities increased to 0.39 and 0.06 respectively.

Management implications

The LIN 3&4 stock appears to have declined from a near virgin state in the late 1980s to about 35% B_0 in 2000. Spawner biomass has decreased about 4000 t since 1999 and is expected to decline further by 2002 under catches of 4500 t. Assuming a TAC of 8500 t, by 2002 the probability that the stock is below 30% is estimated at 0.39 compared with 0.29 for 6500 t and 0.09 for spawner biomass in 2000. The probability that the stock is below 20% B_0 is below 10% for all harvest strategies shown.

The model had difficulty fitting the recent survey catch-at-age data. This resulted in uncertainty in the estimates of recent year class strength. However, as young ling are relatively invulnerable to commercial fishing gears this does not affect the conclusions of this assessment.

The stock appears to be currently be at or slightly above the level likely to provide the maximum sustainable yield. It does not appear that the current levels of removals will be sustainable in the future.

Table B1: Assumed biological parameters and model assumptions

Parameter		Male	Female	Comments
Mean recruitment (R_0)	Estimated			
Steepness (h)	Fixed	0.9	0.9	
M	Fixed	0.18	0.18	
Initial age structure	Fixed			Assumed to be at equilibrium
Recruitment residuals (log)	Estimated			
Commercial selectivity	Fixed			MIAEL least squares estimates*
CPUE catchability (log)	Estimated			
Survey catchability (log)	Estimated			
Survey selectivity	Estimated			
Growth parameters				
L_∞ (cm)	Fixed	119.0	160.1	
k	Fixed	0.108	0.076	
t_0	Fixed	–1.24	–1.05	
Length-weight parameters				
a	Fixed	1.00E–06	1.14E–06	
b	Fixed	3.354	3.318	
Maturity ogive	Fixed			See Table B2
Ageing error	Fixed			15% above and below

* Logbook estimates for longline selectivity were used for sensitivity

Table B2: Assumed maturity ogive

Age	Male	Female
≥4	0	0
5	0.1	0
6	0.2	0.1
7	0.35	0.2
8	0.5	0.35
9	0.8	0.5
10 ≥	1	1

Table B3: Assumed priors used

Parameter	Phase	Prior type	Lower bound	Upper bound	Mean	*c.v.*
Mean recruitment (R_0)	2	uniform	1	1 000 000		
Recruitment residuals (log)	3	normal			0	0.6
CPUE catchability (log)	1	uniform	–20	15		
Survey catchability (log)	1	uniform	–20	5		
Survey selectivity						
S_{full}	4	uniform	1	20		
$\log({}_L v)$	5	uniform	–15	15		
$\log({}_R v)$	5	uniform	–15	15		

Table B4: Joint posterior mode point estimates

Model	B_0	B_{1999}	B_{2000}	B_{2000}/B_0	R_0	q
Base case	79 917	31 469	26 855	0.34	15 160	0.09
Logbook	84 040	37 136	32 386	0.39	15 942	0.09

Table B5: Breakdown of the total negative log-likelihood by the different data for the base and log book selectivity models

Component	Base	Logbook
CPUE	1.00	1.14
Survey biomass	3.52	3.10
Survey catch at age	–399.92	–396.02
Prior penalties	13.10	12.47
Total	–382.30	–379.31

Table B6: Posterior mean and 90% Bayesian confidence intervals for the base case model

B_0	B_{2000}	B_{2000}/B_0	R_0	q
97 063	41 314	0.41	18 459	0.08
(72 403–142 507)	(21 494–76 621)	(0.28–0.57)	(13 735–27 034)	(0.04–0.11)

Table B7: Risk assessment for the base case model assuming TACs of 3000 to 8500 t. 90% confidence intervals are given in parentheses

TAC (t)	B_{2002}/B_0	$P(B_{2002}<0.2B_0)$	$P(B_{2002}<0.3B_0)$
3000	0.40 (0.27 - 0.56)	0.00	0.12
3500	0.39 (0.26 - 0.56)	0.00	0.15
4000	0.39 (0.25 - 0.55)	0.00	0.17
4500	0.38 (0.25 - 0.55)	0.01	0.19
5000	0.38 (0.24 - 0.54)	0.01	0.22
5500	0.37 (0.23 - 0.54)	0.01	0.24
6000	0.36 (0.23 - 0.53)	0.02	0.26
6500	0.36 (0.22 - 0.53)	0.02	0.29
7000	0.35 (0.21 - 0.52)	0.03	0.32
7500	0.35 (0.21 - 0.52)	0.04	0.34
8000	0.34 (0.20 - 0.52)	0.05	0.37
8500	0.34 (0.19 - 0.51)	0.06	0.39

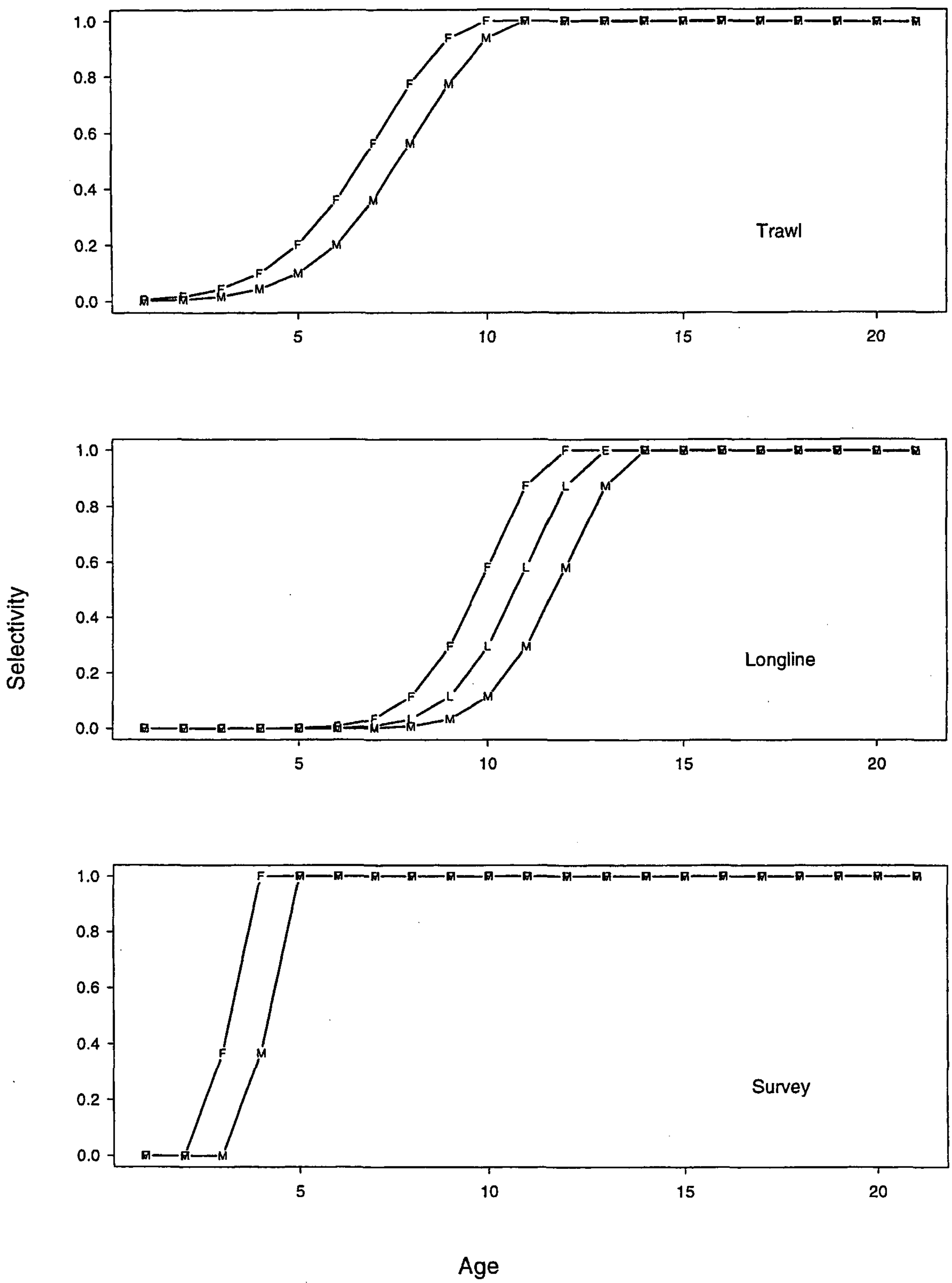

Figure B1: Selectivity curves for commercial gears and the research trawl. F, female; M, male; L, combined sex longline selectivity curve based on the log book data.

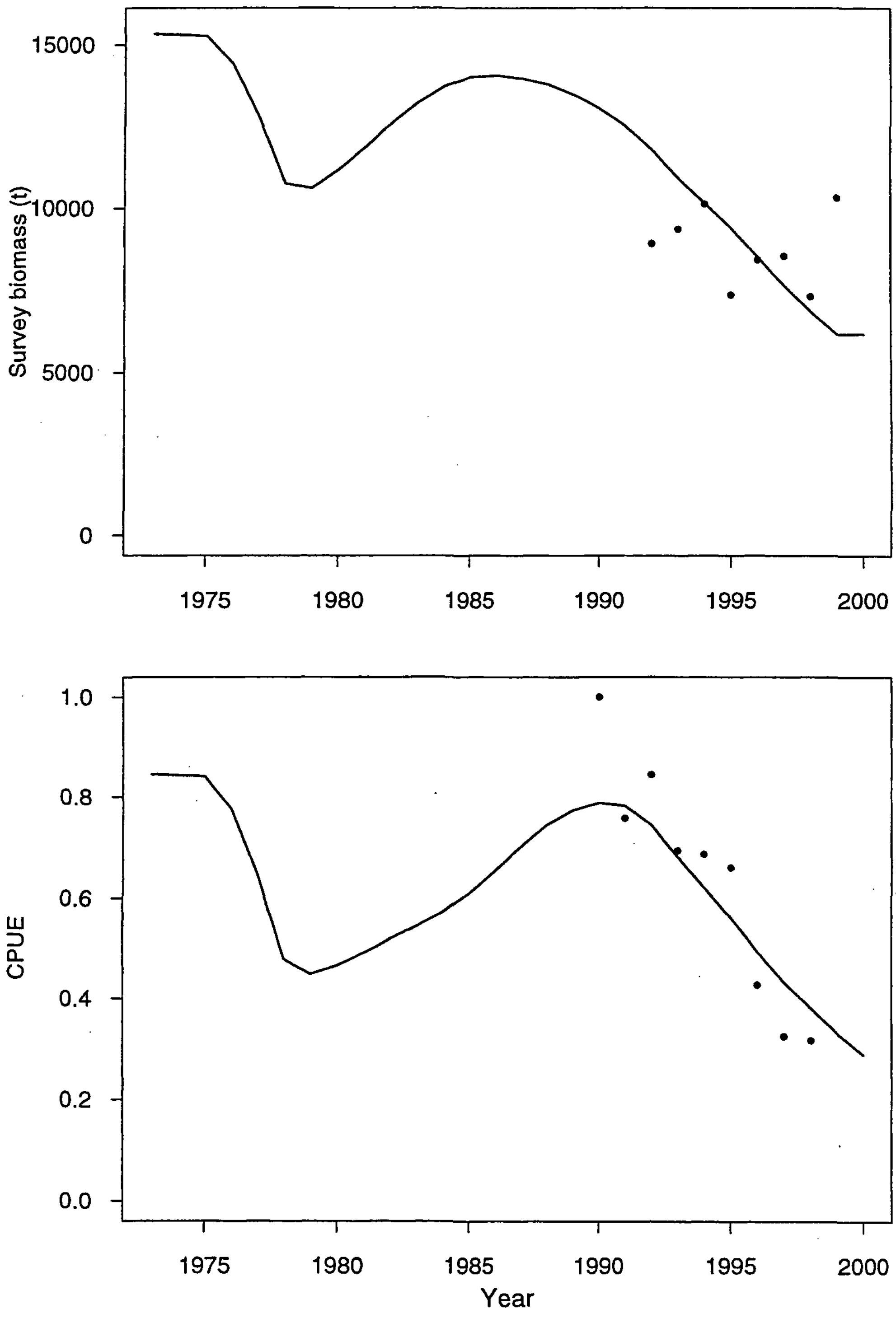

Figure B2: Fits (solid line) to the trawl survey biomass estimates (top) and CPUE indices (bottom).

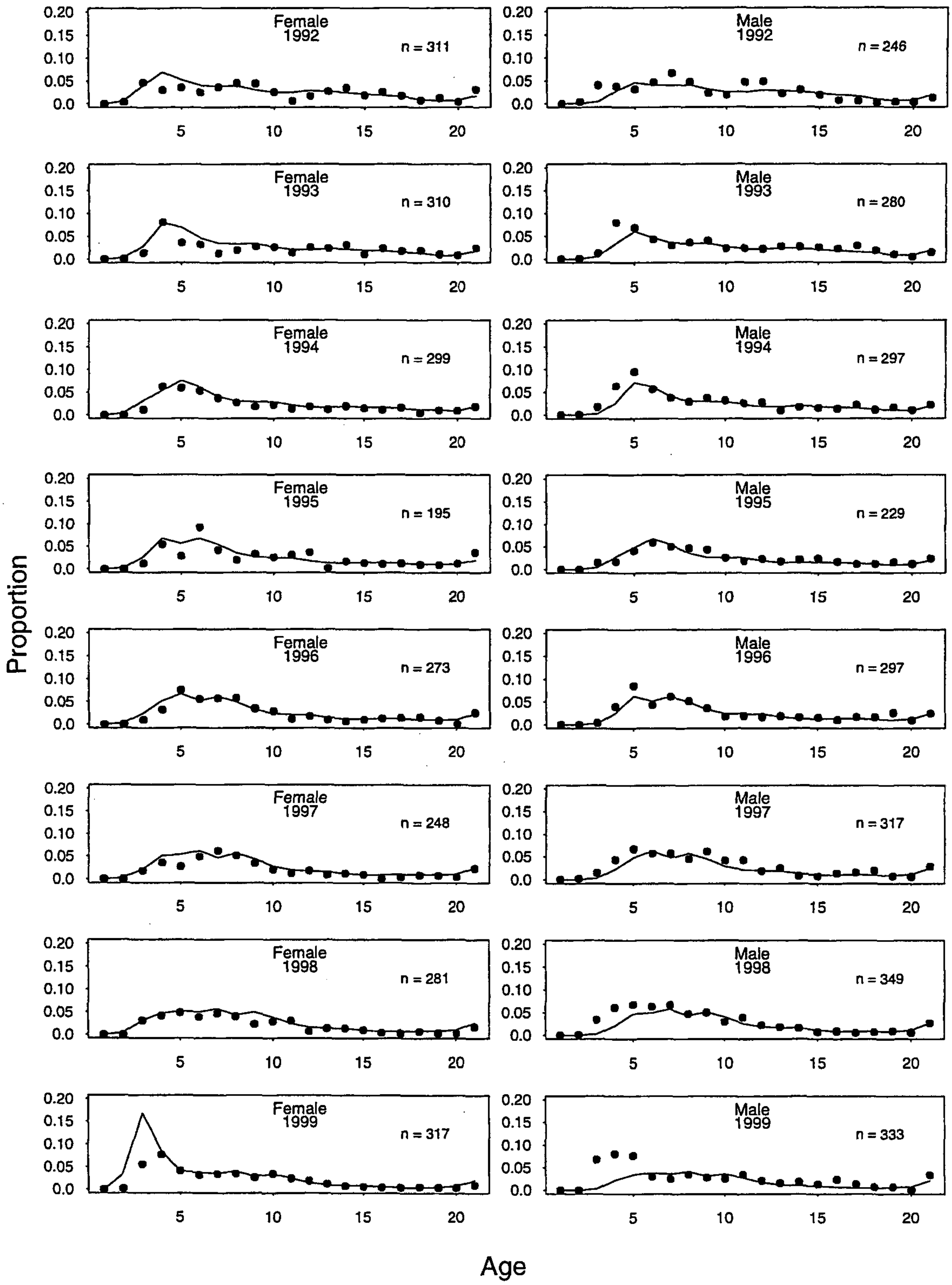

Figure B3: Model fit (solid line) to the observed survey catch-at-age data (filled circles).

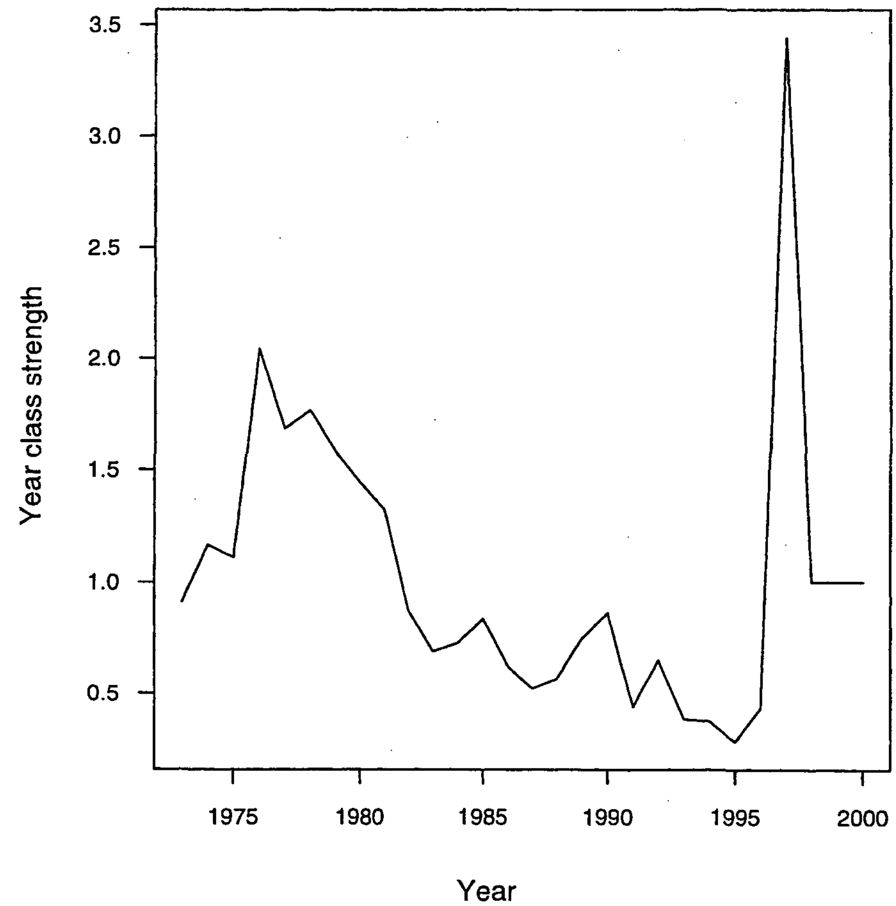

Figure B4: Year class strength estimates.

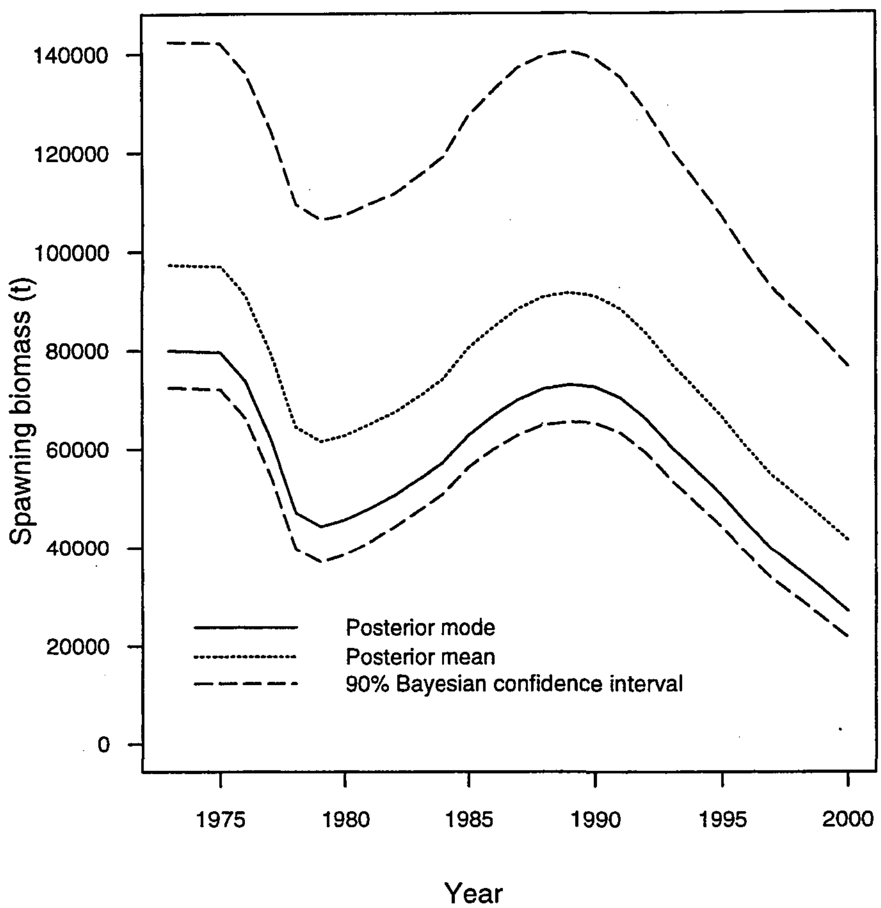

Figure B5: Biomass trajectory. Posterior mode (solid line), posterior mean (dotted line), and 90% Bayesian confidence intervals (dashed line) are given.

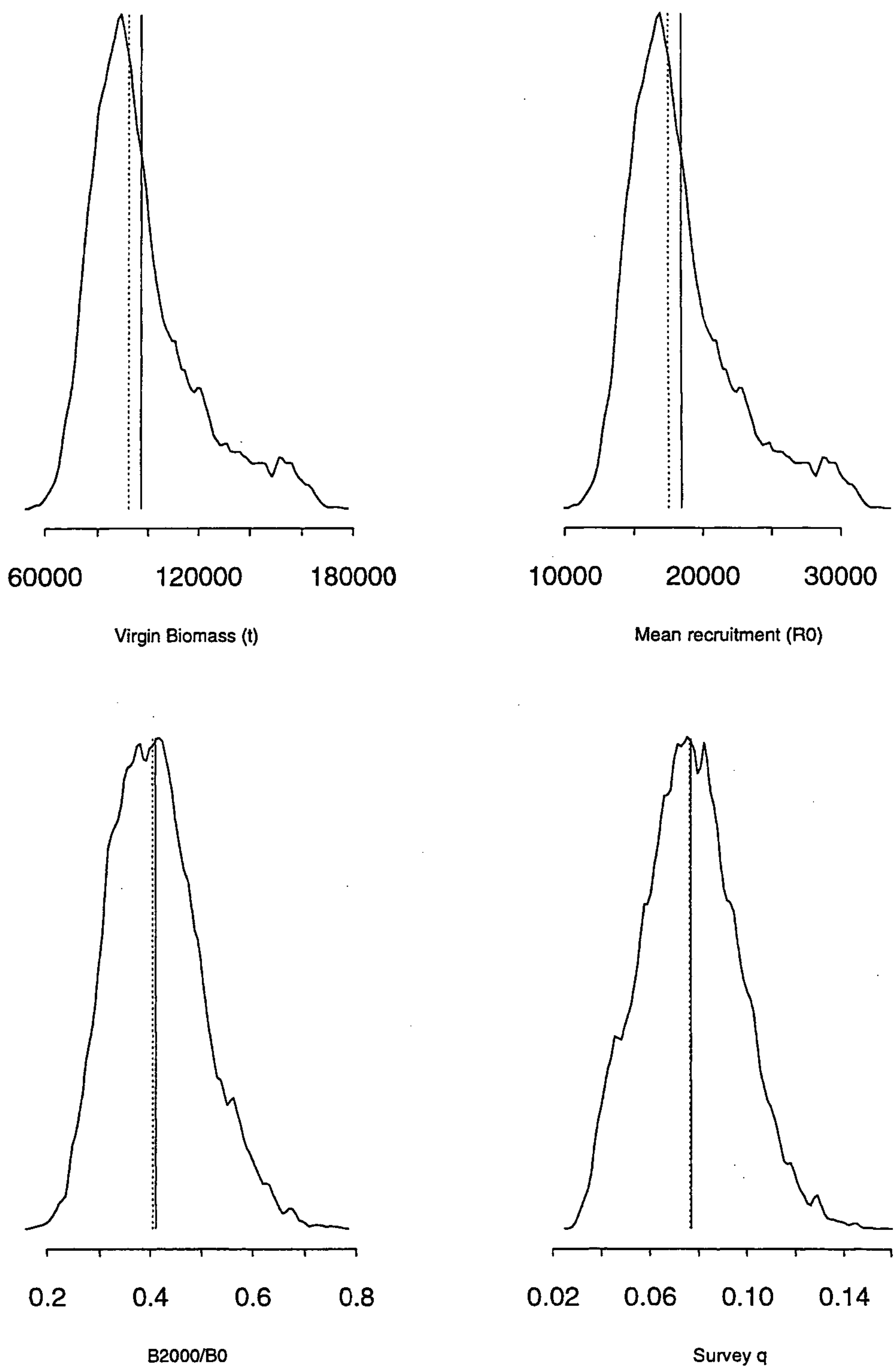

Figure B6: Marginal posterior distributions for virgin biomass (B_0), mean recruitment (R_0), current stock status (B_{2000}/B_0), and trawl survey catchability (q). The posterior mean (solid line) and posterior median (dashed line) are indicated.

Description of Coleraine model structure (from Hilborn *et al.* unpublished results)

Abundance dynamics by sex

Abundance at age and sex is propagated according to the following difference equation

$$N^{s}_{a+1,t+1} = N^{s}_{a,t} e^{-M} \left(1 - u^{s}_{a,t}\right) \qquad \text{for } a = 1, \cdots, A,$$

where M is the instantaneous rate of natural mortality, age A is a "plus" group, and $u^{s}_{a,t}$ is the exploitation rate for all gears combined obtained by summing over all gear-types

$$u^{s}_{a,t} = \sum_{g} u^{s,g}_{a,t}$$

The exploitation rate for each gear is a product of its age-specific selectivity, $s^{s,g}_{a,t}$, and the exploitation rate of fully selected fish

$$u^{s,g}_{a,t} = s^{s,g}_{a,t} \, u^{g}_{t}$$

Stock-recruitment

Recruitment follows a Beverton-Holt stock-recruitment relationship with log-normal error structure of the form

$$N^{s}_{1,t+1} = \lambda \frac{S_t}{\alpha + \beta S_t} e^{\left({}_R\varepsilon_t - {}_R\sigma^2 / 2\right)}$$

where ${}_r\varepsilon_t$ is the recruitment residual for year t (${}_R\varepsilon_t \sim N(0, {}_R\sigma^2)$), and S_t is spawning biomass in year t. The latter is computed as

$$S_t = \sum_{a} w^{f}_{a} \Phi_a N^{f}_{a,t}$$

where Φ_a (maturity ogive) is the fraction of females that have reached maturity by age a and w^{f}_{a} is female weight at age.

Recruitment at equilibrium in the absence of fishing equals

$$R_0 = \frac{SpR - \alpha}{\beta \, SpR} \qquad \text{where} \qquad SpR = \lambda \sum_{a} w^{f}_{a} \Phi_a e^{(-M(a-1))}$$

is the spawning biomass per recruit (a function of the surviving proportion, weight at age and maturity ogive). The model was parameterized with a steepness parameter, z, the proportion of the virgin recruitment that is realized at a spawning biomass level of 20% of the virgin spawning biomass.

Thus both parameters can be formulated as a function of z, R_0 *and* SpR,

$$\alpha = S_0 \frac{1-z}{4z\,R_0}$$

$$\beta = \frac{5z-1}{4zR_0}$$

$$S_0 = 0.5\,R_0\,SpR$$

Selectivity

Selectivity is a process that can be modelled as age or size-based. This model supports an age-based selectivity for the fishing fleet and a size or age-based selectivity for the surveys. In this model the only sex specific variation in the selectivity function arises from the difference between ages of full recruitment.

Selectivity as a function of age

The selectivity function implemented in the model is a double half-Gaussian function of age.

$$s_{a,t}^{s,g} = \begin{cases} \exp\left\{ \dfrac{-\left(a - S_{full}^{\;s,g_i}\right)^2}{{}_L v^{g_i}} \right\} & \text{for} \quad a \le S_{full}^{\;s,g_i} \\ \exp\left\{ \dfrac{-\left(a - S_{full}^{\;s,g_i}\right)^2}{{}_R v^{g_i}} \right\} & \text{for} \quad a > S_{full}^{\;s,g_i} \end{cases}$$

$$S_{full}^{\;s,g_i} = (S_{full}^{\;g_i} + (1-j)\Delta_{S_{full}}^{\;g_i})$$

where j is a dummy variable with value 1 for females and 0 for males and $\Delta_{S_{full}}^{\;g_i}$ is the sex specific difference in age of full recruitment for each gear.

Predicted abundance indices

Commercial CPUE and survey indices, here denoted as I_t^g, are assumed to be directly proportional to the vulnerable biomass in the middle of the year

$$I_t^g = q_t^g\; e^{-0.5M} \left(\sum_s \sum_a s_{a,t}^{s,g}\, N_{a,t}^s\, w_{a,t}^g \right) e^{\,{}_I{}^g \varepsilon_t}$$

where ${}_{I^g}\varepsilon_t \sim N(0, {}_{I^g}\sigma^2)$ and q_t^g is the gear-specific catchability.

Predicted age and size composition

The predicted age composition (in proportions) of the catch at time *t* by *sex* and *gear*, is represented by the following equation

$$P_{a,t}^{s,g} = \frac{s_{i,t}^{s,g} N_{i,t}^{s}}{\sum_{s}\sum_{i} s_{i,t}^{s,g} N_{i,t}^{s}} M_{A\,x\,A}^{pool} \quad \Omega^{S}$$

where Ω^S represents an upper diagonal matrix of age misclassification and $M_{A\,x\,A}^{pool}$ pools the age frequencies for ages $a \geq A_{pool}$ into a plus group.

If no information on age misclassification is available, an identity matrix has to be used.

Similarly, size-compositions are predicted as

$$P_{l,t}^{s,g} = \frac{s_{l,t}^{s,g} \sum_{a} f_{l|a}^{s} N_{a,t}^{s}}{\sum_{s}\sum_{l} s_{l,t}^{s,g} \sum_{a} f_{l|a}^{s} N_{a,t}^{s}}$$

when selectivity is a function of fish size, or as

$$P_{l,t}^{s,g} = \frac{\sum_{a} s_{a,t}^{s,g} f_{l|a}^{s} N_{a,t}^{s}}{\sum_{s}\sum_{a} s_{a,t}^{s,g} \sum_{l} f_{l|a}^{s} N_{a,t}^{s}}$$

when selectivity is a function of mean length at age.

Objective function

1. Robust log-normal Likelihood for proportions:

We use the robust likelihood formulation proposed by Fournier et al (1990) for the age-sex and size-sex catch compositions. The observed frequency data is incorporated to the likelihood function as proportions at age and sex, $\tilde{P}_{a,t}^{s,g}$, or at length, $\tilde{P}_{l,t}^{s,g}$. The lognormal model has been selected instead of the more traditional multinomial error model because there is then no need to specify the effective number of fish sampled.

$$\ln L^g_{\text{age}} = -0.5\sum_{i=1}^{N\text{age}}\sum_{s}\sum_{a=1}^{A}\ln\left[\left(P^{s,g}_{a,t_i}(1-P^{s,g}_{a,t_i})+.1/A\right)\right]$$
$$+\sum_{i=1}^{N\text{age}}\sum_{s}\sum_{a=1}^{A}\ln\left[\exp\left\{\frac{-(\tilde{P}^{s,g}_{a,t_i}-P^{s,g}_{a,t_i})^2}{2(P^{s,g}_{a,t_i}(1-P^{s,g}_{a,t_i})+.1/A)\tau^g}\right\}+0.01\right]$$

where A and τ^g are respectively the number of classes and the inverse of the assumed sample sizes. N_{age} is the number of age composition samples available, which correspond to years $t_1,\cdots,t_{N_{\text{age}}}$. A similar formulation is used for the size-sex compositions.

2. Abundance indices:

Different likelihood functions can be used for the commercial and survey abundance indices, namely normal, lognormal, robust normal and robust lognormal.

Thus a lognormal likelihood function has the following representation:

$$\ln L^g_I = \sum_t \ln\left[\exp\left(-0.5\frac{{}_{I^g}\varepsilon_t^2}{{}_{I^g}\sigma_t^2}\right)+0.01\right]$$

3. Total likelihood:

The total log-likelihood corresponds to the sum of the individual log-likelihood components

$$\ln L = \sum_g \ln L^g_I + \sum_g \ln L^g_{\text{age}} + \sum_g \ln L^g_{\text{length}}$$

4. Penalties:

Several penalties might be affecting the overall objective function, depending on different model assumptions. In general the penalties correspond to prior assumptions made about some of the stochastic processes involved, namely, recruitment variability

$$PSS_r = 0.5\sum_t \frac{{}_r\varepsilon_t^2}{{}_r\sigma^2}$$

5. Global objective function:

Parameter estimates are obtained by minimising the overall objective function

$$f = -\ln L + \text{penalties}$$