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EXECUTIVE SUMMARY

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Northern (SKI 1 and SKI 2) gemfish (*Rexea solandri*) catches increased during the 1980s and were maintained at about 2000–2300 t for 7 years. The Total Allowable Catch (TAC) also increased during this period to a maximum of 2452 t in 1993–94. Catches declined below 70% of the combined TACC in 1995–96 and have continued to fall. The combined TACC was reduced in 1997–98 (1601 t), and again in 1998–99 (980 t), but was still undercaught by 25% in the most recent fishing year. A substantial proportion of the catch is target fished both on non-spawning fish in SKI 2 and on spawning run fish in SKI 1. Catch-per-unit-effort (CPUE) indices show declines both fisheries, 84% in SKI 1 and 93% in SKI 2.

The SKI 1 fishery takes place in two management sub-areas; SKI 1E (in QMA 1) which includes the Bay of Plenty and east Northland; and SKI 1W (in QMA 9) off west Northland. Time series of age frequency data have been developed from commercial catch sampling programmes in SKI 1 (E and W) and SKI 2 and show that patterns of strong and weak year classes can be followed over time. Strong year classes were spawned in 1980, 1982, 1984, and 1991. The comparable data for 1996–97 to 1998–99 for SKI 1E and SKI 1W show no evidence of a separate stock in the newer SKI 1W fishery.

For the 2000 northern gemfish assessment, all relevant biological parameters and commercial catch, CPUE, and proportion at age data were incorporated into a population model using MIAEL estimation techniques (as used in the 1997 to 1999 assessments). Estimates of virgin biomass, current biomass, and yields were obtained. Results from the model suggest that the stock has declined since 1990 to about 10% of virgin biomass, well below B_{MSY}. One year projections suggest that the stock may have stabilised at current levels of catch and TACC. The model is not particularly sensitive to changes in assumed exploitation rates, but is slightly more positive when natural mortality is increased and slightly more negative when more recent (1995, 1996) year class strengths are estimated. MIAEL estimates of stock status had high performance indices (over about 70%) but estimates of virgin and current biomass are less certain.

1. INTRODUCTION

1.1 Overview

The gemfish fishery in New Zealand is managed as five Fishstocks (SKI 1, 2, 3, 7, 10) but is modelled as two stock units, northern (SKI 1+2) and southern (SKI 3+7) (Figure 1). This paper reviews the commercial fishery for gemfish in 1998–99 and describes the northern stock modelling input data, techniques, and results from the 2000 assessment.

Model input data presented here include: commercial catches, split into non-spawning season (SKI 2) and spawning season (SKI 1); two CPUE time series for SKI 1 and SKI 2 from 1989–90; two age frequency time series from commercial catches for SKI 1 and SKI 2 (derived from SKI 1E, winter 1989 to 1994, 1996 to 1999; SKI 1W, winter 1996 to 1999; SKI 2, fishing years 1995–96 to 1998–99).

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1.2. Literature review

Gemfish has been an important Australian fishery and there are numerous published reports on the biology and fishery. Rowling (1994) reviewed the southeast fishery for gemfish, including data from unpublished reports. Key published references are: Paxton & Colgan (1993) on stock structure; Lyle & Ford (1993) on reproductive biology; Withell & Wankowski (1989), Rowling (1990), & Rowling & Reid (1992) on age and growth; Rowling (1994) and Tilzey *et al.* (1990) on the fishery.

New Zealand publications on gemfish include: a review of the early development of the domestic inshore fisheries (Holton 1987); background to the early stock assessments (Hurst 1988); CPUE analyses for the northern fishery (Langley 1995, Ingerson & Colman 1997); the 1997 assessment for northern (SKI 1, 2) and southern gemfish (SKI 3, 7) stocks (Annala & Sullivan 1997); details of the biology, fishery, and assessment for the southern stock in 1997 (Hurst & Bagley 1998) and the northern stock in 1998 (Hurst *et al.* 1998) and 1999 (Hurst *et al.* 1999a); age validation and a review of stock structure of New Zealand gemfish (Horn & Hurst 1999); and the influence of ocean climate on southern (Renwick *et al.* 1998) and northern (Hurst *et al.* 1999b) gemfish recruitment patterns. Development of combined CPUE models for SKI 1 (areas SKI 1E and SKI 1W) and SKI 2 (midwater and trawl methods) were also reported by Hurst *et al.* (1999b).

A number of trawl survey reports since 1980 have included biomass and length frequency data on gemfish. Those relevant to northern gemfish are the reports on surveys of the east coast of the North Island, 1993 to 1996, by RV *Kaharoa*, which sampled juvenile gemfish (Kirk & Stevenson 1996, Stevenson & Kirk 1996, Stevenson 1996a, 1996b). Reports relevant to the southern gemfish stock were listed by Hurst & Bagley (1998).

2. COMMERCIAL FISHERY

2.1 Catch history

2.1.1 Annual catches

Hurst (1988) summarised the development of the New Zealand gemfish fishery up to the mid 1980s. Reported domestic gemfish landings did not exceed 200 t per annum until 1967. They then fluctuated between 200 and 700 t, peaking in 1971. Foreign licensed vessels operating in New Zealand waters during this period also probably caught gemfish, but it was largely unreported during the early and mid 1970s. Hurst & Bagley (1998) estimated catches from 1972 to 1977 for stock assessment modelling for SKI 3 and SKI 7, based on Japanese fishing patterns. No estimates were made for foreign catches in SKI 1 and SKI 2 for the same period because activity in gemfish areas appears to have been minimal.

On 1 March 1978, the 200 mile Exclusive Economic Zone (EEZ) was established and annual catches increased significantly, mainly due to reported catches by foreign licensed and New Zealand chartered deepwater vessels fishing around the South Island (*see* Hurst & Bagley 1998). For the fishing years 1978–79 to 1985–1986, catches were unrestrained and peaked at 8250 t in 1985–86, of which nearly 7000 t was caught in southern waters (Table 1).

The gemfish fisheries in northern waters, SKI 1 and SKI 2, developed through the 1980s, peaking at about 2300 t in 1992–93. Catches were maintained at about or just below quota levels (Table 2) until 1994–95, when they started to decline. The catch history used for stock reduction modelling, divided into spawning (SKI 1) and non-spawning (SKI 2) catch, is given in Table 3. Catches for 1999–00 and 2000–01 (given as catch years 2000 and 2001) were assumed based on the TACC for 1999–00.

2.1.2 Total Allowable Catch (TAC)

On 1 October 1986, Individual Transferable Quota controls were introduced under the Quota Management System (QMS). The quotas for gemfish were initially based on 1983 catch levels (1984 for SKI 1) which were the highest levels of catch recorded at the time yields were estimated (*see* Table 2). This assumed that all gemfish fisheries were still developing. Initial TACs for SKI 1 and SKI 2 were 550 and 860 t, respectively. These were gradually increased over time through Quota Appeal Authority decisions to 1152 and 1300 t. The TACCs for both areas were reduced for the 1997–98 fishing year, as a result of declining CPUE and the 1997 and 1998 stock assessment modelling results. The 1997–98 TACCs for SKI 1 and SKI 2 were 752 and 849 t. They were further reduced to 460 and 520 t for 1998–99.

2.2 Catch-per-unit-effort (CPUE)

Standardised CPUE analyses of two gemfish fisheries are presented here. They update the new models developed in 1999 (Hurst *et al.* 1999b) to incorporate interaction effects and provide combined area indices for SKI 1 (E and W) and combined method (bottom and midwater trawl) indices for SKI 2. This new approach replaces that used previously for SKI 1E (Langley 1995), SKI 2 (Ingerson & Colman 1997), and SKI 1W (Hurst *et al.* 1998, 1999a).

2.2.1 General methodology

All data used are for trawls targeting gemfish. These vessels fill out either Catch, Effort and Landing Returns (CELR) or Trawl, Catch, Effort and Processing Returns (TCEPR). All data were summarised into CELR format, i.e., vessel, day, and statistical area (statarea). In SKI 1 fisheries, target fishing occurs from April to September in statistical areas 001–010 (SKI 1 E) and 046 and 047 (SKI 1W). In SKI 2 target fishing occurs throughout the year but is minimal in winter. Statistical areas included are 011–016.

Raw data were checked and added to the database. Indices of relative abundance were calculated from the commercial catch and effort data using a multiple regression technique (*after* Vignaux 1992). Although the proportion of zero records has increased slightly in recent years (Table 4), CPUE indexes were not sensitive to the number of zero values, at least up to the fishing year 1997–98 (Hurst *et al.* 1999b). Zero catch/day records were therefore arbitrarily assigned a catch of 1 kg to avoid taking the log of zero. The mean catch rate/hour was derived from the catch/day divided by the total hours trawled/day. The index log (mean catch/hour) was then regressed against each of the possible predictor variables to determine which of these variables explained most variability in the CPUE.

Vessel was a categorical variable with each vessel assigned its own category unless there were less than 50 records, when vessels were lumped together. Fishing year, statarea, and data source were included as categorical variables. Data source indicates whether the record was derived from TCEPR or CELR data. Day was treated as a categorical variable comprising eight evenly filled bins that span the range of days fished. For the SKI 2 model only, an additional method categorical variable was included, indicating whether the records were for bottom or mid-water trawl.

A first order model was selected by forward stepwise regression with the criterion that an additional variable must increase r-squared by 2% absolute, i.e., 20 to 22. For SKI 1 the selected model was vessel + year + statarea + day. And for SKI 2 vessel + year + day + statarea (variables given in order of selection.

Interactions were examined between the selected first order terms in each model. However, interactions involving year or vessel were not candidates for including in the model and were examined purely for diagnostics. This left the statarea/day interaction as the only candidate for inclusion in the model. For SKI 1 this interaction increased r-squared by 3.7% and the effects, when plotted, had a believable pattern, so the interaction term was included in the final model. For SKI 2 this interaction added 2.9% to r-squared but the pattern appeared to be somewhat random. This interaction was therefore not included in the final model.

2.2.2 SKI 1 results

A summary of the data used in the model is given in Table 4. The first order stepwise regression results are shown in Table 5. The nested second order interaction term (statarea/day) increased r-squared from 30.5% to 34.2% and the effects, when plotted, had a believable pattern. Therefore, the interaction term was included in the final model (vessel + year + statarea + statarea/day) and resulting CPUE indices are given in Table 6. Plots of the CPUE index from the 2000 model, and the index from the 1999 model, are shown in Figure 2a. Models from both years are similar, with the most recent CPUE index falling from 1.0 in 1989–90 to 0.16 by 1998–99.

2.2.3 SKI 2 results

A summary of the data used in the model is given in Table 4. The first order stepwise regression results are shown in Table 7. The nested second order interaction term (statarea/day) increased r-squared from 24.5% to 27.4% but the pattern appeared to be somewhat random. This interaction was therefore not included in the final model (vessel + year + day + statarea). Resulting CPUE indices are given in Table 6. Plots of the CPUE index from the 2000 model, and the index from the 1999 model, are shown in Figure 2b. Models from both years are similar, with the most recent CPUE index falling from 1.0 in 1989–90 to 0.07 by 1998–99.

2.3 Size and age composition of commercial catches

Otoliths and length frequency data have been collected from the three main commercial fisheries: SKI 1E, winter 1989 to 1994, 1997 to 1999; SKI 1W, winter 1996 to 1999; SKI 2, fishing years 1995–96 to 1998–99.

2.3.1 Length frequencies

Catch sampling data collected by the Ministry of Agriculture and Fisheries (MAF) up to 1992 were presented by Langley *et al.* (1993). From 1995–96, catch sampling in SKI 2 has been by NIWA, and from 1996–97 in SKI 1 by NIWA and Sanford Ltd. Details of the numbers of samples taken in each area and year are given in Tables 8 and 9.

For the 1998 assessment, the SKI 1 length frequencies sampled by NIWA and Sanford were compared before they were combined. There was no indication of any major differences (*see* Hurst *et al.* 1998) and the data were pooled. This procedure was also followed in 1999 and 2000. Length frequencies for 1998–99 are given in Figure 3.

2.3.2 Age frequencies

The full time series of otoliths was aged using the technique developed by Horn & Hurst (1999). A separate age-length key was then derived for each sex, fishery area, and year, and applied to the scaled length frequency to determine the age frequency. The resulting percentages at age, by sex, are given in Tables 8 and 9. Age data for SKI 1E and 1W are combined in the model. The annual mean coefficient of variation (*c.v.*), weighted across all age classes, has ranged from 0.19 to 0.27 for SKI 1 (E and W combined) and 0.13 to 0.21% for SKI 2.

Age frequency data for SKI 1E, SKI 1W, and SKI 2 are shown in Figure 4. Data for SKI 2 (pre-spawning) have been made comparable to SKI 1 (spawning run) by assigning fish their birthday.

The SKI 1E time series now includes 9 years of data and indicates that relatively strong year classes were spawned in 1980, 1982, 1984, and 1991 (Figure 4a). The strong 1980 year class had almost completely disappeared from the age frequencies in 1998. These strong year classes are also apparent in the age frequencies for SKI 1W (Figure 4b) and provide support for the hypothesis that fisheries in SKI 1 are based on the same stock. If the newly developed SKI 1W fishery was totally separate from SKI 1E, the age frequency would have been expected to show a greater proportion of older fish which had been less subjected to exploitation.

A breakdown of age frequency by fishing method (bottom or midwater trawl) in SKI 2 did not show any major differences (*see* Hurst *et al.* 1999a, appendix 2) and so the previous approach of combining all data for SKI 2 was continued. The age frequencies for SKI 2 (Figure 4c) show the same strong year classes as for SKI 1, also supporting the hypothesis that fisheries in SKI 1 and SKI 2 are based on the same stock. The greater prominence of the 1991 year class in SKI 2 is because the fishery is on non-spawning fish. The SKI 1 fisheries are on adults migrating to spawn. These fish are not fully recruited into the fishery until about age 7 or 8 (*see* Section 4). The SKI 2 fishery is on non-spawning fish and includes a greater proportion of young fish that are immature.

Age frequency data were combined for SKI 1E and 1W and proportions at age (Table 10) were determined for input into the model. Both sexes combined sum to 1.0 for each year (unlike the raw data in Table 12 and 13 that sum to 100% for each sex). The SKI 2 proportions at age are fitted in the model at the pre-spawning stage of the year and are lagged one year earlier compared to SKI 1. Age data are assigned a *c.v.* of 35% in the model, weighted by the number of samples per year. These model *c.v.*s are also given in Table 10.

2.4 Non-commercial fisheries

2.4.1 Recreational fisheries

There was no recreational catch reported in marine recreational fishing catch and effort surveys of the MAF Fisheries South and Central regions (1991–92 and 1992–93, respectively). However, there is a target recreational fishery in the Bay of Plenty. Reported gemfish catch in the North region recreational survey December 1993 to November 1994 was negligible (three fish) and scaled up to about 1 t. Gemfish harvest estimates from the 1996 national recreational survey were 5000 fish from SKI 1 and 2 and less than 500 fish from SKI 7.

2.4.2 Maori customary fisheries

Quantitative information on the current level of Maori customary take is not available.

2.4.3 Illegal catch

The amount of gemfish misreported is not available.

2.4.4 Other sources of mortality

There may have been some gemfish discarded before the introduction of the EEZ, but this is likely to have been minimal since the early 1980s as gemfish is a medium value species. Adult and juvenile gemfish are a bycatch in scampi fisheries off the east coast of the North Island (Cryer *et al.* 1999), but the level of catch has not been quantified.

3. RESEARCH

Hurst & Bagley (1998) reviewed gemfish stock structure in New Zealand waters as part of the stock assessment for southern gemfish. Horn & Hurst (1999) presented age frequency data for all gemfish fisheries, estimated age and growth parameters, and updated the review of gemfish stock structure. A summary of these papers, relevant to the northern gemfish stock assessment, is presented here. Other important biological parameters for stock assessment are also listed.

3.1 Stock structure

The current issue for the northern gemfish assessment is the relationship of SKI 1E, SKI 1W, and SKI 2 to each other.

The SKI 1 and SKI 2 fisheries have continued to exhibit the same seasonal patterns as found by Hurst (1988). In the northern fisheries (SKI 1), about 70% of the catch is taken in May and June. In SKI 2, catches are spread throughout the year, except for an almost zero catch during the winter in June to August (Hurst *et al.* 1998, 1999a). Localised fishing patterns suggest a movement of SKI 2 fish north during May and a return via the Bay of Plenty and East Cape in August-September. Running ripe females are recorded only from SKI 1 and the distribution of young fish (15–30 cm, 6–12 months old) is quite localised and consistent with the distribution of ripe females (*see* Hurst & Bagley (1998) figures 24, 25).

Age frequency data for the main SKI 1 and SKI 2 fisheries are presented and discussed in Section 3 and Figure 4. These data show the same pattern of strong year classes, 1980, 1982, 1984, and 1991 and provide support for the hypothesis of one stock in SKI 1 and 2.

Horn & Hurst (1999) derived von Bertalanffy parameters for northern gemfish from the age-length data from the commercial fisheries, as well as length frequency data for juvenile fish from the trawl surveys off the Wairarapa coast (Table 11). A comparison of the von Bertalanffy parameters calculated for the different areas using the combined otolith and length-based data sets showed some significant between-samples differences in the L_{∞} and k parameters, but the differences were not consistent between areas or sexes.

There were no significant differences in mean length at age of gemfish from SKI 1E and 1W in 1997 (Hurst *et al.* 1998). No comparison was made with gemfish from SKI 2 as the samples were taken at a different time of year and included more than just the spawning part of the population.

All the above data provide evidence for an autumn spawning migration from central North Island waters (SKI 2) into more northern waters (SKI 1). The main outstanding issue for stock assessment of northern gemfish is the origin of the west Northland spawners. One hypothesis is that they are from SKI 2, via the east or west coasts of the North Island. An alternative hypotheses could be that they are a separate northwestern stock which is fished only during the spawning migration. However, given the evidence above, this seems unlikely and the current assessment assumes they are all one stock.

3.2 Mortality estimates

Ageing of northern gemfish samples from the current population indicated an A_{max} (i.e., age reached by 1% of the population) of about 15 years for males and 16 years for females (Horn & Hurst 1999) found that.

A range of estimates of natural mortality (M) can be derived from the equation

$$M = \log_e(100)/A_{max}$$

where A_{max} is the age reached by 1% of the virgin population (Sparre *et al.* 1989).

A maximum age of 15 in the current population produces an estimate of M of 0.3. As the samples were clearly not from virgin populations, it seems likely that M for gemfish is in the range 0.2–0.3, with the current best point estimate being 0.25.

3.3 Trawl survey biomass estimates

Biomass estimates are available for northern gemfish from SKI 2, from four east coast North Island surveys, 1993 to 1996, by RV *Kaharoa* (Kirk & Stevenson 1996, Stevenson & Kirk 1996, Stevenson 1996a, 1996b). These surveys sampled out to 400 m depth and may therefore have missed some gemfish, which are known to occur deeper (Hurst & Bagley 1998). Gemfish are also frequently caught by midwater trawl gear off the east coast of the North Island and vertical availability may vary between surveys. The biomass estimates have therefore not been used in the stock assessment modelling. However, the surveys sampled younger age classes (up to about age 4) and these data were used to determine the length at age of northern juvenile gemfish (Horn & Hurst 1999).

4. STOCK ASSESSMENT

The first stock reduction analysis for the northern gemfish stock was carried out in 1997, using MIAEL estimation techniques (Cordue 1993, 1996, 1998a). In 1998, the MIAEL analysis was updated and a new separable Sequential Population Analysis (sSPA) was carried out (Hurst *et al.* 1998). In 1999 (Hurst *et al.* 1999a) and 2000, the stock reduction analysis was again updated using MIAEL estimation. Description of the single stock model and recent improvements to the model (e.g., penalty functions which provide cubic parameterisations of the selectivities and encourage year class strengths to average 1) were given by Cordue (1998b, 2000) Estimates of mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 1999–00 (B_{mid00}), and 2000–01 (B_{mid01}), and estimates of 2001 beginning of year total biomass (B_{beg01}) are presented below.

4.1 Stock hypotheses

One stock hypothesis (SKI 1 and SKI 2) was modelled for northern gemfish in 2000. The alternative hypothesis (SKI 1E and SKI 2) was not modelled as results from previous assessments were similar to those from the SKI 1 and SKI 2 model (*see* Hurst *et al.* 1998).

4.2. The stock assessment model

4.2.1 Input data

The pre-spawning (SKI 2) and spawning season (SKI 1) catches used in the modelling are given in Table 3. Catches for 2000 and 2001 were assumed to be at the level of the 1999–2000 TACC.

Commercial catch-at-age data included in the models (SKI 1E, winter 1989 to 1994, SKI 1E+1W, winter 1996 to 1999; SKI 2, 1995–96 to 1998–99) are given in Table 10. A median *c.v.* of 35% (unless indicated) was assumed for each year's age data and weighted by the number of samples per year (*see* Table 10). Ageing error applied was ± 5% from age 5. Normal error structure was used. Von Bertalanffy growth parameters calculated by Horn & Hurst (1998) are given in Table 11.

Standardised CPUE indices for SKI 1 and SKI 2 are shown in Table 6. A *c.v.* of 35% was applied to the CPUE indices, unless indicated. Lognormal error structure was used.

4.2.2 Model procedure

The MIAEL model uses a two stage process. All the input data are used in the first stage to obtain least squares estimates of YCS, the maturity ogive, and the home (i.e., all fish in the pre-spawning ground, SKI 2) selectivity ogive. The spawning (i.e., mature fish in the spawning ground, SKI 1) selectivity ogive is not estimated and is assumed to be 1.0 for ages 3 to 8. The second stage of the procedure produces the least squares and MIAEL estimates of biomass.

The MIAEL model used for northern gemfish in 2000 was similar to that used for the 1997 (Annala & Sullivan 1997), 1998 (Hurst *et al.* 1998), and 1999 (Hurst *et al.* 1999a) assessments. It was a single stock, age-structured, two-sex population model (*see* Cordue 1993, 1995, 1998b) which used the input parameters for the base case and sensitivity runs listed in Table 12.

Two base case models are presented for the 2000 assessment. The first, Base 1, is an updated version of the base case model used in 1999, The second, Base 2, is the same model except that the maturity and home selectivity ogives were estimated (see below). Sensitivity tests to the second base case (Base 2) were the same as those in the 1999 assessment, although two additional tests (maximum exploitation rate on the spawning ground = 0.35, decreased relative weighting of CPUE indices) were carried out in 2000.

4.2.3. Year class strength and ogives

In the first stage of the MIAEL model, year class strength was estimated for 1978 to 1994 (Table 13). Mean estimated year class strength was encouraged to average 1, as for the 1999 assessment. The most recent year for which YCS was to be estimated was chosen as 1994 because there were at least 3 years of observations of it in the proportion at age data. All other YCS were assumed to be 1, except for sensitivity 4, where YCS for 1995 and 1996 were also estimated. The YCS were re-estimated for each sensitivity run of the model. All runs estimate higher recruitment in the early 1980s and low recruitment from 1989, except for one relatively strong year class in 1991. Mean estimated recruitment variability (*rsd*) was about 1.2, except for the runs where $M = 0.3$ ($rsd = 0.89$) and where the 1995 and 1996 YCS were estimated ($rsd = 1.49$).

Maturity and selectivity ogives are given in Tables 14 and 15. A maturity ogive was estimated for ages 2 to 8, and a home selectivity ogive was estimated for ages 1 to 8 for all runs except the base case comparison with 1999 (Base 1). The estimated maturity ogives for males were more similar to the assumed ogive for the Base 1 run than for females. In the Base 1 run, the home selectivity ogive was based on a 50% selectivity at age 3 (based on a 50% trawl selection length at age 3) and assumed full selectivity at age 5 for both sexes. For the Base 2 and most sensitivity runs, the estimated home selectivity ogive exceeded 1.0 for ages 5 to 7 and was similar for males and females. When $M = 0.3$, the estimated ogive was more similar to the assumed Base 1 ogive.

4.2.4 MIAEL biomass estimates

Estimates and ranges of mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 1999–00 (B_{mid00}), and 2000–2001 (B_{mid01}), and estimates of 2001 beginning of year total biomass (B_{beg01}) were obtained using the MIAEL estimation procedure (Table 16). The estimates of mid-spawning season biomass are for mature fish on the spawning ground and allow for comparisons of current biomass with virgin biomass. The estimates of beginning of year biomass are for all fish on the home ground and are required for estimation of CAY. The least squares estimates reported are from the second step of the model estimation procedure. Initial least squares estimates for B_0 were similar (i.e. within 2 to 16%) and are not reported here.

The MIAEL point estimates of B_0 for Base 1 and Base 2 were 17 400 and 17 800 t. B_0 point estimates for sensitivity tests ranged from about 13 100 to 21 250 t. All were lower than the Base 2 estimate, except where M was 0.2 and $r_{sp.max}$ was 0.35.

Base case MIAEL point estimates of B_{mid00}/B_0 were 9 and 11% for Base 1 and Base 2. Sensitivity runs ranged from 11 to 14%. Forward projections for one year suggested that stock size might remain at similar levels, assuming catches at the level of the current TACC. Point estimates of B_{mid01}/B_0 were 12 and 10% for Base 1 and Base 2. Estimates for sensitivity runs ranged from 5 to 14%. The model was most sensitive to estimated values for recent recruitment and differing values of M. Where recruitment in 1995 and 1996 was estimated to be low, the B_{mid01} estimate was about 5% of B_0. Performance indices for base case runs were high (over 70%) for stock status (B_{mid00}/B_0 and B_{mid01}/B_0)

but less certain for estimates of virgin biomass (about 40%) and 2001 beginning of year biomass (about 50%).

The biomass trajectories of minimum and maximum biomass and the MIAEL estimates of B_{mid00} and B_{mid01} as a percentage of B_0 are shown in Figure 5. Trajectories are similar for most runs, suggesting that biomass increased during the late 1980s followed by a decline caused by lower recruitment and increased fishing pressure.

Base case and sensitivity model fits to SKI 1 and 2 CPUE indices are shown in Figure 6a. In general, the model has difficulty in fitting the steepness of the decline in CPUE. Fits to the proportion-at-age data are shown in Figure 6b, for Base 2 only. Other runs resulted in only minimal changes in the fits. Some of the age data were not well fitted. Down weighting of the CPUE indices was tried in an attempt to improve these fits but resulted in almost no change.

4.2.5 MIAEL estimation of Maximum Constant Yield (MCY)

The method used to estimate MCY was MCY = pB_0, where p is determined for each stock using the method of Francis (1992) such that the biomass does not go below 20% B_0 more than 10% of the time. Details of the modelling procedures that produced the B_0 estimates from which MCY was estimated are given above and in Table 8. The catch ratio used for SKI 1and SKI 2 was 1:1, based on the last 4 years catch. Francis (1992) suggested that, if current spawning biomass is below 20% B_0, the MCY could be scaled down linearly according to current stock status. This assessment suggests that the northern gemfish current biomass may be below 20% B_0. Hence, both the long-term MCY (MCY_{lt}) and scaled down MCY have been estimated. MCY estimates for the Base 1 and Base 2 models are:

Fishstock		B_{MCY} (% of B_0)	MCY (% of B_0)	MCY_{lt} range	MCY_{lt}	Performance index (%)	MCY range	MCY
SKI 1, 2	Base 1	56.7	6.9	730–4260	1200	41	330–1920	540
SKI 1, 2	Base 2	56.7	7.0	750–4370	1250	36	410–2400	700

4.2.6 Estimation of Current Annual Yield (CAY)

The method of Francis (1992) was used to estimate the range and point estimates of CAY from the range (B_{min}, B_{max}) and point estimate (MIAEL) of current biomass (B_{beg00}) given in Table 16. The catch ratio used for SKI 1: SKI 2 was 1:1, based on the last 4 years catch. CAY estimates for Base 1 and Base 2 are:

Fishstock		B_{MAY} (% of B_0)	MAY (% of B_0)	CAY range	CAY	Performance index (%)
SKI 1, 2	Base 1	35.6	10.3		1140	52
SKI 1, 2	Base 2	35.4	10.5	640–8680	1280	47

Results of both base case models are similar to the SKI 1+2 base case in the 1999 assessment. Stock status is estimated to be low and point estimates of virgin and beginning of year biomass are lower in the 2000 assessment, which in turn results in lower point estimates of MCY and CAY (1999: 915 and 1350 t, respectively).

5. MANAGEMENT IMPLICATIONS

There are more data available on which to determine stock relationships for northern gemfish than were available for the 1997 to 1999 assessments. Data on the seasonality of the fisheries, known spawning locations, distribution of juvenile fish, and age frequencies indicate that SKI 1 and SKI 2 gemfish are separate from SKI 3 and SKI 7 gemfish (Hurst & Bagley 1998, Horn & Hurst 1999, Hurst *et al.* 1999a). It appears that the SKI 1W gemfish are probably part of the same stock as SKI 1E and SKI 2, based on catch sampling data for the last 4 fishing years. Therefore, only one stock hypothesis, SKI 1 + 2, was modelled in the 1999 and 2000 assessments.

Standardised CPUE indices have shown declines of about 90% in the SKI 1 and SK1 2 fisheries but appear to have leveled off in the last year. Year class strengths since 1988 appear to have been low, except for one strong cohort in 1991. Base case model results suggest the stock is at about 10% of virgin biomass, which is well below the level that would support the MSY. One year projections suggest that stock size is likely to remain at similar levels if catches at the level of the TACC are taken.

Year classes from 1995 are assumed to be average in the base case models. Estimates of 1995 and 1996 year class strengths, although not well estimated, appear to be low. If these year classes are as low as estimated, one year projection of current biomass suggests that stock size may decline to about 5% virgin biomass.

6. FUTURE RESEARCH RECOMMENDATIONS

- Catch sampling for gemfish was to be discontinued in one of the two northern fishery areas from 1999–2000. There is still uncertainty about recent levels of recruitment of gemfish into the fishery, in particular, selectivity patterns on the home ground (SKI 2) and the maturity ogive for fish in the spawning area (SKI 1). Continued sampling in both areas is required to improve these estimates. Sampling in SKI 2 would allow for new recruits to be estimated sooner and should enable better estimation of home selectivity. However, sampling effort may need to be increased (currently 15 samples per year) to allow for potential variability in fishery selectivity and sampling from an 8 month fishery. Sampling in SKI 1 has the advantage of being on a target fishery for mature adults over a 6 week period but may not allow for reliable estimation of new recruits.

- Age data are not fitted well by the model and this needs to be explored in more detail. Increasing the relative weight on the age data did not improve the fits; future work could consider alternative maximum ages for maturity ogives and investigate any inconsistencies between SKI 1 and SKI 2 or male and female age frequency data. Trawl survey length frequency data for pre-recruits from the east coast North Island series could be analysed to provide extra indices for SKI 2 (note that otoliths were available for only one survey, but the other surveys could be analysed using MIX).

- Combining areas (SKI1 E + W) for SKI 1 and methods (bottom + midwater) for SKI 2 has resulted in the more efficient production of CPUE models which show the same general trends, and may be more robust because they include more data. Future refinements could include the development of a shorter TCEPR data only time series, as most data are now recorded on these forms.

- Modelling of the SKI 1 and 2 stock used a similar approach to previous assessments. Proposed changes to the MIAEL model structure will allow for year class strength and biomass to be estimated in one step, rather than the two-stage process used at present.

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Table 1: Reported landings (t) of gemfish by fishing year and area, by foreign licensed and joint venture vessels, 1978–79 to 1985–86. The EEZ areas correspond approximately to the QMA as indicated. No data are available (N/A) for the 1980–81 fishing year

EEZ area	B	C	D	E - E(A)	E(A) §	F(E)	F(W)	G	H	Total
QMA area	1 & 2	3	4	6	5	5	5	7	8 & 9	
1978–79*	87	638	0	0	342	263	65	1 093	154	2 642
1979–80*	284	369	29	18	944	352	214	303	34	2 347
1980–81*	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1981–82*	0	112	5	0	321	223	361	1 063	167	2 252
1982–83*	0	13	3	0	883	135	310	458	408	2 209
1983–83†	0	92	2	0	44	100	16	1 125	11	1 391
1983–84‡	0	59	2	0	298	582	2 234	1 395	86	4 657
1984–85‡	0	29	1	3	262	758	1 204	1 317	37	3 686
1985–86‡	0	293	7	32	403	2 213	2 315	1 268	28	6 558

* 1 April–31 March.
† 1 April–30 September.
‡ 1 October – 30 September
§ Catches in EEZ area E(A) were mostly from the part of FMA 5 south of 48°30' S.

Table 2: Reported landings (t) of gemfish by Fishstock from 1983–84 to 1996–97 and actual TACs for 1986–87 to 1997–98

	SKI 1		SKI 2		SKI 3		SKI 7		SKI 10		Total	
Fishstock	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1983–84*	588	-	632	-	3 481	-	1 741	-	0	-	6 442§	-
1984–85*	388	-	381	-	2 533	-	1 491	-	0	-	4 793§	-
1985–86*	716	-	381	-	5 446	-	1 468	-	0	-	8 011§	-
1986–87†	773	550	896	860	2 045	2 840	1 069	1 490	0	10	4 783	5 750
1987–88†	696	632	1 095	954	1 664	2 852	1 073	1 543	0	10	4 528	5 991
1988–89†	1 023	1 139	1 011	1 179	1 126	2 922	1 083	1 577	0	10	4 243	6 827
1989–90†	1 230	1 152	1 043	1 188	1 164	3 259	932	1 609	0	10	4 369	7 218
1990–91†	1 058	1 152	949	1 188	616	3 339	325	1 653	0	10	2 948	7 342
1991–92†	1 017	1 152	1 208	1 197	287	3 339	584	1 653	0	10	3 096	7 350
1992–93†	1 292	1 152	1 020	1 230	371	3 345	469	1 663	0	10	3 152	7 401
1993–94†	1 156	1 152	1 058	1 300	75	3 345	321	1 663	0	10	2 616	7 470
1994–95†	1 031	1 152	905	1 300	160	3 355	103	1 663	0	10	2 215	7 480
1995–96†	801	1 152	789	1 300	49	3 355	81	1 663	0	10	1 720	7 480
1996–97†	965	1 152	978	1 300	58	1 500	238	900	0	10	2 240	4 862
1997–98†	627	752	671	849	27	300	44	300	0	10	1 369	2 211
1998–99†	413	460	335	520	17	300	59	300	0	10	824	1 590

* FSU data.
† QMS data.
§ The totals do not match those in Table 1 as some fish were not reported by area (FSU data before 1986–87).

Table 3: Spawning (SKI 1) and non-spawning (SKI 2) catch (t) of gemfish. *, assumed catch based on TACC for 1998–99

Year	SKI 1E & W	SKI 2	Year	SKI 1E & W	SKI 2
1952	5	50	1977	60	180
1953	5	25	1978	90	240
1954	5	60	1979	120	200
1955	5	35	1980	140	450
1956	5	35	1981	120	500
1957	5	55	1982	100	320
1958	5	30	1983	360	730
1959	5	45	1984	588	632
1960	5	85	1985	388	381
1961	5	70	1986	716	381
1962	5	60	1987	773	896
1963	15	70	1988	696	1 095
1964	15	65	1989	1 023	1 011
1965	20	130	1990	1 230	1 043
1966	15	140	1991	1 058	949
1967	35	240	1992	1 017	1 208
1968	40	250	1993	1 292	1 020
1969	100	375	1994	1 156	1 058
1970	95	400	1995	1 032	906
1971	100	420	1996	801	789
1972	130	400	1997	965	978
1973	45	300	1998	627	671
1974	35	230	1999	413	335
1975	10	170	2000*	460	520
1976	30	190	2001*	460	520

Table 4: Catch (tonnes), number of trawls (*n*.trawls), mean tonnes per trawl, and the percentage of zero catch records for CPUE data analysis for SKI 1 and SKI 2

Year	SKI 1				SKI 2			
	catch.(t)	*n*.trawls	t/trawl	%.zero	catch.(t)	*n*.trawls	t/trawl	%.zero
1988–89	150	150	1	0.0	38	27	1.4	0
1989–90	930	1100	0.81	5.6	610	700	0.87	5.2
1990–91	860	1100	0.76	1.8	450	730	0.61	4.1
1991–92	730	1400	0.53	6.7	930	1300	0.71	3.6
1992–93	960	1600	0.6	3.0	680	1300	0.53	6.6
1993–94	950	880	1.1	4.0	790	1300	0.58	7.6
1994–95	900	760	1.2	6.1	710	1100	0.66	15
1995–96	640	970	0.65	8.2	610	1300	0.47	13
1996–97	780	820	0.95	10.0	690	1300	0.54	11
1997–98	500	810	0.62	16.0	370	880	0.42	14
1998–99	300	430	0.69	3.6	230	580	0.4	16

Table 5: Stepwise selection matrix for SKI 1, CPUE model. Inclusion of variables above the line resulted in more than 2% improvement in r-squared

	step1	step2	step3	step4	step5
Vessel	18.4	-	-	-	-
Year	5.8	22.5	-	-	-
Statarea	6.3	20.6	27.0	-	-
Day	7.9	21.8	26.3	30.5	-
Data source	0.1	20.1	22.5	27.1	30.5
improvement	18.4	4.1	4.6	3.4	0.1

Table 6: Standardised CPUE indices (*index*) and standard errors (*se*) for SKI 1 and SKI 2, normalised to 1.0 in the first year of each series

Year	SKI 1E		SKI 2	
	index	*se*	*index*	*se*
1989–90	1.00	0.00	1.00	0.00
1990–91	0.96	0.11	0.75	0.11
1991–92	0.39	0.04	0.53	0.07
1992–93	0.52	0.06	0.29	0.04
1993–94	0.44	0.05	0.24	0.03
1994–95	0.26	0.03	0.13	0.02
1995–96	0.19	0.02	0.13	0.02
1996–97	0.26	0.03	0.11	0.02
1997–98	0.15	0.02	0.07	0.01
1998–99	0.16	0.02	0.07	0.01

Table 7: Stepwise selection matrix for SKI 2, CPUE model. Inclusion of variables above the dotted line resulted in more than 2% improvement in r-squared

	step1	step2	step3	step4	step5	step6
Vessel	12.6	-	-	-	-	-
Year	1.9	18.0	-	-	-	-
Day	3.4	15.9	21.4	-	-	-
Statarea	4.4	14.2	19.8	24.5	-	-
Method	2.5	13.0	18.3	22.3	24.6	-
Data source	1.8	13.3	18.0	21.4	24.5	24.6
Improvement	12.6	5.4	3.5	3.1	0.1	0.0

Table 8. Percentage at age (PAA) and coefficients of variation (*c.v.*) for gemfish from commercial catches in SKI 1E and SKI 1W. M, males; F, females; *n.M.*, number of males measured; *n.F.*, number of females measured; *n.samp*, number of samples; *n.age*, number of fish aged; *wt.c.v.*, mean weighted *c.v.* across all age classes and both sexes

Age	SKI 1(E)																		SKI 1(W)							
	1989		1990		1991		1992		1993		1994		1997		1998		1999		1996		1997		1998		1999	
M	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*
2	0.0	0.00	0.0	0.00	0.0	0.00	0.2	0.73	0.0	0.00	0.0	0.00	0.2	1.28	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	5.26
3	1.0	0.54	7.2	0.32	0.0	0.00	4.1	0.26	0.1	1.30	1.8	0.44	0.1	1.22	0.1	3.15	0.5	1.27	0.2	1.03	0.0	0.00	0.0	2.40	0.3	0.80
4	3.4	0.23	7.0	0.29	2.1	0.47	1.7	0.34	1.4	0.32	0.0	0.00	3.4	0.22	0.5	0.87	1.2	0.78	2.5	0.31	0.2	1.23	0.4	0.74	1.5	0.32
5	19.9	0.13	15.0	0.20	10.4	0.22	5.4	0.25	3.9	0.26	5.1	0.19	4.2	0.22	2.5	0.37	5.0	0.39	18.4	0.16	1.7	0.35	1.0	0.36	4.4	0.24
6	11.5	0.22	21.4	0.15	4.5	0.43	13.8	0.19	9.9	0.23	12.0	0.22	36.1	0.09	10.7	0.23	3.0	0.29	3.8	0.41	22.0	0.10	6.1	0.27	5.8	0.37
7	37.9	0.10	12.7	0.20	22.1	0.18	19.1	0.16	16.2	0.25	15.4	0.21	6.9	0.31	25.7	0.13	5.6	0.23	6.2	0.36	5.5	0.31	19.5	0.15	13.8	0.27
8	6.9	0.27	20.8	0.16	10.9	0.27	32.6	0.12	26.8	0.17	17.8	0.21	8.7	0.27	9.9	0.23	27.9	0.15	10.9	0.28	5.2	0.31	5.9	0.32	28.2	0.12
9	12.9	0.19	4.9	0.33	33.1	0.14	7.4	0.28	25.7	0.17	4.4	0.48	15.2	0.18	7.4	0.28	9.9	0.52	12.0	0.26	16.8	0.18	6.6	0.29	2.3	0.21
10	0.8	0.65	6.6	0.28	5.2	0.40	12.0	0.21	7.2	0.29	22.0	0.19	8.1	0.27	11.3	0.21	10.8	0.54	15.6	0.21	13.8	0.20	13.6	0.19	5.4	0.21
11	1.0	0.66	0.7	1.04	6.2	0.35	1.8	0.50	7.9	0.28	6.0	0.36	7.8	0.24	4.0	0.38	17.7	0.33	6.3	0.34	15.8	0.17	8.0	0.26	11.4	0.16
12	4.1	0.29	1.2	0.68	0.5	1.01	1.9	0.44	0.4	0.72	10.3	0.27	1.1	0.58	8.2	0.24	2.8	0.53	17.4	0.20	3.9	0.41	11.2	0.21	3.2	0.41
13	0.0	0.00	2.5	0.53	3.9	0.41	0.0	0.00	0.6	0.71	2.2	0.62	5.7	0.23	5.4	0.30	7.7	0.25	1.4	0.64	10.5	0.18	5.9	0.29	9.3	0.24
14	0.0	0.00	0.0	0.00	0.0	0.00	0.1	1.41	0.0	0.00	2.6	0.50	0.5	0.71	7.7	0.25	2.4	0.45	3.9	0.38	1.5	0.59	11.8	0.19	5.1	0.45
15	0.5	0.87	0.0	0.00	0.6	1.10	0.0	0.00	0.0	0.00	0.3	1.39	1.2	0.44	2.9	0.46	3.6	0.34	0.0	0.00	2.9	0.46	2.1	0.36	6.7	0.31
16	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.8	0.58	1.5	0.64	0.8	0.64	0.4	1.00	0.0	0.00	6.4	0.28	1.8	0.76
17	0.0	0.00	0.0	0.00	0.5	1.05	0.0	0.00	0.0	0.00	0.1	0.71	0.2	1.02	0.8	0.70	1.1	0.99	0.4	1.06	0.0	0.00	1.6	0.50	0.8	0.54
18	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	1.2	0.64	0.4	0.00	0.5	1.02	0.2	0.58	0.1	1.01	0.0	1.00

Table 8 *continued*

Age	SKI 1(E)																		SKI 1(W)							
	1989		1990		1991		1992		1993		1994		1997		1998		1999		1996		1997		1998		1999	
F	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*
2	0.0	0.00	0.7	0.75	0.0	0.00	2.3	0.31	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00
3	0.3	2.17	3.2	0.35	0.0	0.00	5.8	0.19	0.0	0.00	2.5	0.45	0.2	1.08	0.0	4.31	0.0	1.54	0.3	1.11	0.1	1.32	0.0	0.00	0.3	0.00
4	0.4	0.70	1.3	0.53	1.1	0.62	5.3	0.19	0.2	0.50	0.4	0.84	2.1	0.25	0.3	1.32	0.7	5.31	1.1	0.77	0.1	1.56	0.0	0.00	0.1	0.53
5	7.0	0.26	2.3	0.42	2.3	0.45	3.8	0.29	1.2	0.46	0.3	1.20	1.4	0.36	0.5	1.48	0.2	0.56	7.9	0.23	0.6	0.63	0.4	0.43	0.8	1.22
6	5.1	0.34	15.9	0.20	2.7	0.42	4.7	0.31	5.7	0.27	2.2	0.40	22.4	0.11	2.6	0.44	1.7	1.38	5.6	0.33	20.3	0.11	1.2	0.44	0.6	0.32
7	33.4	0.12	11.4	0.24	18.3	0.21	10.1	0.22	13.7	0.18	11.0	0.26	5.4	0.31	11.0	0.21	3.5	0.46	10.3	0.25	4.3	0.35	5.3	0.26	3.4	0.28
8	10.1	0.23	35.7	0.13	12.8	0.27	19.8	0.16	14.0	0.23	11.2	0.28	5.9	0.28	8.2	0.25	20.9	0.20	14.5	0.20	7.2	0.27	5.5	0.32	17.3	0.13
9	22.7	0.17	8.3	0.28	27.3	0.18	15.7	0.16	29.5	0.15	6.7	0.40	10.3	0.22	9.6	0.23	6.6	0.37	10.3	0.24	14.9	0.18	7.3	0.26	6.2	0.27
10	1.3	0.60	11.4	0.25	8.1	0.33	15.7	0.18	7.0	0.33	27.7	0.17	8.8	0.23	21.2	0.15	13.1	0.29	9.7	0.26	8.4	0.26	20.8	0.14	11.7	0.19
11	8.2	0.26	0.3	1.08	16.6	0.23	3.7	0.35	18.4	0.18	11.4	0.25	12.7	0.18	8.2	0.29	22.0	0.23	9.2	0.26	12.1	0.21	6.4	0.28	17.8	0.14
12	7.3	0.30	5.4	0.38	3.5	0.48	9.8	0.21	2.1	0.46	18.8	0.19	5.6	0.29	13.9	0.21	2.7	0.37	15.8	0.21	5.2	0.30	15.7	0.18	4.9	0.43
13	2.1	0.42	1.2	0.73	5.1	0.36	1.7	0.52	7.2	0.28	0.6	0.88	18.2	0.13	5.4	0.37	8.5	0.23	3.6	0.43	18.9	0.16	6.3	0.27	14.4	0.22
14	1.6	0.54	2.9	0.42	0.6	0.92	1.3	0.64	0.8	0.61	5.0	0.35	1.5	0.44	12.3	0.23	3.7	0.36	7.4	0.31	2.9	0.39	17.0	0.15	5.8	0.34
15	0.0	0.00	0.0	0.00	0.5	0.84	0.3	1.08	0.2	1.08	0.3	1.18	4.9	0.30	1.9	0.55	11.1	0.25	0.2	1.29	3.4	0.35	3.1	0.38	11.1	0.20
16	0.6	0.55	0.0	0.00	0.0	0.00	0.0	0.00	0.3	0.89	1.9	0.67	0.3	1.03	3.6	0.35	3.0	0.67	2.1	0.50	0.9	0.76	8.6	0.23	1.7	0.40
17	0.0	0.00	0.0	0.00	0.6	1.31	0.0	0.00	0.0	0.00	0.1	1.89	0.0	0.00	0.9	0.70	2.4	0.69	1.7	0.63	0.0	0.00	1.3	0.47	1.4	0.41
18	0.0	0.00	0.0	0.00	0.6	0.93	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.4	0.41	0.0	0.00	0.4	1.20	0.7	0.47	0.9	0.55	0.0	0.00
19	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.4	0.98	0.0	0.00	0.0	0.59	0.0	0.00	0.0	0.00	0.4	0.99	2.4	0.00
n.M		1333		545		696		1045		1215		1073		2601		896		600		780		2136		1881		1173
n.F		1157		578		569		862		1115		734		2077		683		411		497		1683		1466		989
n.samp		9		7		8		9		10		8		15		7		5		5		14		13		11
n.age		311		375		295		340		337		321		419		433		251		373		404		435		461
wt. c.v.		0.19		0.23		0.26		0.20		0.22		0.26		0.20		0.25		0.31		0.27		0.21		0.23		0.21

Table 9: Percentage at age (PAA) and coefficients of variation (*c.v.*) for gemfish from commercial catches in SKI 2. M, males; F, females; *n.meas.*, number of fish measured; *n.samp*, number of samples; *n.age*, number of fish aged; *wt.c.v.*, mean weighted *c.v.* across all age classes

Age	Male								Female							
	1996		1997		1998		1999		1996		1997		1998		1999	
	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*	PAA	*c.v.*
2	0.0	0.00	0.2	0.64	0.0	0.00	1.2	0.74	0.0	0.00	0.0	0.00	0.0	0.00	0.6	0.80
3	0.6	0.41	1.2	0.47	0.6	0.84	10.1	0.24	0.4	0.43	1.1	0.31	1.1	0.48	8.2	0.26
4	1.9	0.26	4.9	0.22	10.1	0.27	19.7	0.17	1.2	0.33	2.5	0.36	9.3	0.21	19.3	0.12
5	54.4	0.05	18.5	0.15	13.1	0.17	3.5	0.37	42.9	0.05	16.9	0.15	5.6	0.22	3.0	0.26
6	4.2	0.22	47.4	0.08	16.1	0.17	7.7	0.25	2.8	0.22	44.5	0.07	11.9	0.16	9.3	0.16
7	5.0	0.21	4.1	0.41	23.6	0.14	27.4	0.13	4.8	0.19	4.1	0.33	16.5	0.15	18.9	0.12
8	5.7	0.20	2.8	0.48	5.6	0.32	6.8	0.31	6.5	0.15	4.5	0.27	10.3	0.21	4.9	0.28
9	4.7	0.23	8.7	0.28	9.3	0.23	5.9	0.32	2.4	0.24	8.0	0.19	8.1	0.24	5.8	0.25
10	5.8	0.20	4.0	0.48	11.8	0.20	10.3	0.19	6.7	0.15	2.6	0.32	19.1	0.14	10.4	0.19
11	2.7	0.25	3.2	0.82	0.9	0.78	2.0	0.45	2.8	0.23	6.5	0.22	3.1	0.34	5.3	0.25
12	6.4	0.19	1.6	0.71	5.1	0.24	3.5	0.24	14.2	0.10	1.0	0.58	6.9	0.24	5.8	0.23
13	0.9	0.40	2.6	0.42	0.9	0.89	0.4	0.96	3.2	0.21	4.8	0.28	2.3	0.39	4.6	0.27
14	5.8	0.20	0.0	0.00	1.7	0.30	0.5	0.97	8.2	0.16	1.1	0.63	2.5	0.34	0.8	0.58
15	0.6	0.42	0.8	0.90	0.0	0.00	0.0	0.00	0.3	0.64	1.8	0.43	2.0	0.31	0.5	0.71
16	0.6	0.41	0.0	0.00	1.4	0.43	0.3	1.30	2.7	0.24	0.1	1.80	1.3	0.42	1.6	0.37
17	0.2	0.48	0.0	0.00	0.0	0.00	0.5	1.01	0.0	0.00	0.5	0.79	0.0	0.00	0.7	0.62
18	0.5	0.84	0.0	0.00	0.0	0.00	0.0	0.00	0.4	0.62	0.0	0.00	0.0	0.00	0.2	1.02
19	0.0	0.00	0.0	0.00	0.0	0.00	0.0	0.00	0.3	0.7	0.0	0.00	0.0	0.00	0.0	0.00
n.meas		1965		1149		867		1119		2338		1657		1370		1403
n.samp M+F										21		11		11		21
n.age M+F										698		399		415		436
wt. c.v. M+F										0.13		0.20		0.21		0.21

Table 10: Proportion at age (of the total number of fish per year) for male and female gemfish used in the stock assessment modelling (SKI 2 age 2 were used for sensitivity 4 only). Values of 0.000 were replaced by 0.001 in the model. M, male; F, female; model *c.v.*, model *c.v.* of 35% weighted by the number of samples

Area	1E	1E	1E	1E	1E	1E	1E+W	1E+W	1E+W	1E+W	2	2	2	2
Year	1989	1990	1991	1992	1993	1994	1996	1997	1998	1999	1996	1997	1998	1999
Male age														
2											0.002	0.130	0.002	0.004
3	0.005	0.033	0.001	0.022	0.001	0.012	0.001	0.001	0.000	0.002	0.008	0.021	0.043	0.039
4	0.018	0.032	0.011	0.009	0.007	0.001	0.015	0.006	0.002	0.007	0.234	0.079	0.055	0.075
5	0.104	0.068	0.056	0.028	0.019	0.032	0.110	0.014	0.007	0.027	0.018	0.202	0.068	0.013
6	0.060	0.097	0.024	0.073	0.050	0.076	0.023	0.156	0.040	0.022	0.022	0.018	0.100	0.129
7	0.198	0.058	0.118	0.101	0.081	0.097	0.037	0.037	0.121	0.046	0.025	0.012	0.024	0.105
8	0.036	0.094	0.058	0.172	0.134	0.113	0.065	0.043	0.039	0.157	0.020	0.037	0.039	0.026
9	0.068	0.022	0.176	0.039	0.129	0.028	0.071	0.098	0.040	0.043	0.025	0.017	0.050	0.023
10	0.004	0.030	0.028	0.063	0.036	0.139	0.093	0.067	0.079	0.052	0.012	0.014	0.004	0.039
11	0.005	0.003	0.033	0.009	0.040	0.038	0.038	0.073	0.044	0.090	0.027	0.007	0.021	0.007
12	0.022	0.005	0.003	0.010	0.002	0.065	0.104	0.017	0.064	0.017	0.004	0.011	0.004	0.014
13	0.001	0.011	0.020	0.001	0.003	0.014	0.008	0.051	0.035	0.046	0.025	0.001	0.007	0.001
14	0.001	0.001	0.001	0.001	0.001	0.016	0.023	0.006	0.066	0.018	0.003	0.004	0.000	0.002
15	0.003	0.001	0.003	0.001	0.001	0.002	0.001	0.012	0.013	0.026	0.003	0.001	0.006	0.000
F. age														
2											0.002	0.006	0.006	0.004
3	0.001	0.018	0.001	0.027	0.001	0.009	0.001	0.001	0.000	0.000	0.007	0.014	0.054	0.050
4	0.002	0.007	0.005	0.025	0.001	0.002	0.004	0.003	0.000	0.002	0.244	0.097	0.032	0.119
5	0.033	0.013	0.011	0.018	0.006	0.001	0.032	0.003	0.002	0.002	0.016	0.255	0.068	0.019
6	0.024	0.087	0.012	0.022	0.028	0.008	0.022	0.079	0.006	0.006	0.027	0.024	0.095	0.057
7	0.159	0.062	0.086	0.048	0.068	0.040	0.042	0.022	0.026	0.015	0.037	0.026	0.059	0.117
8	0.048	0.195	0.060	0.094	0.070	0.041	0.059	0.028	0.024	0.087	0.014	0.046	0.047	0.030
9	0.108	0.045	0.128	0.074	0.147	0.025	0.042	0.055	0.031	0.028	0.038	0.015	0.110	0.136
10	0.006	0.062	0.038	0.074	0.035	0.102	0.039	0.039	0.085	0.055	0.016	0.037	0.018	0.064
11	0.039	0.002	0.078	0.017	0.092	0.042	0.037	0.059	0.027	0.091	0.081	0.006	0.040	0.033
12	0.035	0.030	0.016	0.046	0.010	0.069	0.064	0.023	0.062	0.014	0.018	0.027	0.013	0.036
13	0.010	0.006	0.024	0.008	0.036	0.002	0.014	0.074	0.025	0.043	0.047	0.006	0.014	0.029
14	0.008	0.016	0.003	0.006	0.004	0.018	0.030	0.009	0.066	0.018	0.002	0.010	0.011	0.005
15	0.001	0.001	0.002	0.002	0.001	0.001	0.001	0.018	0.012	0.048	0.016	0.001	0.007	0.003
Model *c.v.*	0.35	0.37	0.36	0.35	0.34	0.36	0.41	0.28	0.30	0.31	0.32	0.37	0.37	0.34

Table 11: Von Bertalanffy growth parameters (with 95% confidence intervals) for northern gemfish, by sex and area, from otolith readings and length-based estimates of juvenile growth

	Area	n	L_∞ (cm)		k		t_0 (yrs)	
			mean	range	mean	range	mean	range
Female	SKI 1E	1 016	108.5	106.3–110.7	0.167	0.155–0.179	–0.71	–0.93 to –0.50
	SKI 2	733	103.4	102.3–104.5	0.231	0.220–0.243	–0.10	–0.24 to 0.05
	SKI 1W	429	103.4	101.7–105.1	0.209	0.194–0.224	–0.37	–0.57 to –0.18
	All areas	2 058	105.0	103.8–106.1	0.194	0.185–0.204	–0.55	–0.72 to –0.38
Male	SKI 1E	1 082	88.4	87.1–89.7	0.235	0.219–0.250	–0.54	–0.73 to –0.35
	SKI 2	483	90.8	89.5–92.0	0.287	0.269–0.306	0.00	–0.18 to 0.19
	SKI 1W	468	86.3	85.3–87.2	0.295	0.276–0.315	–0.11	–0.28 to 0.05
	All areas	1 913	87.4	86.7–88.2	0.266	0.252–0.280	–0.35	–0.52 to –0.18

Table 12: Input parameters for base case (Base 1, Base 2) runs and sensitivity tests to Base 2. *rsd*, recruitment variability; *M*, natural mortality; $r_{sp.max}$, maximum exploitation rate; r_{mmx}, minimum exploitation rate when the largest catch was taken; sel., selectivity; *c.v.* coefficient of variation; YCS, year class strength

Parameter	Base 1	Base 2	Sensitivity to Base 2					
	Fixed ogives	Estimated ogives	1	2	3	4	5	6
Steepness	0.9							
rsd	1.0							
% spawning	0.95							
M	0.25		0.2	0.3				
$r_{sp.max}$: pre-spawning	0.3							
: spawning	0.5						0.35	
r_{mmx}	0.01				0.03			
Spawning sel.	1.0							
CPUE weight, *c.v.*	1, 35%							0.1, 50%
Age weight, *c.v.*	1, 35%							1, 35%
Maturity / home selectivity ogives	fixed	estimated						
YCS estimated	1978–94					1978–96		

Table 13: Estimated or assumed (*) year class strengths (YCS) for the base case runs (Base 1, Base 2) and sensitivity (Sens.) tests to Base 2, for SKI 1 and 2. Base and sensitivity tests detailed in Table 12. Mean year class strength (YCS) and recruitment variability (*rsd*) calculated for years when YCS is estimated

Year class	Base 1	Base 2, Sens.3, 5	Sens.1	Sens.2	Sens.4	Sens.6
1977	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*
1978	0.67	0.62	0.52	0.87	0.69	0.53
1979	0.09	0.10	0.09	0.53	0.09	0.10
1980	2.37	2.23	2.04	1.62	2.53	1.89
1981	0.27	0.29	0.28	0.97	0.29	0.30
1982	4.17	4.09	3.96	2.54	4.44	3.41
1983	0.83	0.86	0.86	1.54	0.85	0.82
1984	3.43	3.68	3.73	2.79	3.99	3.39
1985	0.89	0.88	0.91	1.34	0.91	0.92
1986	1.62	1.61	1.69	1.61	1.64	1.88
1987	0.87	0.88	0.94	0.86	0.89	1.02
1988	0.94	0.96	1.04	0.81	0.94	1.19
1989	0.55	0.54	0.60	0.46	0.52	0.65
1990	0.21	0.21	0.23	0.20	0.17	0.26
1991	1.35	1.34	1.53	1.07	1.44	1.78
1992	0.14	0.15	0.16	0.19	0.12	0.20
1993	0.12	0.12	0.14	0.15	0.07	0.19
1994	0.14	0.15	0.17	0.37	0.12	0.25
1995	1.00*	1.00*	1.00*	1.00*	0.06	1.00*
1996	1.00*	1.00*	1.00*	1.00*	0.03	1.00*
1997	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*
1998	1.00*	1.00*	1.00*	1.00*	1.00*	1.00*
Mean YCS	1.10	1.10	1.11	1.06	1.04	1.11
rsd	1.19	1.18	1.16	0.89	1.49	1.07

Table 14: Maturity ogives for the base case runs (Base 1, Base 2) and sensitivity (Sens) tests to Base 2. Base and sensitivity tests detailed in Table 12. (Note that these figures are expressed as the proportion of remaining immature fish in each age group which will mature)

Age	Male						Female					
	Base 1	Base 2, Sens.3, 5	Sens.1	Sens. 2	Sens.4	Sens.6	Base 1	Base 2, Sens.3, 5	Sens. 1	Sens. 2	Sens. 4	Sens. 6
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.02	0.01
3	0.02	0.02	0.02	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01
4	0.20	0.20	0.21	0.21	0.21	0.19	0.02	0.02	0.02	0.02	0.02	0.02
5	0.40	0.39	0.42	0.42	0.49	0.24	0.20	0.11	0.12	0.19	0.12	0.10
6	0.80	0.98	1.00	0.81	0.93	1.00	0.40	0.30	0.30	0.40	0.30	0.30
7	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.40	0.40	0.80	.040	0.40
8+	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 15: Home selectivity ogives for the Base 1 (ogives fixed) and Base 2 and sensitivity (Sens) runs (ogives estimated. Base and sensitivity tests detailed in Table 12

Age	Male						Female					
	Base 1	Base 2, Sens.3, 5	Sens.1	Sens. 2	Sens. 4	Sens. 6	Base 1	Base 2, Sens.3, 5	Sens. 1	Sens. 2	Sens. 4	Sens.6
1	0.01	0.01	0.01	0.01	0.03	0.05	0.01	0.01	0.01	0.01	0.01	0.03
2	0.05	0.01	0.03	0.05	0.28	0.10	0.05	0.01	0.01	0.05	0.15	0.05
3	0.50	0.38	0.41	0.48	0.71	0.44	0.50	0.36	0.38	0.48	0.57	0.34
4	0.95	0.88	0.91	0.90	1.14	0.87	0.95	0.86	0.88	0.90	1.04	0.70
5	1.00	1.30	1.31	1.06	1.42	1.23	1.00	1.28	1.30	1.06	1.38	0.99
6	1.00	1.50	1.50	1.03	1.50	1.39	1.00	1.50	1.49	1.03	1.50	1.12
7	1.00	1.42	1.41	0.96	1.37	1.32	1.00	1.42	1.41	0.96	1.37	1.12
8+	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.02	0.97	1.02

Table 16: Least squares (LS) and bestk estimates of biomass and MIAEL estimates of p, biomass (MIAEL) and performance indices (Perf.), for base case (Base1, Base 2) and sensitivity (Sens.) tests on Base 2. All biomass estimates are in tonnes. r_{mmx}, minimum exploitation rate when the largest catch was taken; *M*, natural mortality; YCS, year class strength; $r_{sp.max}$, maximum exploitation rate; <cpue.wt, decreased weighting on age data. Biomass estimates are: mid-spawning season virgin biomass (B_0), mid-spawning season mature biomass for 1999–2000 (B_{mid00}/B_0), and 2000–01 (B_{mid01}/B_0) as a percentage of B_0, and 2001 beginning of year total biomass (B_{beg01}).

Estimate	Run		B_{min} - B_{max}	LS	bestk	p	MIAEL	Perf. (%)
B_0	Base	1 (fixed ogives)	10 570 – 61 910	11 390	22 530	0.457	17 440	41
	Base	**2 (estimated)**	**10 760 – 62 490**	**11 040**	**22 870**	**0.426**	**17 830**	**36**
	Sens.1	$M = 0.2$	13 490 – 67 570	14 660	27 160	0.473	21 250	42
	Sens.2	$M = 0.3$	10 180 – 63 860	11 050	22 230	0.440	17 310	40
	Sens.3	$r_{mmx} = 0.03$	10 760 – 25 210	11 040	15 980	0.583	13 100	50
	Sens.4	YCS 95,96	11 150 – 63 470	11 430	23 530	0.426	18 370	37
	Sens.5	$R_{sp.max} = 0.35$	12 710 – 70 890	12 710	26 620	0.401	21 040	34
	Sens.6	<cpue.wt.	9 980 – 57 030	9 980	21 080	0.319	17 550	26
B_{mid00}/B_0	Base	1	4 – 69	8.7	11.1	0.844	9.1	83
	Base	**2**	**7 – 71**	**9.3**	**18.3**	**0.771**	**11.4**	**74**
	Sens.1	$M = 0.2$	6 – 78	13.6	16.7	0.817	14.2	79
	Sens.2	$M = 0.3$	6 – 60	11.7	15.7	0.822	12.4	79
	Sens.3	$r_{mmx} = 0.03$	7 – 53	9.3	16.5	0.731	11.3	69
	Sens.4	YCS 95,96	6 – 70	8.5	16.9	0.747	10.7	71
	Sens.5	$R_{sp.max} = 0.35$	9 – 64	8.9	20.4	0.722	12.1	68
	Sens.6	<cpue.wt.	8 – 80	8.2	20.8	0.642	12.7	59
B_{beg01}	Base	1	5 220 – 81 908	6 730	15 350	0.515	10 910	52
	Base	**2**	**6 380 – 85 900**	**6 920**	**17 920**	**0.469**	**12 760**	**47**
	Sens.1	$M = 0.2$	4 828 – 82 770	6 740	14 570	0.530	10 421	54
	Sens.2	$M = 0.3$	8 030 – 97 350	9 880	21 830	0.473	16 180	47
	Sens.3	$r_{mmx} = 0.03$	6 380 – 29 350	6 920	12 440	0.619	9 030	57
	Sens.4	YCS 95,96	3 510 – 65 970	3 910	10 870	0.483	7 510	49
	Sens.5	$R_{sp.max} = 0.35$	7 530 – 90 760	7 530	20 430	0.439	14 770	43
	Sens.6	<cpue.wt.	6 090 – 85 650	6 090	17 340	0.350	13 410	34
B_{mid01}/B_0	Base	1	6 – 65	11.4	15.3	0.787	12.3	76
	Base	**2**	**6 – 65**	**8.3**	**16.3**	**0.773**	**10.1**	**74**
	Sens.1	$M = 0.2$	5 –72	12.3	14.2	0.816	12.6	80
	Sens.2	$M = 0.3$	8 – 58	13.5	18.7	0.816	14.4	78
	Sens.3	$r_{mmx} = 0.03$	6 – 48	8.3	14.7	0.733	10.1	69
	Sens.4	YCS 95,96	3 – 58	3.7	8.5	0.718	5.1	68
	Sens.5	$r_{sp.max} = 0.35$	9 – 60	8.9	20.0	0.721	12.6	68
	Sens.6	<cpue.wt.	7 – 73	6.5	17.2	0.642	10.3	59

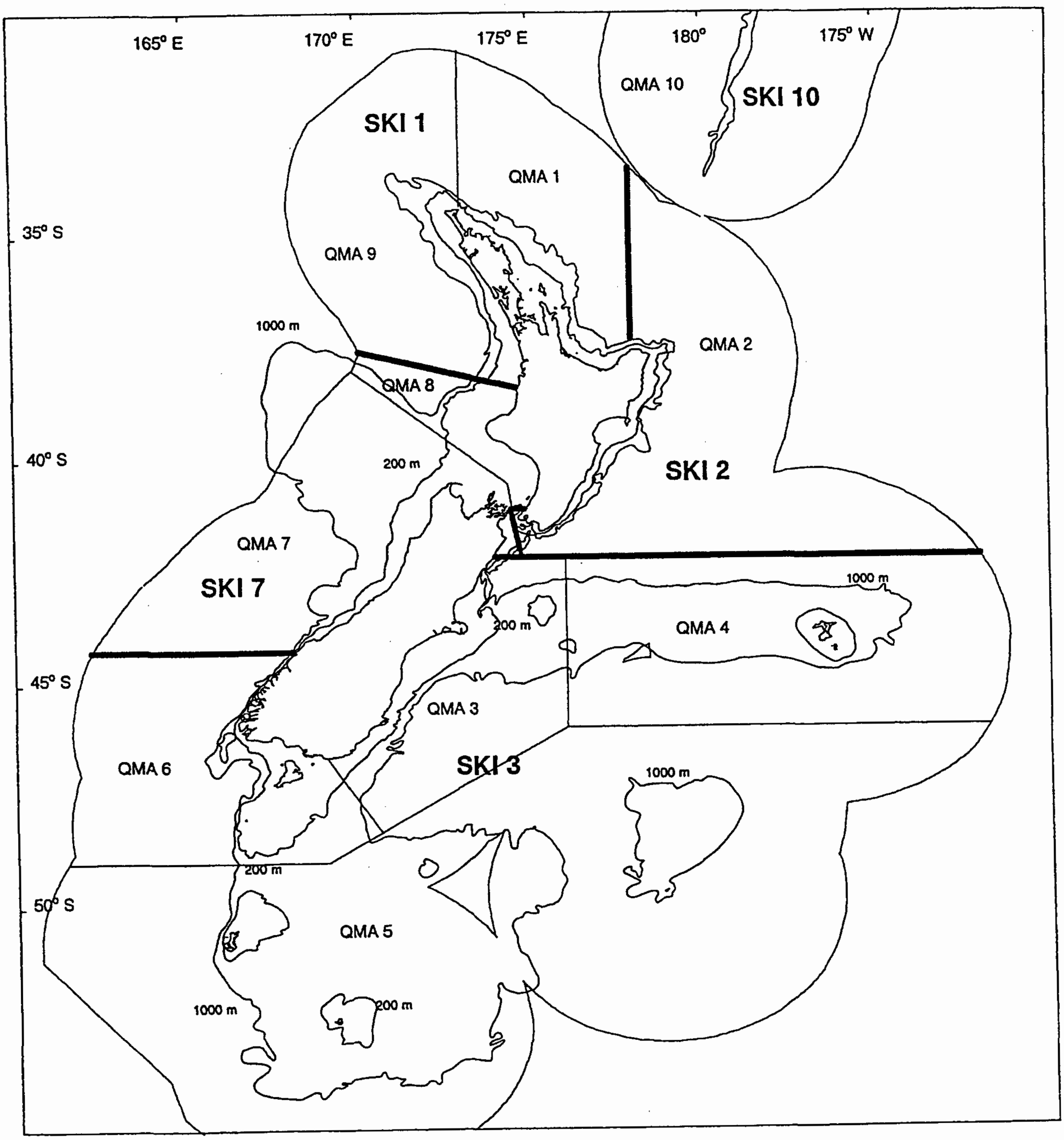

Figure 1: Map of the New Zealand 200 mile Exclusive Economic Zone (EEZ), Quota Management Areas (QMA), and gemfish Fishstock areas (SKI)

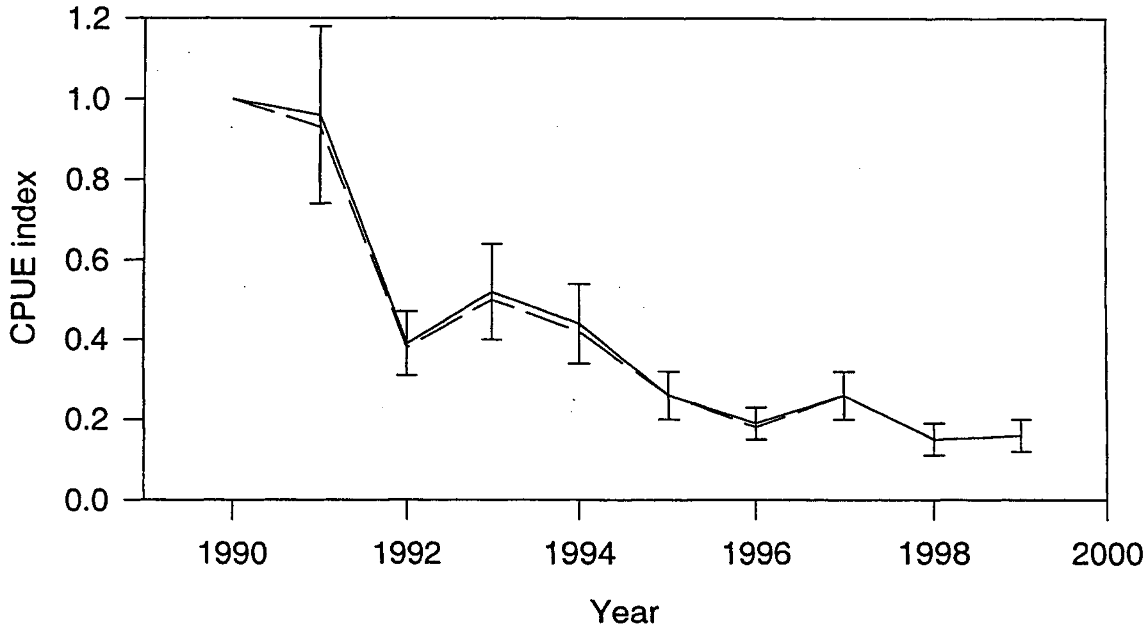

Figure 2a: **Comparison of the 2000 SKI 1 model CPUE index (solid line, error bars = 2 standard errors) with the index from 1999 (dashed line).**

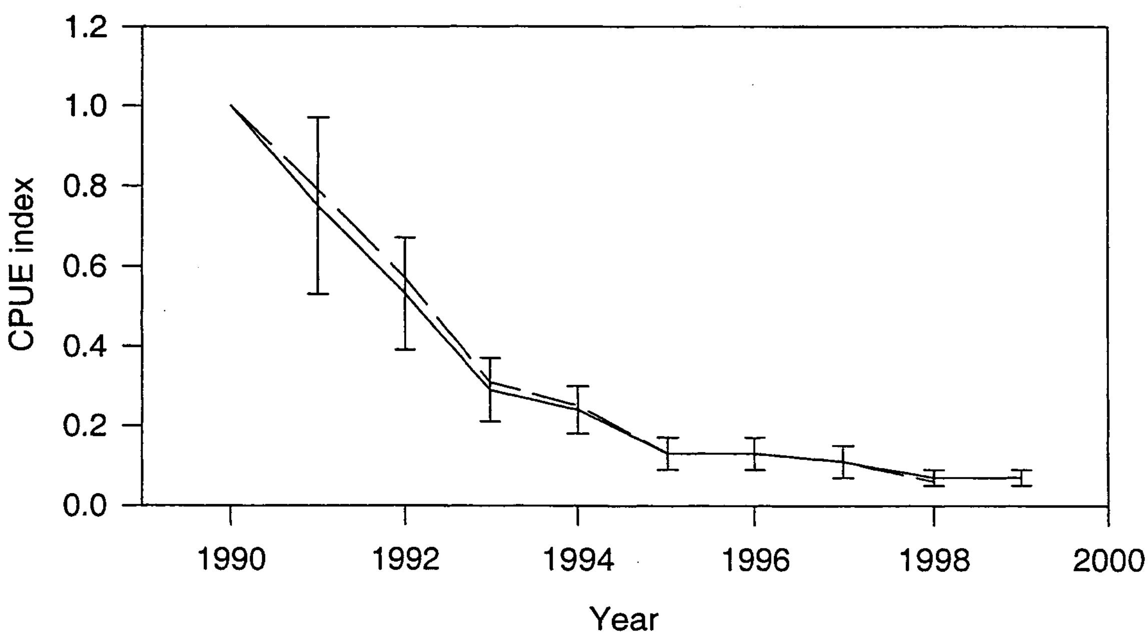

Figure 2b: **Comparison of the 2000 SKI 2 model CPUE index (solid line, error bars = 2 standard errors) with the index from 1999 (dashed line).**

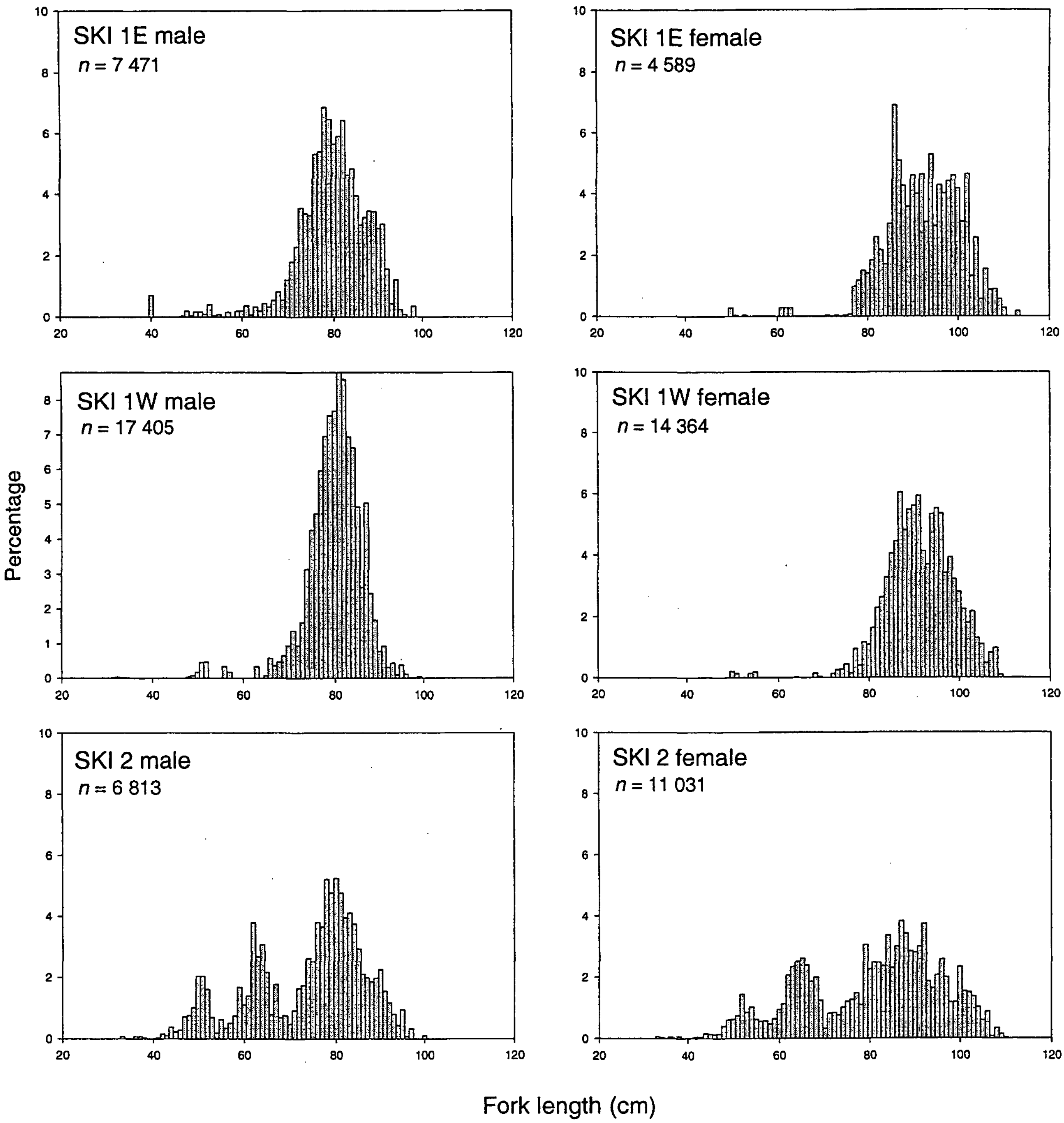

Figure 3: Length frequencies of male and female gemfish from the SKI 1 and SKI 2 sampled catch, 1998–99. (*n*, number of fish measured).

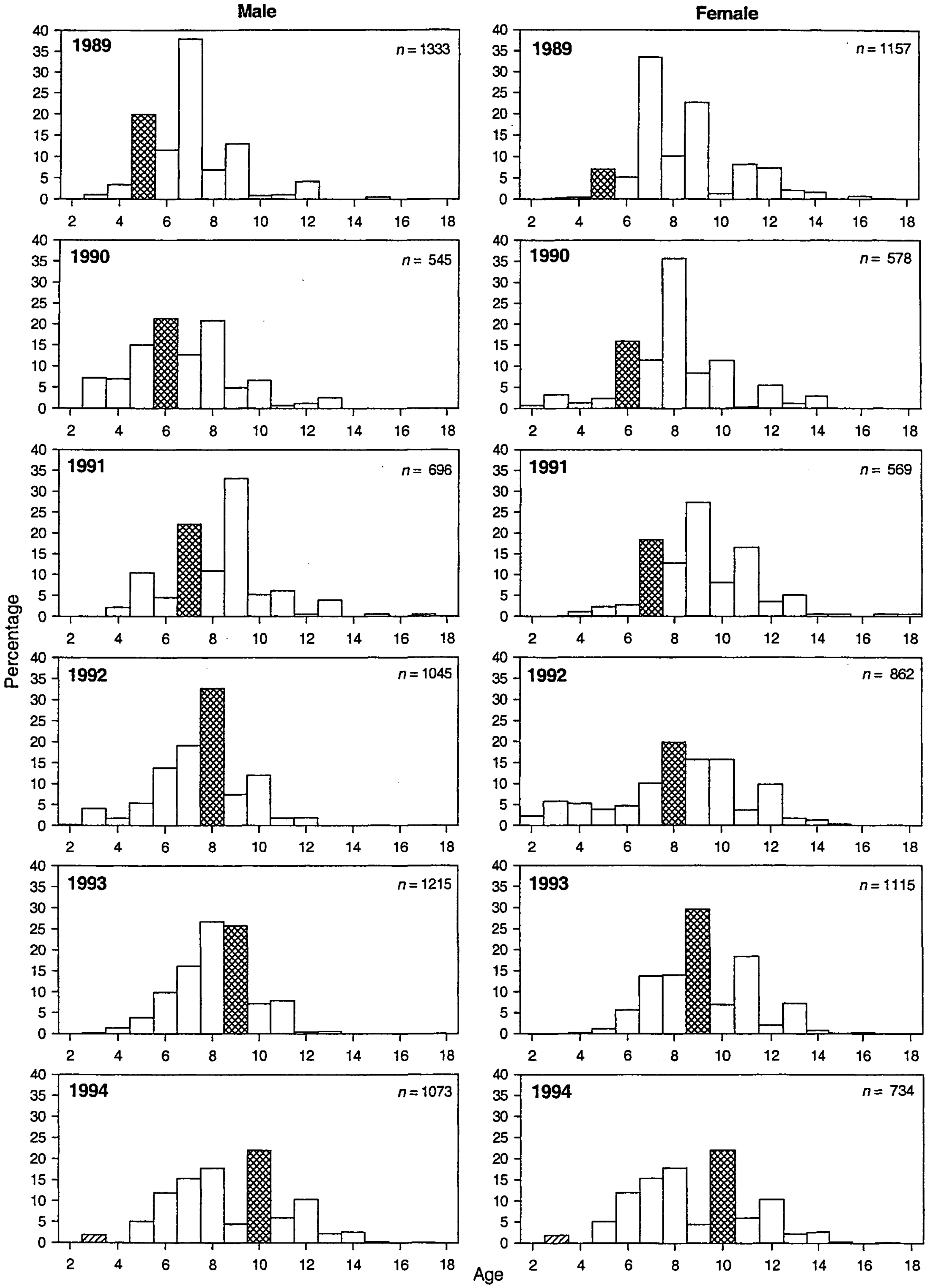

Figure 4a: Age frequencies of male and female gemfish from the SKI 1E sampled catch, 1989–1994. Shaded year classes are 1991 (lines) and 1984 (cross hatched). *n*, number of fish measured.

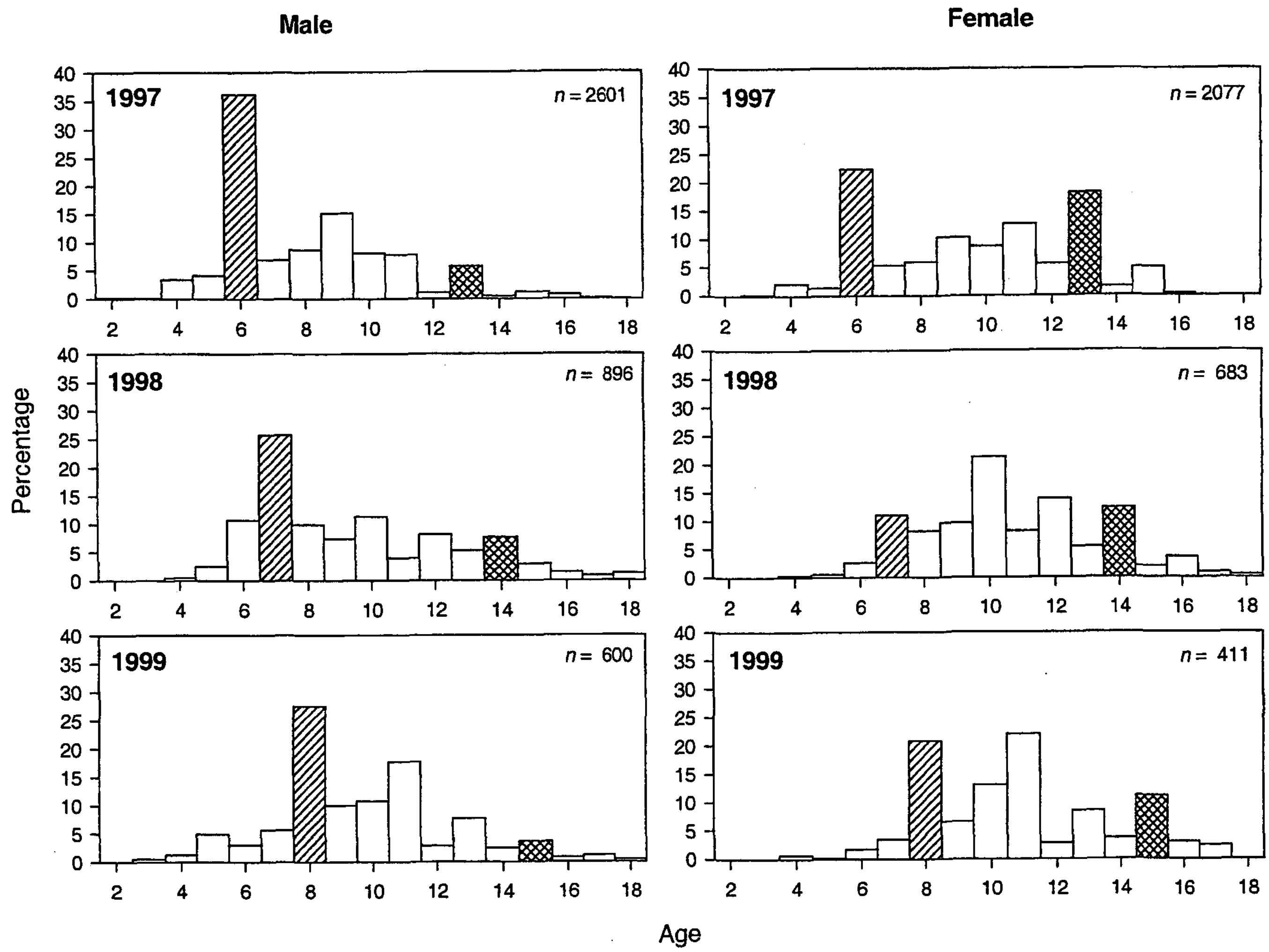

Figure 4b: **Age frequencies of male and female gemfish from the SKI 1E sampled catch, 1997–1999. Shaded year classes are 1991 (lines) and 1984 (cross hatched).** ***n*****, number of fish measured.**

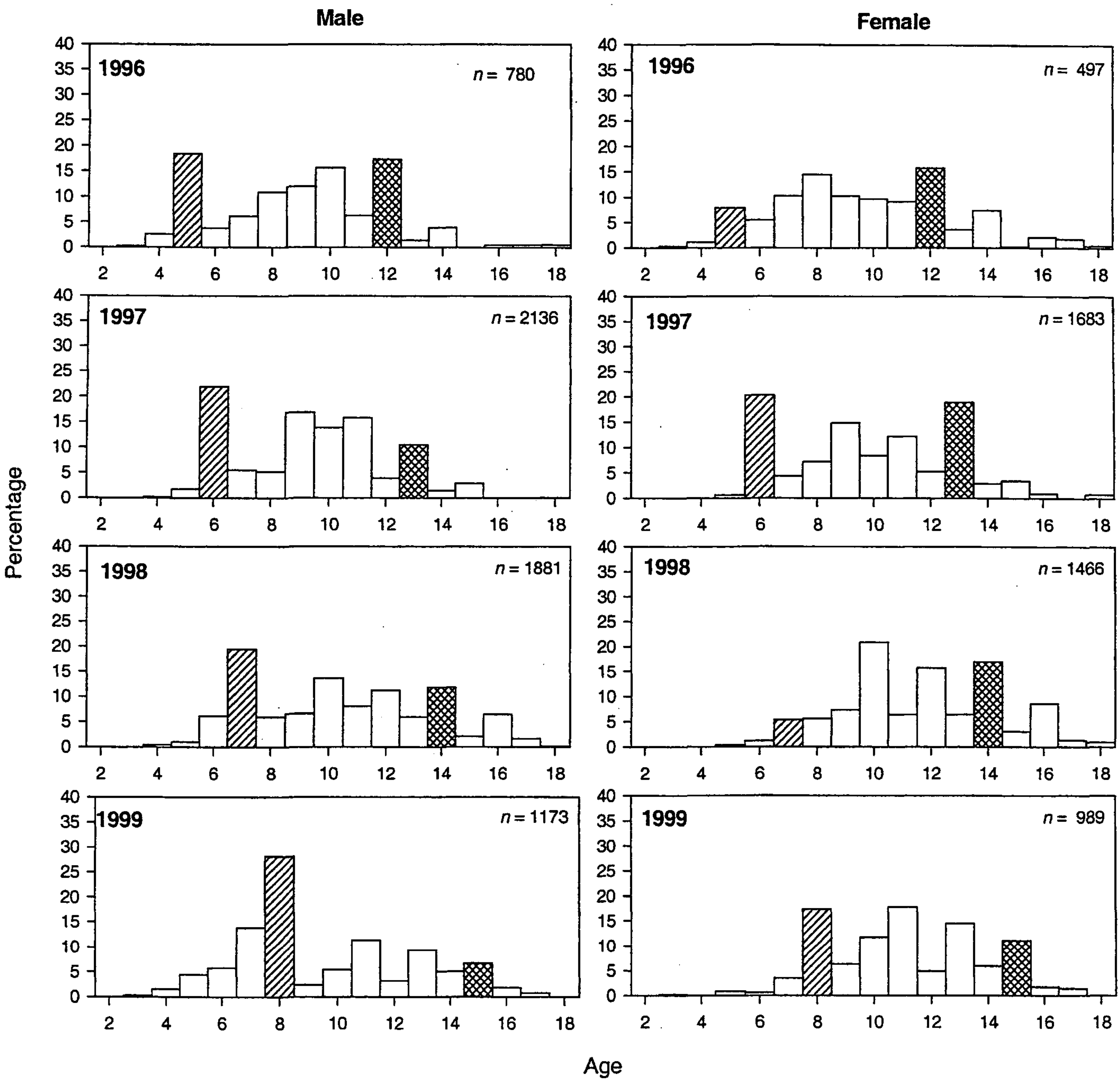

Figure 4c: Age frequencies of male and female gemfish from the SKI 1W sampled catch, 1996–1999. Shaded year classes are 1991 (lines) and 1984 (cross hatched). *n*, number of fish measured.

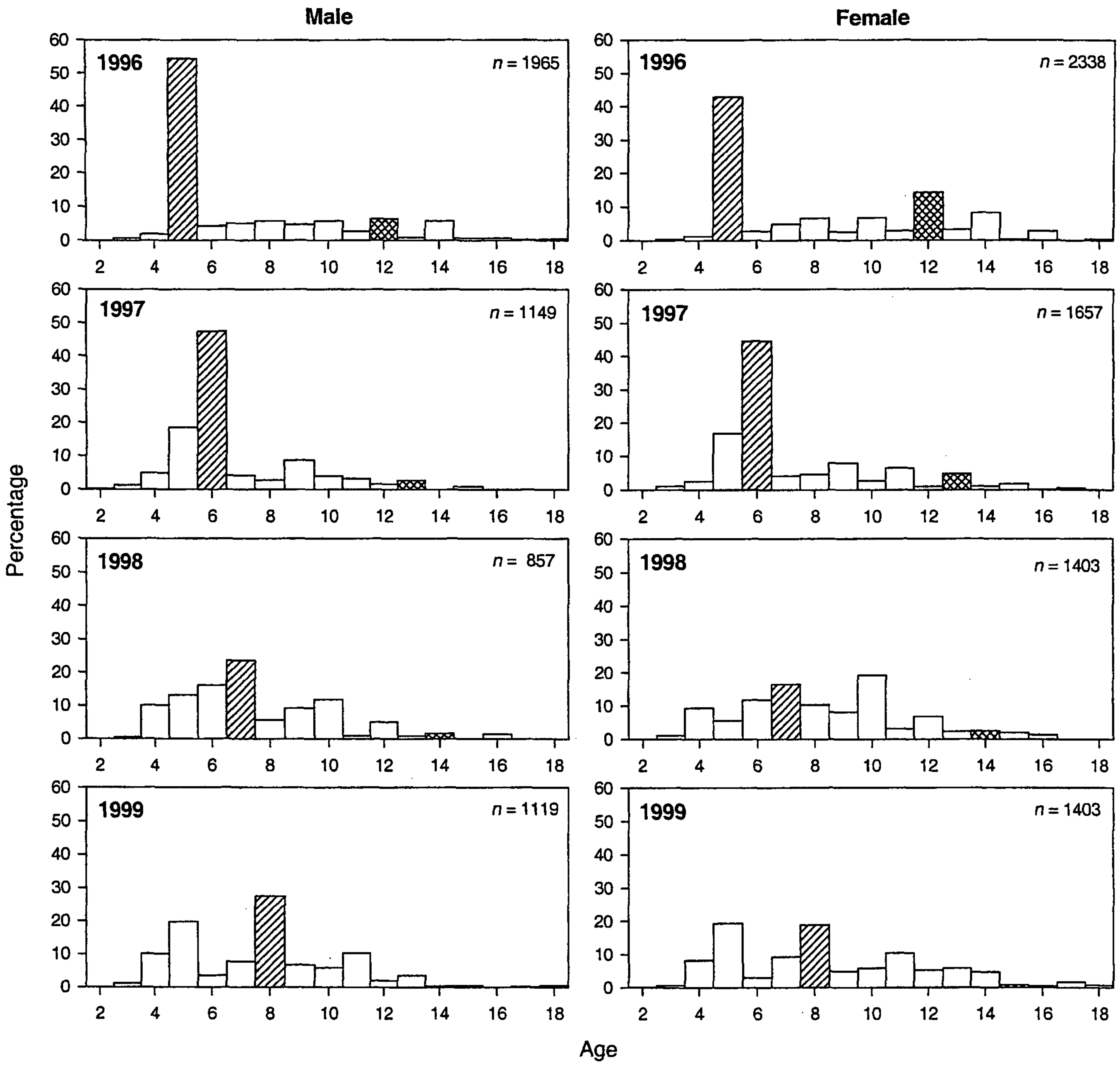

Figure 4d: **Age frequencies of male and female gemfish from the SKI 2 sampled catch, 1996–1999 (the 1999 birthday has been assigned for comparability with SKI 1 data). Shaded year classes are 1991 (lines) and 1984 (cross hatched). *n*, number of fish measured.**

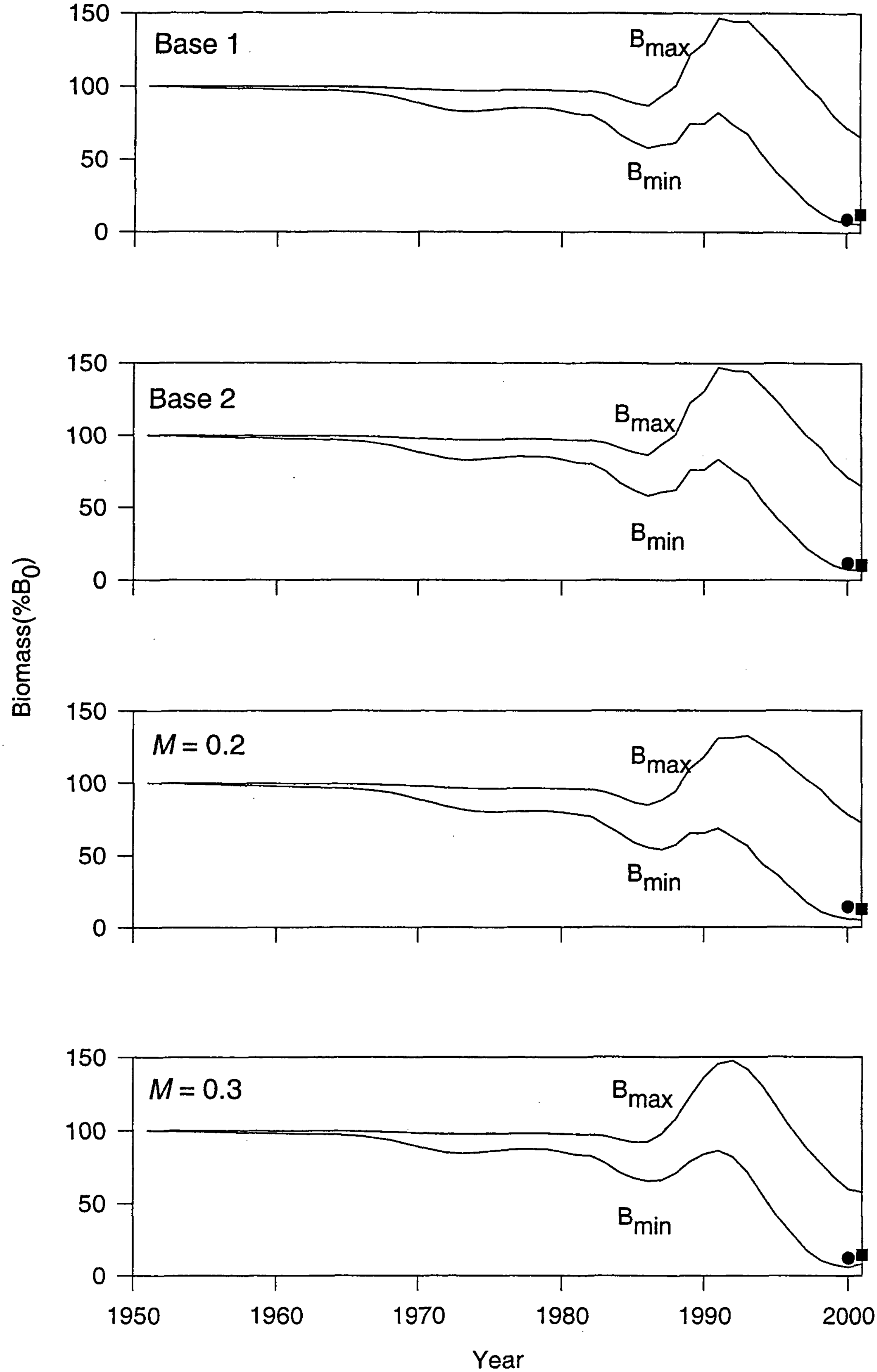

Figure 5. Trajectories for minimum (B_{min}) and maximum (B_{max}) estimates of biomass (circle, $Bmid_{00}$; square, $Bmid_{01}$) for the base case and sensitivity runs.

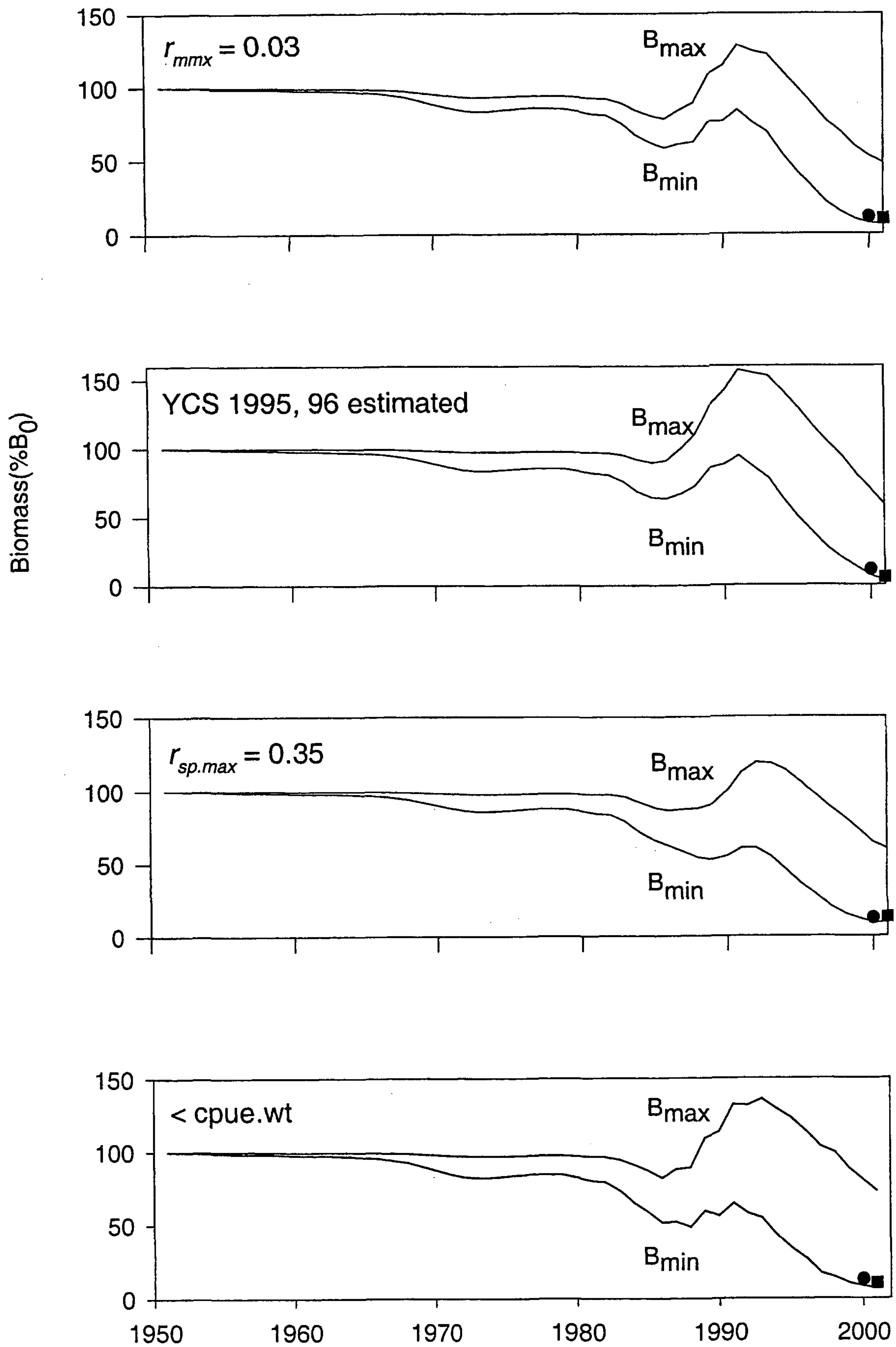

Figure 5 ***continued.*** **Trajectories for minimum (B_{min}) and maximum (B_{max}) estimates of biomass (circle, $Bmid_{00}$; square, $Bmid_{01}$) for sensitivity runs.**

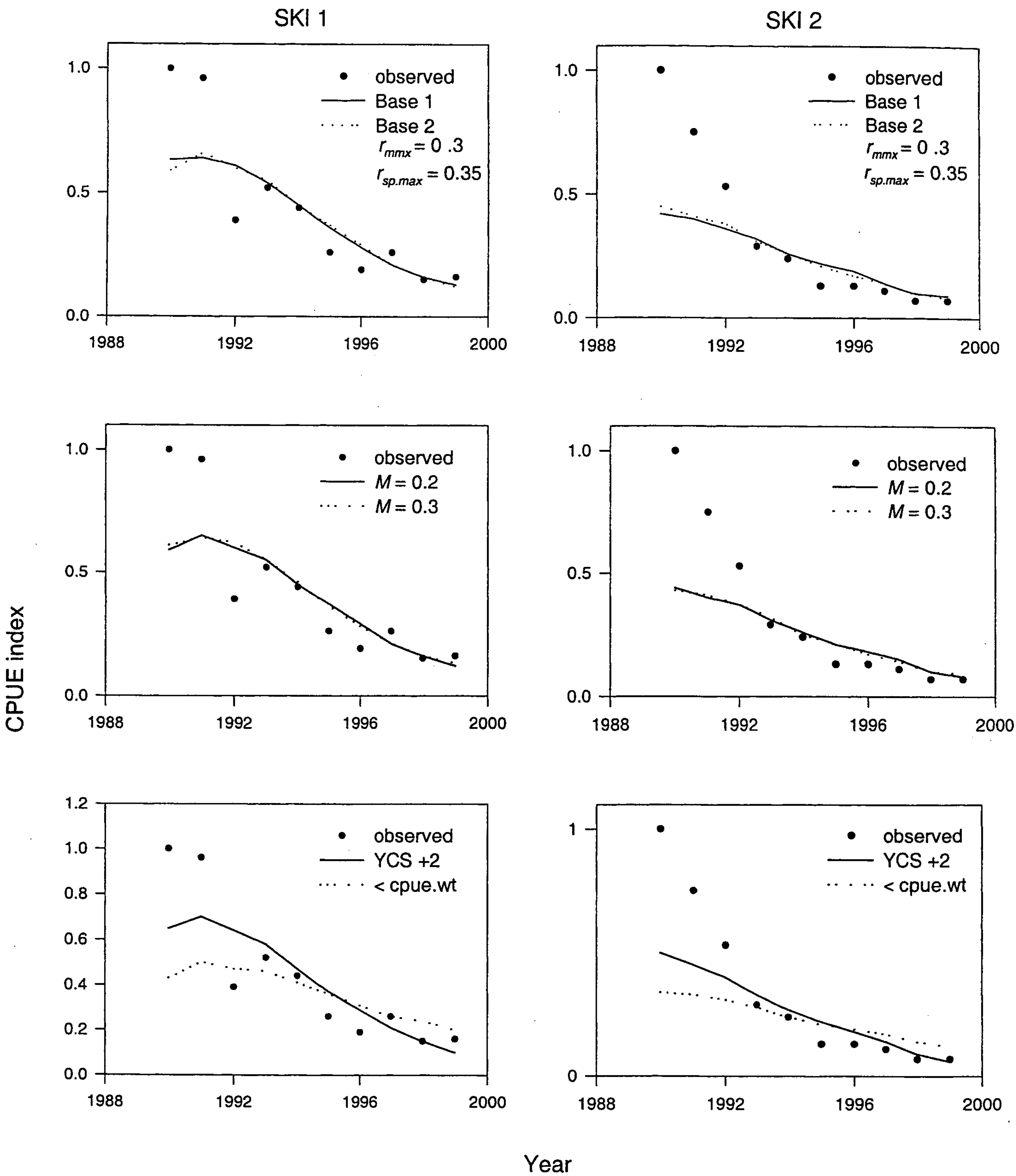

Figure 6a: Least squares fits to cpue indices for base case and sensitivity runs (circle, observed; line, observed).

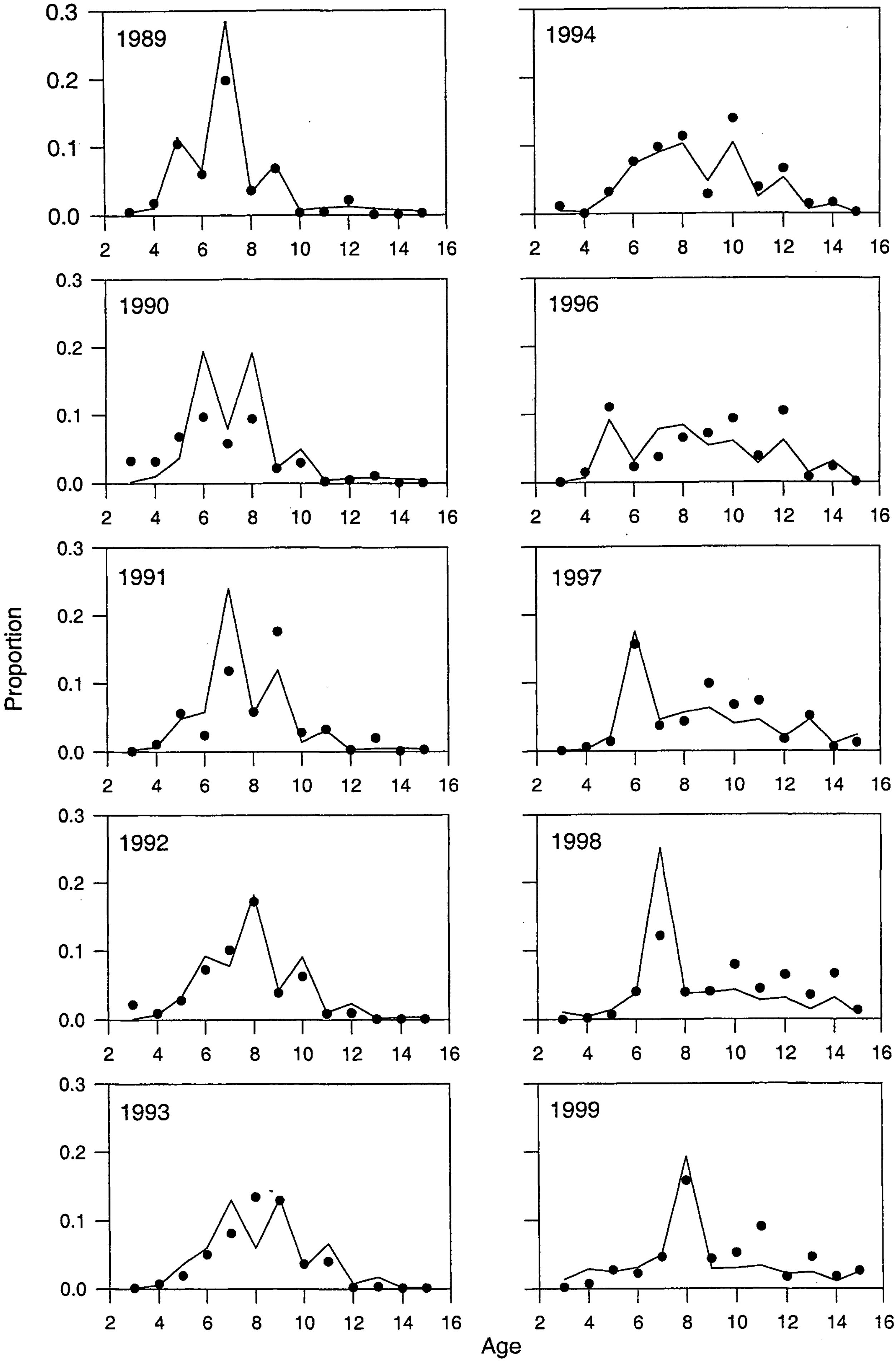

Figure 6b: **Base 2 least squares fits to proportion-at-age data (i) male SKI 1 (circle, observed line, predicted).**

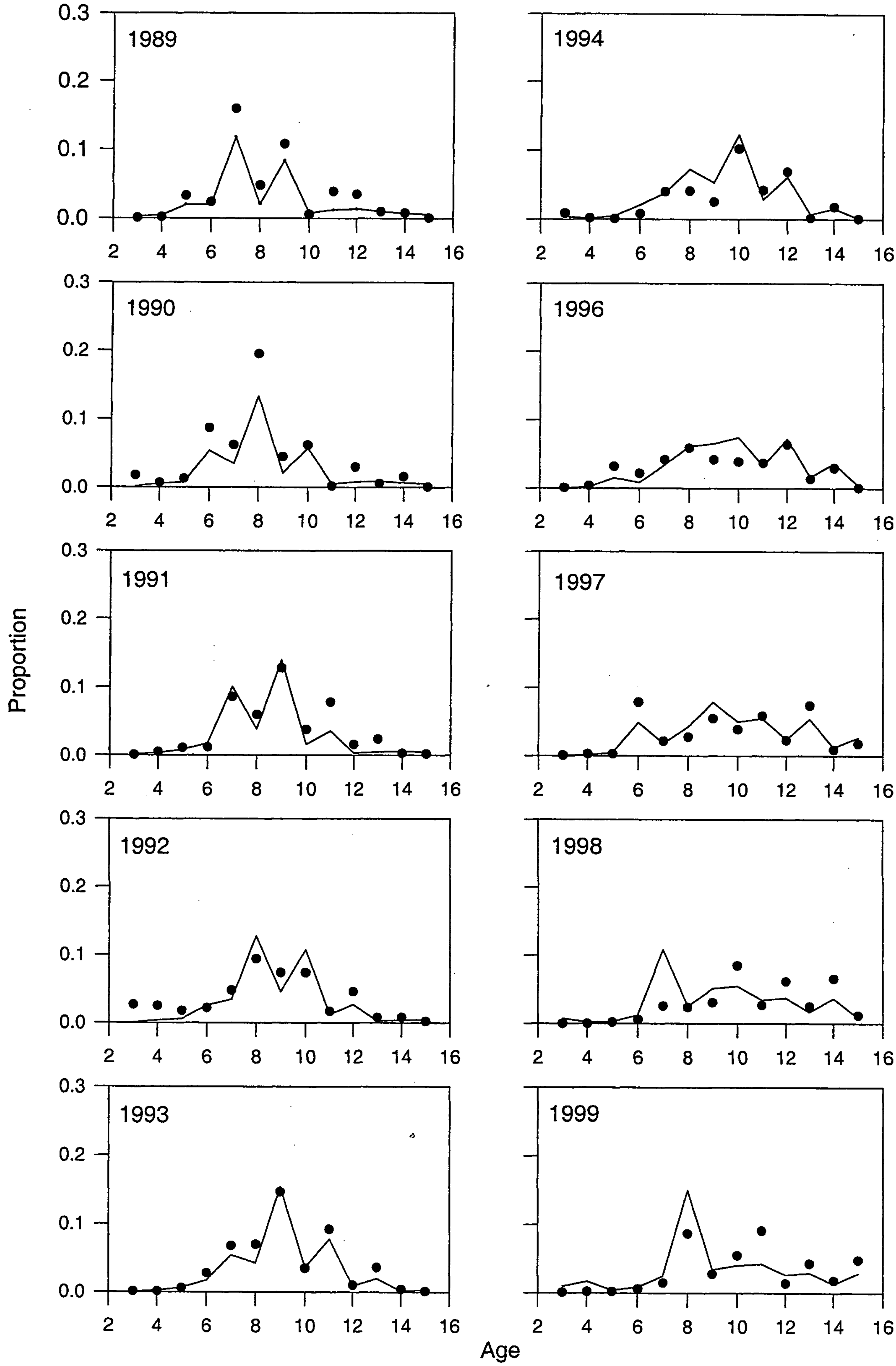

Figure 6b: **Base 2 least squares fits to proportion-at-age data (ii) female SKI 1 (circle, observed line, predicted).**

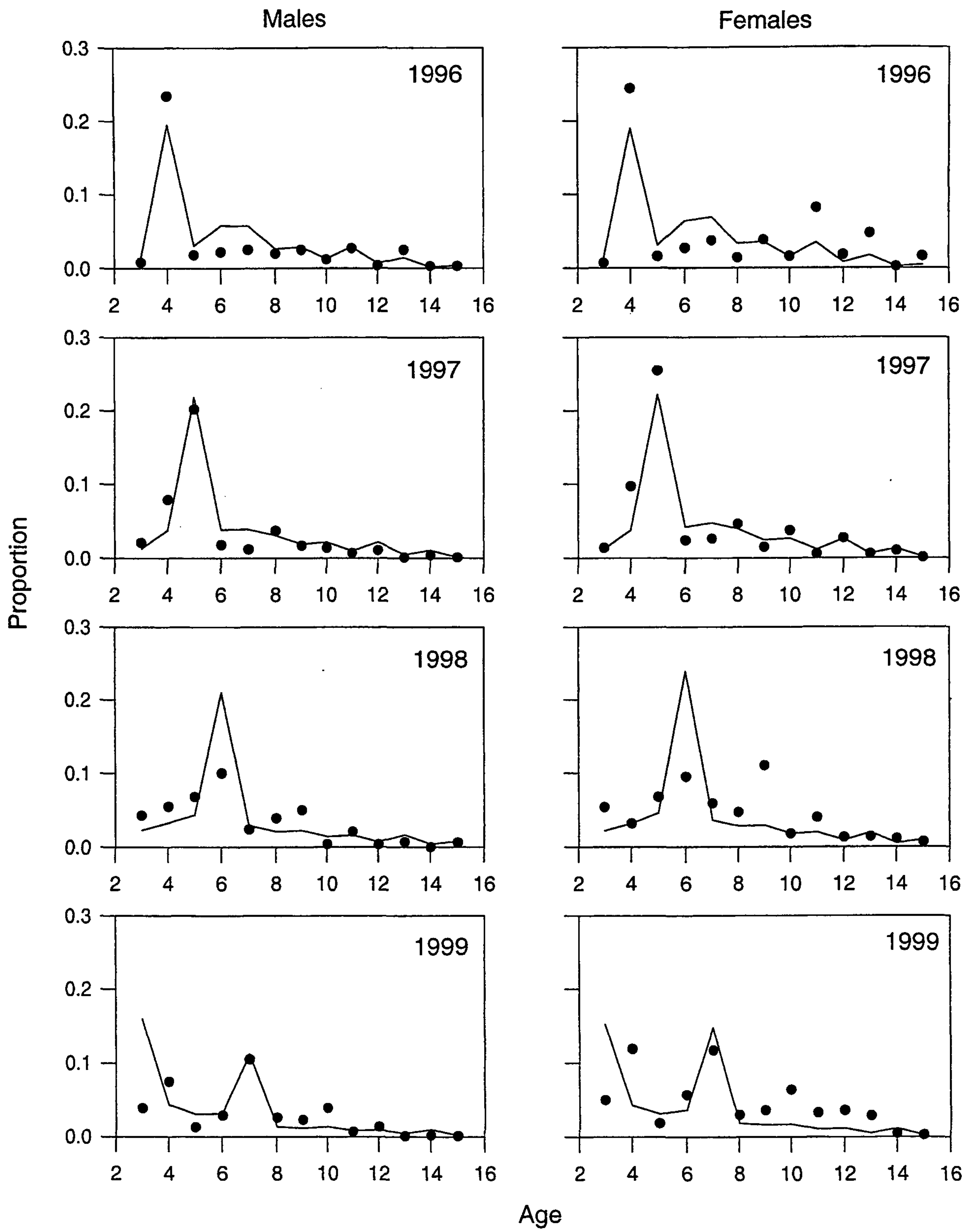

Figure 6b: **Base 2 least squares fits to proportion-at-age data (iii) SKI 2 (circle, observed line, predicted).**